Renewable Energy 200 (2022) 379–386

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Are renewable energy sources more evenly distributed than fossil fuels?

Indra Overland [a,*], Javlon Juraev [b], Roman Vakulchuk [c]

[a] Norwegian Institute of International Affairs (NUPI), C.J. Hambros plass 2D, PB 7024 St, Olavs Plass, 0130, Oslo, Norway
[b] OSCE Academy, Botanicheskiy Pereulok 1A, 720040, Bishkek, Kyrgyzstan
[c] Norwegian Institute of International Affairs (NUPI), C.J. Hambros Plass 2D, PB 7024 St, Olavs Plass, 0130, Oslo, Norway

A R T I C L E I N F O

Keywords:
Renewable energy
Fossil fuels
Distribution
Geopolitics
Gini coefficient
Lorenz curve

A B S T R A C T

The energy transition literature assumes that renewable energy sources are more evenly distributed globally than fossil fuels. This assumption implies that the shift from fossil fuels to renewables will enable more countries to pursue energy self-sufficiency and end their dependence on imported energy. However, if the assumption is wrong, the energy transition will depend on transboundary electricity or hydrogen trade, creating new international relationships and opportunities for both cooperation and conflict. The contribution of this study is to test the assumption of the even distribution of renewable energy resources on a quantitative empirical basis. Lorenz curves are compared and Gini coefficients calculated for three types of fossil fuels and three types of renewable energy in 161 countries. The study concludes that renewable energy is indeed more evenly distributed than fossil fuels. This finding lends support to claims that energy transition will bring about a more decentralized global energy system centered on prosumer countries with few long-distance energy relationships. However, the difference between the evenness of the distribution of renewable energy resources and that of fossil fuel reserves is not as great as the literature assumes. International trade in energy, and by extension international energy politics, will not disappear entirely.

1. Introduction

Historically, the literature on the geopolitics of energy focused on oil, gas, and security of supply [1–4]. From around 2010, a new literature on the geopolitics of energy started emerging, centered on renewable energy rather than fossil fuels [5–13]. A common assumption in many of these new geopolitical works is that renewable energy sources are distributed more evenly than fossil fuel reserves among countries [14–21]. It is therefore thought that the transition to a renewables-based energy system will make international energy relations more symmetric [22–26]. As countries increasingly rely on their own renewable energy resources, it is expected that there will be reduced dependence on major fossil fuel exporters such as Russia and Saudi Arabia [27–29] and, as a result, less long-distance energy dependence [30,31]. As a corollary, geopolitical hotspots like the Straits of Hormuz or the Straits of Malacca will lose their global significance [30,32]. Renewable energy is also seen as contributing to improved energy security and economic development [20–23,33–35].

While the literature cited above is based on an assumption about the even distribution of renewables and foresees a "flatter world" [36], a contrasting literature focuses on the differences in renewable energy endowments and sees countries rich in renewable energy resources as gaining a geopolitical upper hand thanks to energy transition [37–39]. There are numerous examples that could be used to create a picture of renewables as unevenly distributed: North African countries have far higher levels of solar irradiation than European countries, especially North European ones. Northern Japan, southern Argentina, and the UK have rich wind resources, while there is almost no wind around the equator. The existence of large-scale hydropower resources depends on both climatic and geographical conditions and is therefore limited to a few locations [29]. While Nepal and Tajikistan are hydropower giants, neighboring countries such as India and Turkmenistan have small hydropower resources per capita. The world's geothermal resources are also highly concentrated in a few countries such as Iceland, Indonesia, and the Philippines.

Further complicating matters, fossil fuels may not be as unevenly distributed as suggested by the commonplace image of a world dependent on a handful of petrostates. Many countries have at least one of the three types of fossil fuel reserves even if they lack the others. While only a few countries, such as Saudi Arabia and Venezuela, have exceptional

* Corresponding author.
E-mail addresses: ino@nupi.no (I. Overland), j.juraev@osce-academy.net (J. Juraev), rva@nupi.no (R. Vakulchuk).

https://doi.org/10.1016/j.renene.2022.09.046
Received 23 December 2021; Received in revised form 8 August 2022; Accepted 11 September 2022
Available online 25 September 2022

oil resources, many countries have *some* oil and/or gas. Few non-energy experts might think of Denmark or Germany as oil producers, but they are. And while oil gets a lot of attention due to the Organization of the Petroleum Exporting Countries (OPEC) and the long history of oil-related conflict, gas and especially coal tend to stay below the geopolitical radar.

The divergent views in the literature and the anecdotal evidence in support of both views motivate us to test the assumption that renewable energy resources are more evenly distributed globally than fossil fuel reserves. Our contribution to the literature is to resolve this contradiction and to do so through the introduction of quantitative analysis of relevant empirical evidence so that this field of research is not only anchored in assumptions.

2. Methodology

We use Lorenz curves and Gini coefficients to compare how evenly/unevenly renewable and fossil energy resources are distributed globally. Traditionally, the Gini coefficient is mainly used to measure wealth or income inequality within a country [40–43]. However, it can also be used to assess the distribution of energy-related factors. For instance, the Gini coefficient has been used to measure the distribution of energy consumption [44–46] and inequalities in carbon emissions [47]. Some scholars assess inequalities in energy consumption (both renewable and non-renewable) by creating Lorenz curves and Gini indices for global consumption of coal, oil, and natural gas and comparing them with similar indicators for the consumption of energy from hydropower, geothermal, and nuclear sources [48]. Such analysis is similar to the traditional analysis of economic inequality, just transposed onto the demand side of the energy sector. In this article, we complement this analysis with a look at the supply side of energy and thereby marry the inequality theme with a geopolitical perspective.

2.1. Data and variables

We create Lorenz curves and calculate Gini coefficients for three types of fossil fuel (coal, natural gas, and oil) and three types of renewable energy (hydro, wind, and solar). Building on the approach of Overland et al. [36] these three renewable energy sources were chosen because they are the ones being developed most intensively. We used data for the most recent year available, which was from 2014 to 2019.

Table 1
Variables and data sources.

Fossil fuel reserves		
Coal	Sum of proved and estimated reserves of bituminous coal/anthracite, sub-bituminous coal/lignite, and peat	UN Energy Statistics Yearbook, 2015 [50]
Natural gas	Proved reserves	
Oil	Sum of proved reserves of crude oil, natural gas liquids, oil shale, and bituminous sands	
Renewable energy sources		
Hydro	Hydropower potential	UN Energy Statistics Yearbook, 2015 [50]
Wind	Sum of offshore and onshore wind energy potential	National Renewable Energy Laboratory, Wind resources by class and country at 50m, 2018 [51]
Solar	Solar resources	National Renewable Energy Laboratory Solar Resources by Class and Country, 2014 [52]
Common denominator		
Population		United Nations, Department of Economic and Social Affairs, Population Division, 2019 [53]

Table 1 summarizes the variables and data sources used.

Renewable energy resources are calculated as gigawatt hours (GWh) per year. For example, the average solar radiation of a country is multiplied by its surface area. Fossil fuel indicators are convertedso through the introduction to GWh to make it possible to aggregate and compare them with the renewable energy indicators. Although bioenergy is a renewable enerso through the introductiongy source, we did not include it in our analysis, because its adverse impact on the environment is more debated than that of other sources of renewable energy and data on bioenergy may be less reliable [49].

We carry out our calculations using data on 161 countries, all countries for which data were available. The countries omitted from our analysis are very small and lack data, for example Andorra, the Faroe Islands, Kiribati, and so on. When we use the words “world”, “global”, or “all countries” below, we are referring to the 161 countries covered by our data.

2.2. Lorenz curves and Gini coefficients

The Lorenz curve gives a graphical representation of the distribution of a factor across cumulative percentages of units [54]. The Gini index is a numerical indicator of distribution ranging from 0 (total equality) to 1 (total inequality).

Because our goal was to calculate a global Gini index, we first intended to use individual countries as the units among which to assess the distribution of energy resources. That approach would have been in line with the approaches in the existing studies that compare the nominal energy resources of countries without further adjustment [55–57]. However, although this approach can be applied to studies of the resources and power of countries as political entities in global energy affairs, it is unsuitable for an analysis of the distribution of energy resources, because variations in the size of countries would distort the results. For example, China has oil reserves of over 50 billion metric tons, and Kuwait has around 14 billion metric tons. However, China’s population and territory are vastly larger and, consequently, so is its energy demand. A direct comparison between two such countries makes little sense.

Another example is provided by the histograms of the distribution of hydropower in Fig. 1. Panel A shows groups of countries by their respective shares of global hydropower resource endowments: 151 countries each hold less than 2% of global hydropower resources, whereas 10 countries hold 2–16% each. This gap creates the impression that the distribution of hydropower around the globe is more uneven than it actually is. If we look at Panel B, it is clear that if one takes into account population size, the distribution of hydropower is not as uneven as that: 20% of the world population holds 49% of the hydropower resources, and the remaining 80% of the world population holds 51%.

We considered several options for achieving proportionality among countries, including dividing fossil fuel production by gross domestic product (GDP) and renewable energy resources by domestic electricity or energy consumption. However, each of these options has limitations and it would be difficult to combine them. We therefore opted to divide all resource indicators by population because it is a transparent measure with good data availability, is relatively stable, can be applied consistently to all resource indicators, and has a long track record of use in the literature [44,48,58].

The sum of energy resources of all countries is taken as global reserves/resources (100%). Similarly, the combined population of all countries is taken as the global population (100%). Next, we calculate the share of each country in global reserves/resources and population (as percentages) and obtain the slope of a section of the Lorenz curve for each country according to the following formula:

$$Slope = \frac{Share\ of\ country\ X\ of\ global\ energy\ resources}{Share\ of\ country\ X\ of\ global\ population}$$

Sorting the lists of countries from the smallest to the largest by the

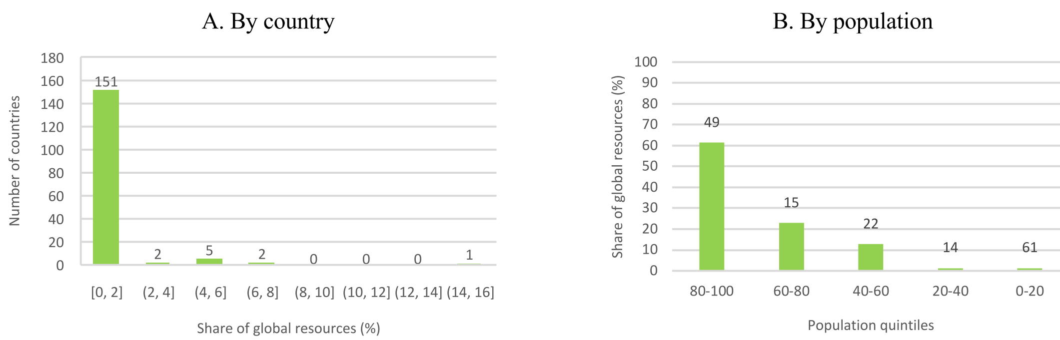

Fig. 1. Country-vs. population-based distribution of global hydropower resources.

slope indicator gives us ascending lists: the countries with the smallest energy reserves/resources relative to their population size are at the beginning of each list, and countries with the largest reserves/resources relative to their population are at the end.

Next, we calculate the cumulative share of population (horizontal axis) and corresponding cumulative share of energy reserves/resources (vertical axis). Plotting them against one another in a scatterplot and connecting the points gives the Lorenz curve (see Fig. 2). The Gini coefficient is obtained by dividing the area between the diagonal of perfect equality and the Lorenz curve by the total area under the diagonal of perfect equality. The area below the Lorenz curve is calculated by summing the areas of the trapezoids for each of the countries. Fig. 2 provides a simplified illustration of the area below the Lorenz curve with the five hypothetical countries A, B, C, D, and E.

The area of each trapezoid is the arithmetic mean of its two sides multiplied by its height. The shorter side of the trapezoid is the cumulative share of energy reserves/resources *before* including the country's share. The longer side of the trapezoid is the cumulative share of energy reserves/resources *after* including the country's share. The height of the trapezoid is the country's population share. The area under the diagonal of perfect equality is 5 000, and the total number of countries is 161. Hence, the formula for the Gini coefficient for a given energy resource is:

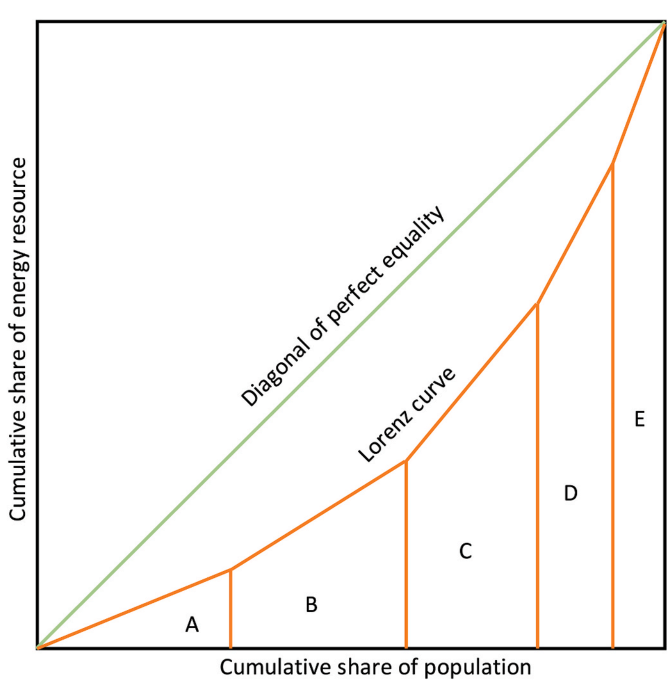

Fig. 2. Example of a Lorenz curve.

$$G = 1 - \frac{\sum_{i=1}^{161} P_i \left(\frac{\sum_{i=1}^{i-1} E_{i-1} + \sum_{i=1}^{i} E_i}{2} \right)}{5\ 000}$$

or

$$G = 1 - \sum_{i=1}^{161} P_i \left(\frac{\sum_{i=1}^{i-1} E_{i-1} + \sum_{i=1}^{i} E_i}{10\ 000} \right)$$

where E_{i-1} is the cumulative share of energy resources of all countries before country i, E_i is the cumulative share of energy of all countries before country i plus the share of country i, and P_i is the population share of country i.

2.3. Limitations

For the sake of simplicity and feasibility, the analysis builds on several premises. First, it is assumed that a country is able to utilize its proven fossil fuel reserves. In reality, the ability of a country to turn available resources into an economic asset depends on many factors, such as demand, the availability of extraction technologies, the efficiency of industrial management, and political stability. However, future values for these indicators cannot be estimated with a sufficient degree of accuracy to make them useful. Obviously, not all reserves can be exploited. However, due to globalization, the capacity of countries to exploit their resources is convergent in most countries. For example, over the past decades, the know-how and enhanced oil recovery technologies of international oil companies have become available in oil-producing states such as Iraq and Russia, which previously had low extraction ratios for their oilfields [59], while low-cost Chinese solar panels have become available in most parts of the world [60]. Future research might consider using indicators of technological and governance levels as proxies for the capacity of countries to exploit their resources.

3. Results and discussion

In this section, we first examine the distribution of each of the three fossil fuels and each of the three types of renewable energy sources separately. At the end of the section, we create one aggregate of the fossil fuels and another of the renewables and compare their distributions.

3.1. Distribution of fossil fuel reserves

Fig. 3 summarizes the results for fossil fuels around the world. As expected, their distribution is uneven. Just 11 countries hold approximately 90% of global coal reserves, 39 countries hold more than 90% of

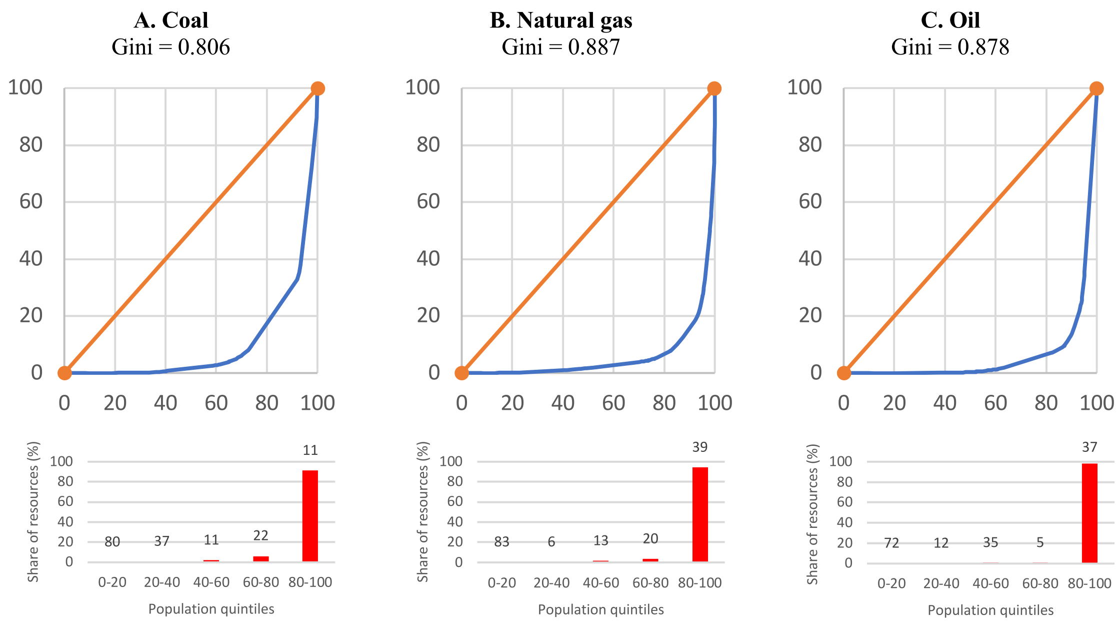

Fig. 3. Gini indexes, Lorenz curves, and distribution across population quintiles for global fossil fuel reserves (number of countries in quintiles given above bars).

global natural gas reserves, and 37 countries hold close to 100% of global oil reserves. The figure also shows that coal is the least unevenly distributed fossil fuel, with a Gini index close to 0.8. The indices of oil and natural gas are higher—both at nearly 0.9. The similar values for oil and gas may be related to the fact that natural gas and oil reserves are often found together.

The fact that coal has the lowest Gini coefficient is not surprising, because global reserves of coal are abundant and prices have traditionally been low. However, the difference between the Gini coefficients of coal and oil is not as great as one might expect considering how much more attention oil receives as an object of geopolitical competition, cartelization, embargo, and war. The fact that the Gini coefficient of coal is not actually that low also means that the burden of transitioning away from coal is unevenly distributed. Although coal is rarely an export earner on the same level as oil, it is the backbone of domestic electricity generation, heating, and heavy industry in some countries. The top 10 countries in terms of coal reserves per capita are Botswana, Australia, Mongolia, Russia, the United States, Canada, Poland, Kazakhstan, New Zealand, and Kyrgyzstan, in that order. In those countries, the transition away from coal will be challenging.

It is also worth noting which countries have the most abundant fossil fuel reserves taking into account population size. Table 2 lists the ten most resource-rich countries for each type of fossil fuel.

Table 2
Top 10 countries in terms of fossil fuel reserves per capita (the underlined countries are those that appear in more than one column).

Coal	Natural gas	Oil
Botswana	Qatar	Kuwait
Australia	Turkmenistan	Estonia
Mongolia	UAE	United States
Russia	Kuwait	Canada
United States	Iran	UAE
Canada	Norway	Venezuela
Poland	Saudi Arabia	Saudi Arabia
Kazakhstan	Trinidad and T.	Qatar
New Zealand	Libya	Libya
Kyrgyzstan	Russia	Kazakhstan

3.2. Distribution of renewable energy sources

Our results indicate that renewable energy resources are spread more evenly than fossil fuel reserves, confirming the assumption found in part of the literature (see Fig. 4).

With a Gini coefficient of 0.561, hydropower resources are the most evenly distributed type of renewable energy. Solar radiation has a Gini coefficient of 0.655 and is thus less evenly distributed than hydropower. Wind, with a Gini index of 0.691, is the most unevenly distributed renewable energy resource. The histograms in Fig. 4 also show that hydropower resources are more evenly distributed across population quintiles than solar radiation is.

The finding that hydropower resources are more evenly distributed than solar and wind resources may appear counterintuitive. Hydropower depends on precipitation and mountainous terrain, neither of which is evenly distributed. Some very small countries have outsized hydropower resources, for example, Bhutan, Laos, and Norway. By contrast, the sun shines on every part of the planet, including the Arctic and Antarctica, and there is also wind everywhere. However, population density tends to be significantly higher near rivers, evening out the availability of hydropower resources when population is taken into account. Furthermore, the countries with the greatest solar resources are desert countries, and deserts typically have very low population density. Thus, when one takes population into account, the world's hydropower is not so unevenly distributed after all.

Table 3 compares the distribution of hydro and solar power between two groups of countries—the lowest 150 and the top 11 by share of global resources. As we can see, the top 11 countries in terms of hydropower resources, which also have 52% of the world's population, hold 64% of the world's hydropower resources. On the other hand, the lowest 150 countries in terms of solar energy potential also represent 52% of the global population, while holding only 47% of global solar resources. In other words, hydropower is evenly distributed because it is concentrated in populous countries.

Table 4 lists the 10 countries with the greatest resource potential for each of the three types of renewable energy. Countries that appear in more than one of the columns are underlined. The large number of underlined countries shows that many countries are rich in multiple types of renewable energy.

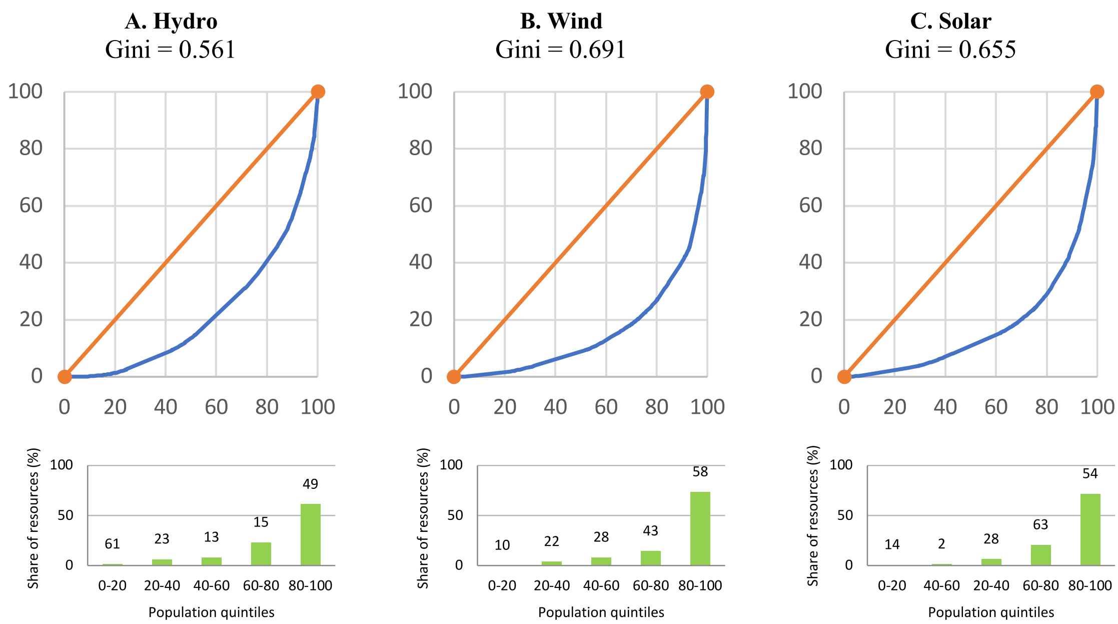

Fig. 4. Gini indexes, Lorenz curves, and distribution across population quintiles for global renewable energy resources (the number of countries in each quintile is given above the bars).

Table 3
Hydro and solar power resource endowments of the 150 most poorly and 11 most richly endowed countries.

	Hydro		Solar	
	Share of resources	Share of world population	Share of resources	Share of world population
Most poorly endowed 150 countries	36%	48%	47%	52%
Most richly endowed 11 countries	64%	52%	53%	48%

Table 4
Top 10 countries by renewable energy resource endowment (the underlined countries are those that appear in more than one column).

Hydro	Wind	Solar
Iceland	Iceland	Mongolia
Bhutan	Australia	Congo
Norway	Namibia	Namibia
Guyana	New Zealand	Australia
Gabon	Libya	Libya
Tajikistan	Mauritania	Botswana
Canada	Mongolia	Mauritania
Cyprus	Norway	Guyana
Peru	Botswana	Canada
Costa Rica	Kazakhstan	Taiwan

3.3. *Fossil fuel reserves vs. renewable energy sources*

Fig. 5 shows the distribution of aggregate fossil fuel reserves and aggregate renewable energy resources. It shows that aggregate renewable energy resources (Gini coefficient = 0.657) are more evenly distributed than aggregate fossil fuel reserves (Gini coefficient = 0.802). This more even distribution can also be seen in the quintile charts in Fig. 5: the highest population quintile consists of 12 countries that hold more than 90% of the world's fossil fuel reserves, while, in the case of renewable energy resources, the highest population quintile consists of 58 countries that hold around 70% of global resources.

It is worth noting the changes in the list of top countries (see Table 5). Australia, Botswana, Canada, Mongolia, and New Zealand are abundantly endowed with both fossil fuel reserves and renewable energy resources and therefore underlined. Russia with its vast territory and large rivers is still absent from the renewable energy sources column: its renewable energy potential is relatively low when it is divided among its population. Norway, on the other hand, is among the top 10 countries in terms of renewable energy potential (largely due to its hydropower resources), but absent from the fossil fuel column because it has already depleted a significant part of its oil and gas reserves.

3.4. *Main findings*

We have three main findings. First, the data confirm that renewable energy resources are more evenly distributed than fossil fuel reserves. This difference in evenness of distribution is shown by the Gini coefficients of the aggregate fossil fuel reserves and renewable energy resources and by the fact that even the Gini coefficient of the most evenly distributed fossil fuel (coal) is greater than that of the most unevenly distributed renewable energy resource (wind). This indicates that many of the points and sub-topics in the literature on the geopolitics of the energy transition make sense. Many countries will have the opportunity to pursue a greater degree of energy autarky. This pursuit will lead to a more decentralized international energy system dominated by prosumer countries with fewer long-distance energy relationships as well as reduced importance of energy-related geopolitical hotspots such as the Straits of Hormuz or the South China Sea.

However, our second major finding is that the difference between the evenness of the distribution of renewable energy resources and the evenness of the distribution of fossil fuel reserves is not very great. Especially when aggregate fossil fuels and aggregate renewables are compared, the difference is moderate. In a world running on renewable energy, there will still be some resource-rich and some resource-poor countries, meaning that some of the geopolitical phenomena linked to the international energy affairs of the fossil fuel era may reappear in a (re)new(able) guise. For example, some of the countries richest in

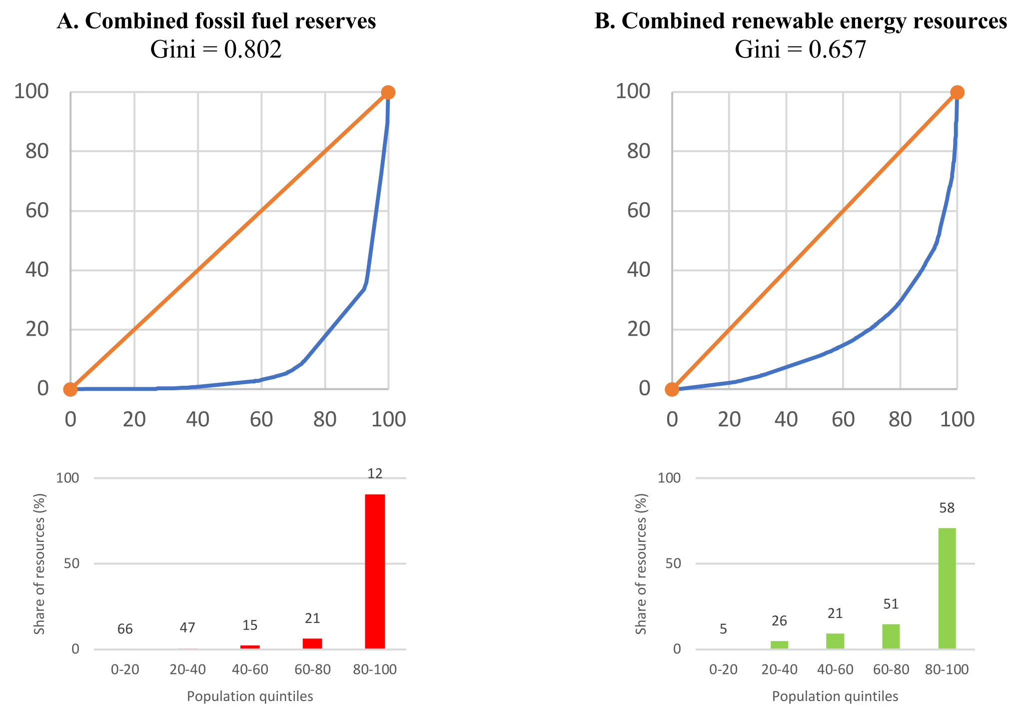

Fig. 5. Gini coefficients, Lorenz curves, and distribution across population quintiles for combined global fossil fuel reserves and combined renewable energy resources.

Table 5
Top 10 countries by total fossil fuel reserves per capita vs. top 10 by total renewable energy resources per capita (the underlined countries are those that appear in both columns).

Fossil fuel reserves	Renewable energy sources
Botswana	Iceland
Australia	Australia
Mongolia	Namibia
Russia	Mongolia
United States	Libya
Canada	Mauritania
Poland	New Zealand
Qatar	Norway
Kazakhstan	Botswana
New Zealand	Canada

renewable energy resources might become major net exporters of hydrogen, electricity, or renewable energy embedded in energy-intensive products such as steel or cement, while some countries that are poorest in these resources might become dependent on imports of such goods.

A third and even more unexpected finding is that hydropower resources are the most evenly distributed of all six renewable and fossil energy sources covered in this article when one takes into account population size. The reasons for this unexpected finding are that population density tends to be higher near rivers (where hydropower resources are located) and lower in deserts (where solar power resources are concentrated). The even distribution of hydropower resources also strengthens the prospects for hydropower to function as a complement to intermittent sources of renewable energy [61].

3.5. Caveats

A couple of caveats are in order. First, although not all that much more evenly *distributed* than fossil fuels, renewable energy resources are generally more *abundant*. For example, although Algeria may have much greater solar resources than Germany does, Germany has enough to cover much of its energy needs. What proportion of its energy needs a country such as Germany can cover with solar power depends on the efficiency of renewable energy technologies [62–64], which is steadily improving. The more efficient they become, the greater the extent to which countries such as Germany, which are *comparatively* resource poor, will nonetheless be able to cover their energy needs with domestic solar power resources [65,66].

Second, during the period 2020-2050, renewable energy use is going to grow while fossil fuels continue to play some role even if that role steadily shrinks. It will not be either/or but coexistence [67]. Thus, during these decades, the distribution of *total* energy sources will be more even than indicated by the Gini coefficients. Few countries are poor in both fossil fuels and renewables. If cost-efficient carbon capture, storage, and use (CCSU) is achieved—or if climate policy fails—this situation might even be perpetuated beyond the end of this century.

4. Conclusion

In the introduction, we showed that central arguments and expectations in part of the literature on the geopolitics of renewable energy hinge on the assumption that renewable energy resources are more evenly distributed than fossil fuel reserves are. However, this assumption has never actually been properly backed up with data and analysis, and the purpose of this article has been to test the assumption with empirical data.

We made three main findings. First, we confirmed that the part of the literature that assumes renewables are more evenly distributed than are fossil fuels is right. Secondly, however, we found that the difference is not as great as one might assume. Third, and to our surprise, we found that hydropower resources are the most evenly distributed of all six renewable and fossil energy sources covered in this article, when one takes into account population size.

Our findings have several implications for policymakers. First, they should be prepared for a less asymmetric world and reduced importance of geographical chokepoints in energy logistics. Fossil fuel-rich countries will lose much of the power which their resources have conferred upon them in the past. But countries rich in renewable energy resources will not replace them as international energy superpowers, because renewable resources are more evenly distributed than fossil fuels and most countries have a chance to work towards a higher degree of autarky. The leaders of countries rich in fossil fuels or renewable energy should take note and adapt to this flattening world.

Countries that have been dependent on fossil fuel imports may benefit from fulfilling their domestic renewable energy generation potential at an accelerated pace. However, as there will still be some interdependence, all policymakers would benefit from behaving cautiously, especially towards their immediate neighbors. Whereas past international energy dependence has often spanned long distances, future dependence will often be between close neighbors helping each other handle the intermittency of renewable energy sources.

Our findings open at least two avenues for further research. First, the analysis could be extended by including governance and innovation indicators as proxies for the ability of states to exploit the resources at their disposal. Second, it would be possible to introduce cut-off points for which energy resources are actually economically and technically usable, both on the renewables side and on the fossil fuels side. The challenge then would be to identify those cut-off points, as they change along with evolving technologies and the entire economies surrounding the exploitation and marketing of energy resources.

Data availability

All data analyzed in this study are included in the supplementary information file and are also freely available from the United Nations and the National Renewable Energy Laboratory (see details in Table 1).

CRediT authorship contribution statement

Indra Overland: Funding acquisition, Project administration, Conceptualization, Data curation, Methodology, Resources, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing. **Javlon Juraev:** Formal analysis, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **Roman Vakulchuk:** Data curation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.renene.2022.09.046.

References

[1] D. Yergin, The Prize: the Epic Quest for Oil, Money & Power, Free Press, New York, 2008.
[2] R.A. Kelanic, The petroleum paradox: oil, coercive vulnerability, and great power behavior, Security Studies 25 (2016) 181–213, https://doi.org/10.1080/09636412.2016.1171966.
[3] J.D. Sharples, The shifting geopolitics of Russia's natural gas exports and their impact on EU-Russia gas relations, Geopolitics 21 (2016) 880–912, https://doi.org/10.1080/14650045.2016.1148690.
[4] G. Bahgat, The new geopolitics of oil: the United States, Saudi Arabia, and Russia, Orbis 47 (2003) 447–461, https://doi.org/10.1016/S0030-4387(03)00041-3.
[5] M. O'Sullivan, The Geopolitics of Renewable Energy, Renewable Energy., 2017, p. 71.
[6] S. Paltsev, The complicated geopolitics of renewable energy, Bull. At. Sci. 72 (2016) 390–395, https://doi.org/10.1080/00963402.2016.1240476.
[7] I. Overland, The geopolitics of renewable energy: debunking four emerging myths, Energy Res. Social Sci. 49 (2019) 36–40, https://doi.org/10.1016/j.erss.2018.10.018.
[8] I. Fischhendler, L. Herman, J. Anderman, The geopolitics of cross-border electricity grids: the Israeli-Arab case, Energy Pol. 98 (2016) 533–543, https://doi.org/10.1016/j.enpol.2016.09.012.
[9] A.M. Jaffe, The role of the US in the geopolitics of climate policy and stranded oil reserves, Nat. Energy 1 (2016) 1–4, https://doi.org/10.1038/nenergy.2016.158.
[10] F. Proedrou, Geopolitics and development in a steady-state world, in: F. Proedrou (Ed.), Energy Policy and Security under Climate Change, Springer International Publishing, Cham, 2018, pp. 145–175, https://doi.org/10.1007/978-3-319-77164-9_5.
[11] S. Heinonen, J. Karjalainen, J. Ruotsalainen, K. Steinmüller, Surprise as the new normal - implications for energy security, Eur J Futures Res 5 (2017) 12, https://doi.org/10.1007/s40309-017-0117-5.
[12] G. Escribano Francés, J.M. Marín-Quemada, E. San Martín González, RES and risk: renewable energy's contribution to energy security. A portfolio-based approach, Renew. Sustain. Energy Rev. 26 (2013) 549–559, https://doi.org/10.1016/j.rser.2013.06.015.
[13] R.J. Matson, M. Carasso, Sustainability, energy technologies, and ethics, Renew. Energy 16 (1999) 1200–1203, https://doi.org/10.1016/S0960-1481(98)00482-0.
[14] P.A. Owusu, S. Asumadu-Sarkodie, A review of renewable energy sources, sustainability issues and climate change mitigation, Cogent Engineering 3 (2016), 1167990, https://doi.org/10.1080/23311916.2016.1167990.
[15] Z. Şen, Solar energy in progress and future research trends, Prog. Energy Combust. Sci. 30 (2004) 367–416, https://doi.org/10.1016/j.pecs.2004.02.004.
[16] A. Månsson, A resource curse for renewables? Conflict and cooperation in the renewable energy sector, Energy Res. Social Sci. 10 (2015) 1–9, https://doi.org/10.1016/j.erss.2015.06.008.
[17] D. Scholten, R. Bosman, The geopolitics of renewables; exploring the political implications of renewable energy systems, Technol. Forecast. Soc. Change 103 (2016) 273–283, https://doi.org/10.1016/j.techfore.2015.10.014.
[18] J. Rifkin, The Third Industrial Revolution. How Lateral Power Is Transforming Energy, the Economy, and the World, Palgrave Macmillan, New York, 2011. https://us.macmillan.com/thethirdindustrialrevolution/jeremyrifkin/9780230341975. (Accessed 15 February 2021). accessed.
[19] R. Vakulchuk, I. Overland, D. Scholten, Renewable energy and geopolitics: a review, Renew. Sustain. Energy Rev. 122 (2020), 109547, https://doi.org/10.1016/j.rser.2019.109547.
[20] S.V. Valentine, Emerging symbiosis: renewable energy and energy security, Renew. Sustain. Energy Rev. 15 (2011) 4572–4578, https://doi.org/10.1016/j.rser.2011.07.095.
[21] I. Ozturk, Energy dependency and energy security: the role of energy efficiency and renewable energy sources (the Mahbub Ul Haq Memorial Lecture), PDR 52 (2013) 309–330, https://doi.org/10.30541/v52i4Ipp.309-330.
[22] J. Lilliestam, S. Ellenbeck, Energy security and renewable electricity trade—will Desertec make Europe vulnerable to the "energy weapon"? Energy Pol. 39 (2011) 3380–3391, https://doi.org/10.1016/j.enpol.2011.03.035.
[23] W. Lacher, D. Kumetat, The security of energy infrastructure and supply in North Africa: Hydrocarbons and renewable energies in comparative perspective, Energy Pol. 39 (2011) 4466–4478.
[24] Z. Xin-gang, Y. Yi-sheng, F. Tian-tian, Y. Yu-heng, International cooperation on renewable energy electricity in China - a critical analysis, Renew. Energy 55 (2013) 410–416, https://doi.org/10.1016/j.renene.2012.11.039.
[25] B. Guler, E. Çelebi, J. Nathwani, A 'Regional Energy Hub' for achieving a low-carbon energy transition, Energy Pol. 113 (2018) 376–385, https://doi.org/10.1016/j.enpol.2017.10.044.
[26] F. Proedrou, Energy Policy and Security under Climate Change, Palgrave Macmillan, Cham, 2018.
[27] S. Peters, Courting future resource conflict: the shortcomings of western response strategies to new energy vulnerabilities, Energy Explor. Exploit. 20/21 (2002) 29–60.
[28] T. Van de Graaf, Battling for a shrinking market: oil producers, the renewables revolution, and the risk of stranded assets, in: The Geopolitics of Renewables, Springer, Cham, 2018, pp. 97–121. http://hdl.handle.net/1854/LU-8544872. (Accessed 15 February 2021). accessed.
[29] B. Johansson, Security aspects of future renewable energy systems - a short overview, Energy 61 (2013) 598–605, https://doi.org/10.1016/j.energy.2013.09.023.
[30] I. Overland, Future petroleum geopolitics: consequences of climate policy and unconventional oil and gas, in: Handbook of Clean Energy Systems, Wiley, Chichester, 2015, pp. 3517–3544, https://doi.org/10.1002/9781118991978.hces203.
[31] G. Escribano, The geopolitics of renewable and electricity cooperation between Morocco and Spain, Mediterr. Polit. 24 (2019) 674–681, https://doi.org/10.1080/13629395.2018.1443772.
[32] Global Commission on the Geopolitics of Energy Transformation, A New World: the Geopolitics of the Energy Transformation, 2019.
[33] J. Ren, B.K. Sovacool, Prioritizing low-carbon energy sources to enhance China's energy security, Energy Convers. Manag. 92 (2015) 129–136, https://doi.org/10.1016/j.enconman.2014.12.044.
[34] F. Umbach, Energy Security in a Digitalised World and its Geostrategic Implications, Konrad-Adenauer-Foundation (KAS), 2018.

[35] O.B. Adekoya, J.K. Olabode, S.K. Rafi, Renewable energy consumption, carbon emissions and human development: empirical comparison of the trajectories of world regions, Renew. Energy 179 (2021) 1836–1848, https://doi.org/10.1016/j.renene.2021.08.019.
[36] I. Overland, M. Bazilian, T.I. Uulu, R. Vakulchuk, K. Westphal, The GeGaLo index: geopolitical gains and losses after energy transition, Energy Strategy Rev. 26 (2019) 1–16, https://doi.org/10.1016/j.esr.2019.100406.
[37] S. Raman, Fossilizing renewable energies, Sci. Cult. 22 (2013) 172–180, https://doi.org/10.1080/09505431.2013.786998.
[38] D. Freeman, China and renewables: the priority of economics over geopolitics, in: D. Scholten (Ed.), The Geopolitics of Renewables, Springer Nature, Cham, 2018, pp. 187–201, https://doi.org/10.1007/978-3-319-67855-9.
[39] T. Van de Graaf, I. Overland, D. Scholten, K. Westphal, The new oil? The geopolitics and international governance of hydrogen, Energy Res. Social Sci. 70 (2020), 101667, https://doi.org/10.1016/j.erss.2020.101667.
[40] A.B. Atkinson, On the measurement of inequality, J. Econ. Theor. 2 (1970) 244–263, https://doi.org/10.1016/0022-0531(70)90039-6.
[41] A. Ultsch, J. Lötsch, A data science based standardized Gini index as a Lorenz dominance preserving measure of the inequality of distributions, PLoS One 12 (2017), e0181572, https://doi.org/10.1371/journal.pone.0181572.
[42] J. Chen, Y. Si, F. Li, A. Zhao, An analysis of relationship among income inequality, poverty, and income mobility, based on distribution functions, Abstr. Appl. Anal. 2014 (2014) 1–10, https://doi.org/10.1155/2014/186564.
[43] A. Heshmati, Inequalities and Their Measurement, IZA Discussion, 2014, pp. 1–20. Paper No. 1219.
[44] S. Lawrence, Q. Liu, V.M. Yakovenko, Global inequality in energy consumption from 1980 to 2010, Entropy 15 (2013) 5565–5579, https://doi.org/10.3390/e15125565.
[45] A. Druckman, T. Jackson, Measuring resource inequalities: the concepts and methodology for an area-based Gini coefficient, Ecol. Econ. 65 (2008) 242–252, https://doi.org/10.1016/j.ecolecon.2007.12.013.
[46] E. Fernandez, R.P. Saini, V. Devadas, Relative inequality in energy resource consumption: a case of Kanvashram village, Pauri Garhwal district, Uttranchall (India), Renew. Energy 30 (2005) 763–772, https://doi.org/10.1016/j.renene.2002.10.001.
[47] L. Groot, Carbon Lorenz curves, Resour. Energy Econ. 32 (2010) 45–64, https://doi.org/10.1016/j.reseneeco.2009.07.001.
[48] C. Duan, B. Chen, Analysis of global energy consumption inequality by using Lorenz curve, Energy Proc. 152 (2018) 750–755, https://doi.org/10.1016/j.egypro.2018.09.240.
[49] D.O. Hall, J.I. Scrase, Will biomass be the environmentally friendly fuel of the future? Biomass Bioenergy 15 (1998) 357–367, https://doi.org/10.1016/S0961-9534(98)00030-0.
[50] Un Energy Statistics, United Nations Statistics Division. https://unstats.un.org/unsd/energy/yearbook/2015.htm, 2015. (Accessed 15 February 2021) accessed.
[51] National Renewable Energy Laboratory, Wind Resources by Class and Country at 50m, U.S. Department of Energy, 2018. https://openei.org/doe-opendata/dataset/wind-resources-by-class-and-country-at-50m. (Accessed 15 February 2021). accessed.
[52] National Renewable Energy Laboratory, Solar Resources by Class and Country, US Department of Energy, 2014. https://openei.org/doe-opendata/dataset/solar-resources-by-class-and-country. (Accessed 15 February 2021). accessed.
[53] UN World Population Prospects, UN Department of Economic and Social Affairs, 2019. https://population.un.org/wpp/Download/Standard/Population/. (Accessed 15 February 2021). accessed.
[54] N.C. Kakwani, Applications of Lorenz curves in economic analysis, Econometrica 45 (1977) 719–727, https://doi.org/10.2307/1911684.
[55] H. Rempel, Geographical distribution of oil and natural gas deposits - different means of transportation to the consumption centers, in: 16th Pipeline Technology Conference, 2006. https://www.pipeline-conference.com/abstracts/geographical-distribution-oil-and-natural-gas-deposits-different-means-transportation. (Accessed 15 February 2021). accessed.
[56] R. Smith, These are the world's biggest coal producers, World Economic Forum (2018). https://www.weforum.org/agenda/2018/01/these-are-the-worlds-biggest-coal-producers/. (Accessed 15 February 2021). accessed.
[57] Y. Zhou, M. Hejazi, S. Smith, J. Edmonds, H. Li, L. Clarke, K. Calvin, A. Thomson, A comprehensive view of global potential for hydro-generated electricity, Energy Environ. Sci. 8 (2015) 2622–2633, https://doi.org/10.1039/C5EE00888C.
[58] A. Jacobson, A.D. Milman, D.M. Kammen, Letting the (energy) Gini out of the bottle: Lorenz curves of cumulative electricity consumption and Gini coefficients as metrics of energy distribution and equity, Energy Pol. 33 (2005) 1825–1832, https://doi.org/10.1016/j.enpol.2004.02.017.
[59] M.J. Arentsen, R.W. Künneke, Developments and trends in east-central europe and Algeria, in: National Reforms in European Gas, Elsevier, 2003, pp. 309–325, https://doi.org/10.1016/B978-008043687-6/50015-8.
[60] L.M. Fraas, Low-cost Solar Electric Power, Springer, Cham, 2014.
[61] J. Markard, B. Truffer, C. Bratrich, Green marketing for hydropower, Int. J. Hydropower Dams (2001) 81–86.
[62] D. Ansari, Rigging economics, Nat. Energy 4 (2019) 263–264, https://doi.org/10.1038/s41560-019-0352-z.
[63] L.C. King, J.C.J.M. van den Bergh, Implications of net energy-return-on-investment for a low-carbon energy transition, Nat. Energy 3 (2018) 334–340, https://doi.org/10.1038/s41560-018-0116-1.
[64] P.E. Brockway, A. Owen, L.I. Brand-Correa, L. Hardt, Estimation of global final-stage energy-return-on-investment for fossil fuels with comparison to renewable energy sources, Nat. Energy 4 (2019) 612–621, https://doi.org/10.1038/s41560-019-0425-z.
[65] G. Palmer, Renewables rise above fossil fuels, Nat. Energy 4 (2019) 538–539, https://doi.org/10.1038/s41560-019-0426-y.
[66] G. Escribano Francés, E. San Martín González, Managing energy interdependency in the Western Mediterranean, Paix et Securite Internationales, 2014, pp. 81–102, https://doi.org/10.25267/Paix_secur_int.2014.i2.05.
[67] J. Markard, The next phase of the energy transition and its implications for research and policy, Nat. Energy 3 (2018) 628–633, https://doi.org/10.1038/s41560-018-0171-7.