Energy Strategy Reviews 26 (2019) 100406

Contents lists available at ScienceDirect

Energy Strategy Reviews

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

The GeGaLo index: Geopolitical gains and losses after energy transition

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ARTICLE INFO

Keywords:
Geopolitics
Energy resources
Energy transition
Fossil fuels
Renewable energy
Index design

ABSTRACT

This article presents the GeGaLo index of geopolitical gains and losses that 156 countries may experience after a full-scale transition to renewable energy. The following indicators are considered for inclusion in the index: fossil fuel production, fossil fuel reserves, renewable energy resources, governance, and conflict. Some of these represent potential gains; some represent losses; and some the capacity of countries to handle changes in geopolitical strength. Five alternative versions of the index are developed to work out the optimal design. First, the energy resource indicators are combined with equal weights to create two simple versions of the index. Next, governance and conflict indicators are included to create three more complex versions of the index. The index provides useful pointers for strategic energy and foreign policy choices: geopolitical power will be more evenly distributed after an energy transition; Iceland will gain most; Russia may be one of the main holders of stranded geopolitical assets; China and the USA will lose more geopolitically than foreseen by other analyses. The index also indicates a lack of emphasis in parts of the literature on space for renewable energy infrastructure and on domestically sourced coal for the current strength of countries such as China and the United States.

1. Introduction

The energy transition has given impetus to a new geopolitical literature. While the post-World War II geopolitical literature was centered on competition over petroleum resources [1–4], the new literature is underpinned by the idea that countries will gain or lose geopolitical advantages as a consequence of the energy transition [5–10]. It is thought that major fossil fuel exporters will find that their main sources of income and leverage over importers become stranded geopolitical assets. Conversely, the importers will be relieved of a financial burden and dependency, while countries rich in renewable energy resources might also have a new advantage. A country such as Algeria should be weakened due to the end of fossil fuel exports, but part of this loss could be offset by the country's abundant solar power resources. For countries such as Russia and Saudi Arabia, which use oil and gas revenue to prop up their armies and are embroiled in armed conflicts with their neighbors, a geopolitical weakening could be particularly challenging.

While the new literature presents some striking scenarios, their basis is largely anecdotal. This article therefore explores the quantification of the geopolitics of renewables and seeks to bridge the gap between the budding literature on the geopolitics of renewables and the more established literature made up of indexes that map the strengths and weaknesses of countries. We do so through the creation of the Index of Geopolitical Gains and Losses (GeGaLo). Its purpose is to map the geopolitical strengthening and weakening that states may experience relative to the current situation when a transition to renewable energy has been completed. Though energy security is one aspect of GeGaLo, it is not an energy security index, nor is it an index covering all aspects of geopolitical power—only those related to the energy resource bases of countries.

In the next section, we provide a brief overview of 34 existing country indexes before going on to examine indicators that might form part of GeGaLo. Once the indicators have been identified, we develop five alternative versions of the index, subject them to sensitivity analysis, and discuss the results.

2. Existing indexes

Existing indexes relating to the positions of countries in the world can be grouped into six broad categories: power, security, vulnerability, energy security, other energy issues, and climate change (see Table 1). Many of them are published only as gray literature but are nonetheless influential among policy makers and academics alike.

The Energy Transition Index published by the World Economic Forum is particularly relevant for our project. It builds on a grand total

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https://doi.org/10.1016/j.esr.2019.100406
Received 19 January 2019; Received in revised form 5 August 2019; Accepted 14 August 2019
Available online 15 October 2019

Table 1
Existing indexes.

	Countries	Description	Creator
Power indexes			
Composite Index of National Capability (CINC)	193	Measures national power in terms of demography, economics, and military strength.	Singer, Correlates of War [11,12]
State Power Index	168	Quantifies state power using capital, militarization, land, human resources, culture, natural resources, and diplomacy as indicators.	Lewicki and Arak [13]
Asia Power Index	25	Measures power of Asian states in eight dimensions: economic resources, military capability, resilience, future trends, diplomatic influence, economic relationships, defense networks, and cultural influence.	Lowy Institute [14]
World Power Index	n/a	Rates a country's power through the lens of nuclear capability, land, population, industrial base, and military size.	German [15]
National Power Index	n/a	Measures state power, with population size, energy, and steel production as the key variables.	Fuchs [16]
International Power Index	n/a	Historical comparison of international power, with the following indicators: surface area, total population, government revenue, military expenditure, size of armed forces, and trade.	Ferris [17]
Security indexes			
Global Cybersecurity Index (GCI)	193	Quantifies cybersecurity in five dimensions: legal, technical, organizational, capacity building, and cooperation.	International Telecommunication Union [18]
International Security Index (ISI)	n/a	Measures the probability of events threatening international security (not focused on individual countries).	PIR Center [19]
Global Peace Index (GPI)	163	Measures the relative peacefulness of countries in three dimensions: safety and security, militarization, and ongoing conflict.	Institute for Economics and Peace [20]
Global Conflict Risk Index (GCRI)	138	Assesses the statistical risk of violent conflict in the next 1–4 years in five dimensions (social, economic, security, political, and geographical/environmental), and measures the probability and intensity of violent conflict.	European Commission [21]
Vulnerability indexes			
Fragile State Index (formerly Failed State Index)	178	Assesses states' vulnerability to collapse by studying pre-, ongoing, and post-conflict situations.	Fund for Peace [22]
Composite Vulnerability Index for Small States	111	Measures the vulnerability of small countries, especially to external economic factors and environmental hazards.	Atkins et al. [23]
Climate indexes			
Environmental Vulnerability Index (EVI)	[a]	Covers the environmental vulnerability of countries, focusing on climate, geology, geography, ecosystem resources and services, and human population.	South Pacific Applied Geoscience Commission [24]
Climate Change Vulnerability Index (CCVI)	193	Measures the vulnerability of countries to climate change in the coming 30 years. Shows exposure of countries to climate-related natural hazards; the sensitivity of populations in terms of concentration, development, agricultural dependency, and conflict; and the adaptive capacity of governments and infrastructure.	Maplecroft [25]
Global Climate Risk Index	181	Measures the extent to which countries were affected by weather events, such as storms, floods, heat waves, etc. from 1998 to 2017.	Eckstein et al. [26]
Energy security indexes			
Global Energy Architecture Performance Index (EAPI)	127	Measures the ability of countries to provide secure, affordable, and sustainable energy and shows their performance.	World Economic Forum [27]
Energy Trilemma Index	125	Ranks countries in three areas: energy security, energy equity, and environmental sustainability.	World Energy Council [28]
Energy Transition Index	114	Assesses energy system performance in three areas: energy access and security, environmental sustainability, and economic development.	World Economic Forum [29]
International Energy Security Risk Index	75	Identifies policies and factors that affect international energy security positively or negatively, focusing on major energy consumers.	Global Energy Institute [30]
Oil Vulnerability Index (OVI)	26	Focuses on the sensitivity of net oil-importing countries to developments in the oil market in 2004.	Gupta [31]
Energy Security Index	18	Measures countryies' performance on energy security over time taking into account such interrelated factors as availability, affordability, efficiency, sustainability, governance and matching them with 20 metrics.	Sovacool [32]
Sustainable Energy Security Index (SES)	n/a	Covers the supply, conversion, distribution, and demand aspects of the energy system. Each aspect is evaluated in four dimensions: availability, affordability, efficiency, and environmental acceptability.	Narula and Reddy [33]
Energy Supply Security Index	1	Includes physical energy security, economic energy security, and environmental sustainability.	Kamsamrong and Sorapipatana [34]
Energy Security Index	[a]	Covers diversity, availability, affordability, and acceptability of energy.	Ranjan and Hughes [35]
Security Physical Availability Index (ESPAI)	2	Covers price and physical availability.	Lefèvre [36]
Energy Security Index	22	Covers availability, affordability, energy and economic efficiency, environmental stewardship.	Sovacool and Brown [37]
Oil Import Vulnerability Index	1	Includes crude oil import dependency of primary energy consumption, crude oil import bill as a share of GDP, non-diversification of import sources, and share of oil in total energy import.	Ediger and Berk [38]
Oil Import Risk Index	1	Focuses on external dependence, supply stability, trade economy, and transportation safety.	Zhang et al. [39]

(*continued on next page*)

Table 1 (*continued*)

	Countries	Description	Creator
Composite Index of China's Energy Security	1	Covers energy supply security and energy consumption.	Wu et al. [40]
Other energy indexes			
Regulatory Indicators for Sustainable Energy (RISE)	133	Based on 27 indicators; assesses countries' policy support for three pillars of sustainable energy: access to modern energy, energy efficiency, and renewable energy.	Energy Sector Management Assistance Program [41]
Multidimensional Energy Poverty Index (MEPI)	29	Measures factors that limit access to modern energy services in Africa. Covers both the incidence and intensity of energy poverty.	Nussbaumer et al. [42]
Energy for Development Index (EDI)	80	Measures the progress in transitioning to reliable, clean, and efficient fuels and energy services at the household and community levels.	International Energy Agency [43]
Sustainable Energy Development Index (SEDI)	62	Focuses on technical, economic, social, environmental, and institutional dimensions of energy development.	Iddrisu and Bhattacharyy [44]
Energy Access Index	[a]	Covers the quality of the energy supply in developing countries in three dimensions: supply of household fuels, electricity, and mechanical power.	Practical Action [45]

[a] Developed as an analytical tool, but not applied to countries.

of 38 disparate sub-indicators. The range of indicators is so broad that it is difficult to tell what the index actually captures. Some of the indicators may also have unintended impacts. For example, one of the indicators for energy security is the diversity of energy sources. Thus, in the case of a country such as Norway, the vast amounts of reliable, cheap, domestic hydropower paradoxically reduce the score.

Similar criticism of using too many indicators has been levelled against the Fragile State Index [46,47]. In the current study, we experiment with a narrower index based on fewer indicators in the hope of addressing our topic more clearly.

A group of indexes particularly relevant for GeGaLo is that which concerns energy security [48]. GeGaLo differs from and adds to this literature on energy security in several ways. First, GeGaLo is not about energy security as such, but rather *geopolitics*, and security of energy supply is only one aspect of geopolitics (see discussion below). Second, we use a definition of "energy security" that is narrower and clearer than those of most existing indexes (see discussion below). Third, our index is oriented toward a future hypothetical situation rather than the current or past situation as most energy security indexes. Fourth, we cover a larger number of countries than most energy security indexes. Ang et al. [49] analyzed 104 energy security indexes and identified the geographical focus of each index. The vast majority cover only one or a few countries e.g. [50–52]. Most entirely focus on large and powerful countries e.g. [53]. They are thus indexes of a very different nature from ours, which is aimed at comparing as many countries as possible. Hardly any of the 104 indexes cover more than 100 countries, and only one of them, Jewell et al. [54], has a global focus. However, it covers the whole world as one unit rather than comparing countries. Fifth, we introduce a new formula for calculating fossil fuel dependency. Sixth, our index is unusual in that it focuses on access to physical energy resources, in accordance with a classical geopolitical perspective. Seventh, as Ang et al. [49] point out, almost no energy security indexes have been subjected to sensitivity analysis, but ours has.

There have also been some attempts at specifically analyzing the geopolitical fate of different countries or regions in connection with the energy transition (see Table 2). These are the most relevant existing indexes for GeGaLo, though most of them are qualitative assessments of a handful of countries rather than proper indexes based on quantitative data. They find that Russia and Saudi Arabia are likely to be some of the greatest losers. Sweijs et al. [57] focus on the vulnerability of fossil fuel exporters dependent on EU markets and conclude that seven countries are most likely to lose out due to the EU's energy transition. Van de Graaf [55] looks primarily at potential losers in the transition, such as Brazil, Nigeria, Russia, and Venezuela. However, in his view, the greatest losses will be incurred by Saudi Arabia because of its high level of dependence on oil revenue and rapidly growing population. By contrast, he sees the United States as a clear winner, along with China, Japan, and Europe.

Table 2
Three existing analyses of energy transition geopolitics.

Sweijs et al.: Least and most exposed to EU energy transition [57]	Van de Graaf: Oil exporters vs. importers [55]	Smith Stegen: Geopolitical winners vs. laggards [56]	
(*Least exposed*) • Saudi Arabia • Qatar • Kazakhstan • Egypt • Libya • Russia • Algeria (*Most exposed*)	*Oil importers win* • United States • China • Japan • Europe *Oil exporters lose* • Saudi Arabia • Venezuela • Nigeria • Brazil • Russia	*Winners* • Uruguay • Namibia • Kenya • Mali • Sweden • Finland • France • Nicaragua • Honduras • India • Jordan • Mongolia • Sri Lanka • China • United States • Algeria	*Losers* • Brunei • Qatar • Bahrain • Kuwait • Timor-Leste • Trinidad • Bhutan • Slovakia • Belize • Georgia • Bangladesh • Gabon • Samoa • Puerto Rico

Most of these existing analyses do not put much emphasis on methodology. Smith Stegen's [56] typology of winners and losers in the transition to renewable energy is an exception. It is based on three indicators representing factors that either impede or facilitate a transition: renewable energy potential, political receptiveness, and the hydrocarbon lobby. Smith Stegen's is also the only one of these analyses that covers a large number of countries. Like Van de Graaf, she sees China and the United States as winners. Compared with Smith Stegen's index, we use different indicators and combine them according to a different formula. Our purpose is also different: while her index assesses the prospects for taking the lead in the energy transition, ours aims to identify which countries are likely to gain and lose most geopolitically after a global energy transition has been completed. Accordingly, our results also diverge significantly.

3. Purpose of the index

According to Jacobson et al. [58], limiting global warming to 1.5 °C will require reaching 80% zero emissions energy by 2030 and 100% by 2050. Achieving this without widespread carbon capture or nuclear power would require a rapid, large-scale transition to renewable energy. The purpose of our exercise is not to estimate whether, when, or to what degree countries might succeed in doing so. Instead, we explore possible indicators of how the energy-related geopolitical positions of countries in terms of their resource bases might change relative to today's situation *if* that should happen. Thus, GeGaLo relates to a hypothetical future situation where the world already derives almost all its energy from renewable sources—the *post*-energy transition phase. We therefore do not seek to measure which countries currently have the best policy frameworks for renewables, are transitioning fastest, or face the stiffest resistance from domestic fossil fuel incumbents.

As our analysis does not assess the probability of realizing a full-scale energy transition, by extension, neither can we say when it might occur. This means that we do not operate with a specific target year for our hypothetical situation. It could occur in 50 years, or 150 years, or never.

GeGaLo also does not seek to reflect the overall geopolitical power of countries after energy transition. Rather, it is about the *changes* in geopolitical power *relative* to the situation before the energy transition and specifically related to energy resource access. Thus, a country may well remain geopolitically important for other reasons, even if it has lost some of its energy-related geopolitical clout.

Although our index relates to a hypothetical situation at some point in the future, it must rely on data regarding the current situation as that is what is available. For example, the capacity of a state to govern in the future may be greater or lesser than it currently is, but all we have are data on the current governance. This caveat applies to not only a social indicator such as governance but to all our indicators. For example, a seemingly unchanging indicator such as fossil fuel reserves may be altered by the discovery of new deposits, the development of new technologies for exploration, or the development of new technologies for resource extraction and processing (such as fracking technology did in the past). It is, therefore, not feasible to make reliable forecasts of what the data will be in the future, and this is an inherent limitation of any such index. However, the results may still be of interest insofar as they say something about the possible challenges and benefits states and other actors may want to take into account in their energy strategies.

4. Concepts

GeGaLo takes as its starting point a physical geography perspective and is therefore focused on physical energy resource indicators. Geopolitics also has other aspects, such as geographical location, military might, and non-energy resources, but they are outside the scope of this article.

The term “geopolitics” can have many different meanings depending upon whom it is used by. We adhere to the mainstream understanding of the term in the academic literature dedicated to geopolitics [59–64]. Thus, for the purposes of this article, “geopolitics” is defined as the influence of geography on the power of states and international affairs, emphasizing the strategic importance of natural resources, their location, and transportation routes [65].

By extension of our physical geography starting point, definition of geopolitics and focus on energy, we define “geopolitical power” as a combination of (1) the security of the energy supply of a country, (2) power over the energy supplies of other countries, and (3) economic strength derived from energy exports. We see access to physical energy resources as enhancing all three aspects of geopolitical power. Although economic strength is not geopolitical as such, it can be used to bolster (a) military power, (b) soft power, (c) attractiveness for international alliances, and (d) to withstand international sanctions.

A review of 83 energy security definitions reveals that the concept of energy security depends on the context and that there are so many different uses of the term that it is quite loose [49]. Of the seven main meanings of “energy security” identified, only one, energy availability, is directly relevant for our study.

Geopolitical power as defined above involves elements of energy security, but only in the narrow sense of access to physical energy resources. This is the sense in which the term “energy security” is used in the geopolitics literature [66,67], and diverges from the way it is used in the part of the literature on the stability and reliability of energy systems, which focuses on the ratio of intermittent renewable energy that an energy system can support. In the hypothetical situation GeGaLo deals with, these challenges must have already been dealt with as the world has fully transitioned to renewables.

The definitions presented here are important to bear in mind for readers who are not from a geopolitics background and may think of geopolitics in other and broader terms, as the definitions have implications for our choice of indicators and methodology.

5. Indicators

As pointed out by Bazilian et al. [68] and Ang et al. [49], the selection of indicators to reflect energy resources and flows in the real world is a complex undertaking in itself. In addition, we need to take into consideration the availability of and necessary modifications to the data (division per capita, etc.). Consequently, much of the time that went into preparing this article was spent searching for and assessing possible indicators and data. Many of the datasets used by existing country indexes are either not publicly available, do not cover enough countries, or do not fulfill the requirements of our index.

5.1. Fossil fuel dependency (FFD)

In the current global energy system, some countries have an advantage in that they produce fossil fuels, while others have the disadvantage of having to buy them. If fossil fuels are replaced by renewable energy, former fossil fuel producers will lose an advantage, and former importers will rid themselves of a burden. The purpose of this indicator is to reflect how much of a (dis)advantage would be lost in a post-energy transition world.

Several variants of this indicator were considered. Using data on the net fossil fuel *trade balance* would make it possible to distinguish between varying degrees of advantage for net exporters and burden upon import-dependent countries in the current energy system. However, that would leave out large countries that are resource rich in fossil fuels but use a significant portion of them for domestic consumption (for example, coal in China, Russia, and the United States). Using data on fossil fuel *production* would avoid this problem but introduce another concern, as one could no longer differentiate between varying degrees of import dependence, and all non-fossil fuel producers would look the same. The first solution we tried out to avoid these problems was to calculate this indicator as fossil fuel production minus imports. This enabled us to take into account different degrees of fossil fuel import dependency, export dependency, *and* self-sufficiency. It worked for almost all countries. However, for a certain type of country it led to distorted index scores: those that import and re-export large amounts of fossil fuels. That includes major oil refining hubs, such as the Netherlands and Singapore, and a major gas transit country such as Ukraine. In order to avoid this problem, we further developed the formula so that we subtract exports from imports before subtracting imports from production. That results in the following formula:

$$FFD = p - (i - e) \tag{1}$$

where p is production, i is imports, e is exports and FFD stands for fossil fuel dependency. This formula has one side effect: for major exporters, fossil fuels are counted twice, first as production and second as exports. This is because they have no or limited imports to counterbalance their exports in the $i - e$ part of the formula. After some deliberation, we concluded that this is justified because there is a significant difference between producing enough fossil fuels for domestic consumption and producing so much that there is a large export surplus.

To our knowledge, this solution has not been used in the literature before. It gives a better impression of the fossil fuel (in)dependence of different countries than the simple oil trade balance, which is often used in discussions about the oil import dependency of China, the

United States, and other countries [69,70]. While these countries are dependent on oil imports, a significant proportion of their consumption is covered by domestic production, which countries that are even more import-dependent lack.

5.2. Fossil fuel reserves (FFR)

This indicator includes the oil, gas, and coal reserves possessed by countries. There are three reasons to include a second fossil fuel indicator. First, although fossil fuel production and fossil fuel reserves are generally correlated, for some countries, they diverge. Due to better regulatory frameworks, access to capital, and other factors, developed countries have been quicker to produce oil and gas than underdeveloped countries. Sanctions can also disconnect production from reserves: oil and gas production in Iran and Russia is currently held back by foreign sanctions [71]. While production and consumption represent the current role of fossil fuels in a country's economy, resources represent a (sometimes much larger) future value—which will not be captured by the index if fossil fuels reserves are no longer to be included.

Second, if one does not take into account imports, which are bundled with our fossil fuel production indicator, one misses out on one of the main consequences of transitioning to renewable energy: importing countries will be relieved of the need to import energy which involves both a financial burden and energy supply risks. Therefore, we cannot replace our first fossil fuel indicator with this one.

Third, by including two fossil fuel indicators, fossil fuels are given greater weight in the index. This makes sense because the dissolution of the fossil fuel energy system would entail a fundamental and possibly sudden downgrading of the position of fossil fuel producers in the world. For most fossil fuel importers, the effect might be less dramatic, but would cumulatively amount to a significant change in their long-term predicament. By contrast, the consequences of the growth of renewable energy, which is more evenly distributed among countries, will likely be less dramatic. It therefore makes sense to give fossil fuel indicators extra weight by including a double set of them, while also taking the opportunity to differentiate between reserves and current production/exports/imports.

5.3. Renewable energy sources (RES)

This indicator includes the solar radiation, wind, and river flow available in each country. Bioenergy is not included, partly due to the lack of data and partly because the current prospects for the large-scale use of bioenergy are unclear, with both biodiesel and ethanol raising concerns [72]. While traditional biomass currently plays an important role in many developing countries, it is often unsustainable, and in our scenario, it is assumed to have been phased out. Geothermal energy is not included either, as it makes up a small part of the current global supply of renewable energy and is not growing rapidly. Meanwhile, photovoltaic and wind power are growing exponentially, aided by their plummeting prices [73]. Hydropower is important as well because it is by far the largest and most established form of renewable energy and because it has an important role to play in storage and balancing for energy systems with a large proportion of intermittent renewables [74].

As costs fall, solar and wind power are becoming increasingly cost-efficient, even in parts of the world with low solar radiation and wind speeds. Accordingly, one might argue that since all countries have some sunshine and wind, it is of little interest to compare their resources. However, although sunshine and wind are more evenly distributed around the world than are fossil fuels [75], some countries are still better endowed than others. Solar panels may be viable in, for example, Iceland, despite low solar radiation, but it would take more solar panels (and thus more capital) to produce the same amount of electricity there as in, say, Chile.

We also considered applying a threshold for the use of renewable resources. Otherwise, a country such as Russia, with a large surface area, but not necessarily very rich resources per square meter, might get a disproportionately high score. On the other hand, Russia's vast size means that it does have space available for installing millions of solar panels, whereas sunnier countries like Bahrain or Bangladesh have less available space. Therefore, the spatial factor should to some extent compensate for Russia's moderate solar radiation intensity. We also note that spatial conflicts in connection with renewable energy, especially wind farms, are on the rise and both solar and wind power are being pushed offshore, indicating that space may be a valuable resource in a world running on renewables. We therefore decided not to set a threshold for what level of solar radiation or wind to take into account. This also accords well with our decision to use total fossil fuel resources, rather than technical or economic reserves. In both cases, we avoid peak oil type reasoning and leave the door open to more efficient future technologies.

Finally, we deliberated on whether to include maritime territories in our calculations or not. We decided to do so for wind power as it is possible that floating wind power could become a key source of renewable energy, especially considering the growing spatial conflicts over renewable energy facilities onshore. Because of this choice, countries with outsize maritime territories, such as Iceland or Japan, get high renewable energy scores. If floating wind turbines continue to fall in cost, such countries could potentially become the Saudi Arabias of wind power.

5.4. Governance (G)

We include governance as a possible variable not because it makes it possible for states to transition faster and more efficiently to renewables (although it also does that), but because it is relevant for how well states are likely to handle changes in their geopolitical strength. A comparison of the consequences of the 2014 oil crash for Canada and Venezuela—possessing the world's third largest and largest oil reserves, respectively—can serve as an example. In Canada, there was a slight rise in unemployment, mainly in Alberta—but the economic impact was limited, and the country remained stable. By contrast, Venezuela descended into chaos with hyperinflation, severe shortages of most goods, fighting on the streets, and many people fleeing to other countries. The different fates of Canada and Venezuela after the 2014 oil crash are related both to their capacity for governance and their level of domestic and international conflict (see next indicator).

5.5. Conflict (C)

Oil and gas revenues have long influenced the balance of power among rivalling countries. For example, Saudi Arabia's approach to the conflict in Yemen and standoff with Iran might have played out differently had not Saudi Arabia's military prowess been propped up by oil exports. In the case of Russia, changes in political and military outlook have famously coincided with variations in the price of oil (see Fig. 1).

Oil and gas revenues have not only fueled the military campaigns of petrostates, but have also enabled some countries to provide more foreign aid than they might otherwise have done. For example, Norway, Saudi Arabia, and Venezuela have all channeled funds to poorer countries that they have sought to help or influence.

The loss of fossil fuels as a source of energy, export revenue, and leverage over the energy supplies of other countries may also destabilize states internally. Countries that experience major domestic political instability also become more vulnerable in international affairs. This can be a problem in fuel-producing countries that have major internal ethnic or political divisions and have used fossil fuel revenues to dampen these, and/or to keep foreign powers at bay.

We considered several different possible data sources for the conflict indicator, including the Uppsala Battle-Related Deaths dataset and armed conflict data. However, using these datasets alone would provide

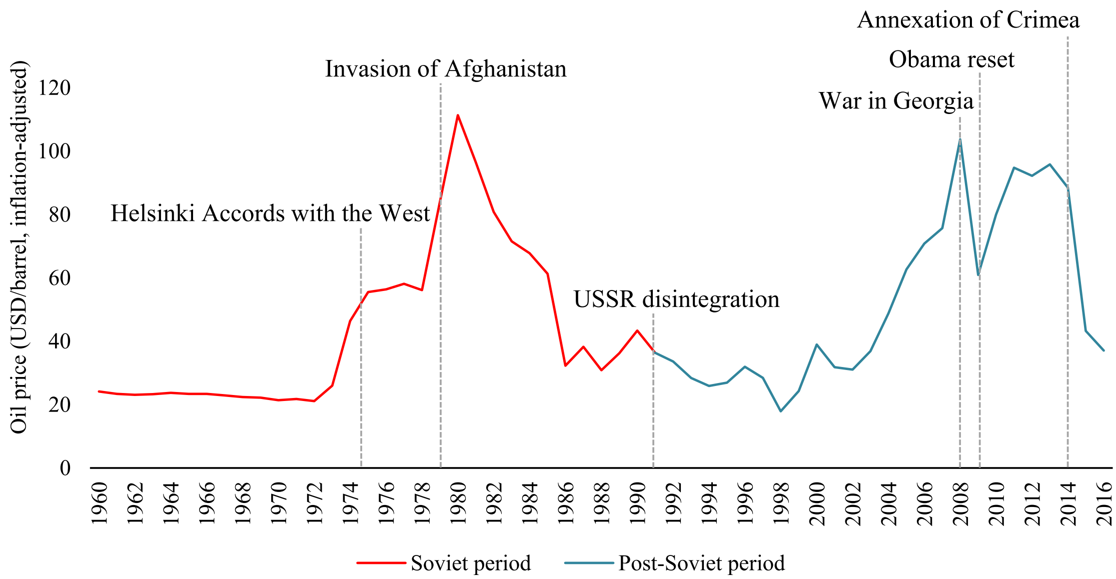

Fig. 1. The oil price and Soviet/Russian involvement in international armed conflict.

only a partial picture of a country's involvement in external conflict. For instance, the Uppsala data on the conflicts in Ukraine and Yemen list them as internal conflicts and note that Russia and Saudi Arabia are involved in those conflicts, yet this information is not taken properly into account in the scores of Russia and Saudi Arabia.

We also considered using the data from the Armed Conflict Location and Event Data Project (ACLED). However, the geographical coverage was too limited for our purposes. Moreover, ACLED sub-indicators are mainly concerned with domestic conflict and do not give the full picture of a country's involvement in international conflict.

Ultimately, we opted for the Global Peace Index, which includes dimensions such as safety and security, military spending, and ongoing conflict (both internal and external) and which is increasingly used in other studies [76–79]. Unlike some of the other datasets, the Global Peace Index captures the best known conflict-ridden petrostates with, for example, Libya, Nigeria, and Russia among the worst performers in the index.

6. Adaptation and normalization

Before combining the indicators to create an index, they had to be adjusted to the dimensions of each country to ensure proportionality. For example, China produces around four million barrels of oil per day, far more than Brunei's 100,000 barrels. But China has a large population to divide its oil among and is therefore a significant net importer, while Brunei, with a population of less than half a million, is a major exporter in per capita terms.

We assessed several options for achieving proportionality, including dividing fossil fuel production by GDP and renewable energy resources by domestic electricity or energy consumption. However, there are problems with each of these options, and we ultimately opted to divide all resource indicators by population, as it is a transparent measure that can be applied consistently to all resource indicators.

Because the indicators come in different units and on different scales, we also needed to normalize them before bringing them together. One option would be to convert them all to a common unit such as US dollars, British thermal units, or barrels of oil equivalent. However, this is difficult with such disparate indicators [49], and there are several counter-arguments. First, while oil, gas, and coal could be easily converted to common units, solar radiation and wind are harder to convert as they are infinite resources. Second, oil and coal are hardly exchangeable in the current energy system. Third, reliable data on oil imports and exports are unavailable for many countries and are mainly found in the form of trade statistics, which are in USD rather than physical volumes. Fourth, the purpose of our analysis is to compare relative positions of countries rather than assess the specific energy content of energy types. Accordingly, we simply normalized the resource sub-indicators to a scale of 0–100, which became a scale of 0–300 when three sub-indicators were added up to make an indicator. The societal indicators governance and conflict were normalized to 0–300 or 0–1, depending on how they are used in the index.

The indicators contribute to the index in different ways. For the fossil fuel indicators, a high initial score should count negatively (as an advantage that is lost), whereas a low initial score should count positively (as a burden that is alleviated). In the calculation of the index, it is therefore necessary to invert the fossil fuel indicators from minus to plus and vice versa. For the renewable energy indicators, a high score counts as a strength and no inversion is needed.

7. Indicator checks

We examined the characteristics of each indicator (see Table 3). All indicators have a theoretical range of 0–300. Fossil fuel dependency (FFD), fossil fuel reserves (FFR), and renewable energy sources (RES) are all based on three sub-indicators each which were normalized from 0 to 100. Thus, whether the indicator values actually span the whole range from 0 to 300 depends on how the sub-indicators add up. The indicators have different means and distributions. These are discussed in the section below on the sensitivity analysis.

Next, we looked at how outlier countries scored on specific indicators to make sure that they would not skew the results. We found that Greenland and Iceland have such large territories and small populations that they distort the whole index by making the differences between the renewable energy resources of other countries seem small and, thus, stunting their impact on the index. They were therefore

Table 3
Data characteristics.

	FFD	FFR	RES	G	C
Min	0	170	0	0	0
Average	261	294	17	150	187
Max	300	300	174	300	300
St dev	33	18	30	69	62

removed from the dataset.

In the case of Greenland, this conclusion was clear as it is an extreme outlier. It is six times larger than Germany but has a population of only 56,000. In the case of Iceland, more detailed analysis was needed. We did test runs of the basic index calculations with and without Iceland and found that, although the overall index remained largely the same, most countries moved up or down 3–4 places, and a few moved many more. The major movers included two other countries rich in renewable energy resources: Australia (up 102 places) and Canada (up 16 places). Thus, the effect of removing Iceland was to allow the significant renewable energy resource advantages of other countries to have a greater impact on the index. We would rather capture these differences than have them overshadowed by the renewable energy prowess of Iceland (population 338,000). However, when Iceland is included, it is placed at the top of all five versions of the index. And that is not even taking into account Iceland's considerable geothermal resources, as our data only cover hydro, solar, and wind resources. Clearly, Iceland is the country that has the most to gain from a global transition to renewable energy. Accordingly, we removed Iceland while calculating the rankings of other countries, but reintroduced it in the final versions of the index.

Another issue we investigated was the impact of missing values and their replacement. There were a few missing values in the wind, solar, and hydropower sub-indicators, and we tried out different options for replacing them and assessed their impact in test runs of the index calculation. First, we replaced missing values with the averages of all the other countries for the indicator in question. This gave more convincing results for most countries, but distorted the results of some. For example, Montenegro was suddenly the top-ranked country because, for a small country such as this, the average amount of wind resources of other countries far exceeds what it could have. To remedy this, we instead calculated the average amount of resources per square kilometer for all the other countries, and then applied this to Montenegro (and likewise for other countries with missing values).

Another concern was the way in which Singapore's role as an oil trading hub with large-scale oil imports and re-exports gave it an unjustified high score on the fossil fuel dependency indicator. This forced us to redesign the FFD indicator so that exports were subtracted from imports before imports were subtracted from production (see the section on the FFD indicator above).

The result of the preceding discussion is a collection of three energy resource indicators and two societal indicators, building on a total of 11 sub-indicators. These are presented in Table 4.

Table 5
Correlation of indicators.

	FFR	RES	FFD	G	C
FFR	1.00				
RES	−0.36	1.00			
FFD	0.88	−0.34	1.00		
G	−0.12	0.04	−0.11	1.00	
C	−0.05	0.05	−0.06	0.70	1.00

Note: FFR = fossil fuel reserves; FFD = fossil fuel dependency; RES = renewable energy sources; G = governance; C = conflict.

8. Sensitivity analysis

We started the sensitivity analysis with a correlation table of the indicators (see Table 5). As expected, FFR and FFD are highly correlated. Some might therefore argue against including both. Thus, in the next section, we develop versions of the index with only FFR as well as with both of FFR and FFD.

Next, we combined the indicators in different ways to create five different versions of the index. The purpose was to identify how different indicator combinations and aggregation formulas impact the final index. The five versions are presented briefly in Table 6, and more detailed mathematical formulas are in Appendix 1.

In Fig. 2, the five index versions are subjected to one-factor “what if” analysis, the most common type of sensitivity analysis. The graphs show how many percentage points the indexes change for every percentage point change in each of the indicators. The steeper the line representing an indicator, the greater its influence on the index.

The graphs in Fig. 2 track the average impact of the indicators on all the countries. Although the average impact of an indicator is low, the impact on some countries can be substantial. RES has little overall impact compared to FFR and FFD, but for those countries that have major renewable energy resources, such as Australia and Canada, it plays an important role in their index scores.

In versions 1b and 2b of the index, also the governance (G) and conflict (C) indicators are introduced but have limited impact. This is because they are only applied to FFR and FFD and only to net fossil fuel exporters. In version 3, all indicators are simply added up, and G and C become more important as they then apply to all countries. This yields the index that looks most robust at the level of the sensitivity graphs shown in Fig. 2, as the influence of the indicators is more balanced. However, as we will discuss in the next section, this also has some disadvantages, and it depends on what one wants to achieve with the index.

Table 4
Overview of indicators.

	Sub-indicators	Sources
Fossil fuel dependency (FFD)		
Exports subtracted from imports, then subtracted from domestic production, divided by population, normalized 0–100, negative/positive values inverted	Coal	MIT 2018 [80]
	Oil	MIT 2018 [80]
	Gas	MIT 2018 [80]
Fossil fuel resources (FFR)		
Resources divided by population, normalized 0–100, inverted to negative values	Coal	UN 2015 [81]
	Oil	CIA 2018 [82]
	Gas	CIA 2018 [83]
Renewable energy sources (RES)		
Calculated as GWh, the three indicators summed up, divided by population, normalized 0–100	Solar	NREL 2018 [84]
	Wind	NREL 2018 [85]
	Hydro	UN 2015 [81]
Governance (G)		
Normalized 0–100 or 0–1, depending on index version	Governance	WB 2018 [86]
Conflict (C)		
Normalized 0–100 or 0–1, depending on index version	Conflict	IEP 2018 [20]

Note: CIA = Central Intelligence Agency; EIA = Energy Information Administration; IEP = Institute for Economics and Peace; MIT = Massachusetts Institute of Technology; NREL = National Renewable Energy Laboratory; UN = United Nations; WB = World Bank.

Table 6
Versions of index.

No.	Formula	Description
1	FFR + RES	Basic index with only fossil fuel reserves and renewables.
1b	FFR * ([G + C]/2) + RES	Adds weighting of fossil fuels by governance and conflict.
2	FFR + FFD + RES	Back to basic index, now with two fossil fuel indicators.
2b	(FFR + FFD) * ([G + C]/2) + RES	Adds weighting of fossil fuel by governance and conflict.
3	FFR + FFD + RES + G + C	All indicator groups simply added up with equal weights.

Fig. 2 shows that FFD and FFR influence the index outcomes more than RES. This is due to the distributions of the countries on the indicators. As the histograms in Fig. 3 show, for both the fossil fuel and the renewable energy indicators, most countries crowd together with similar scores. However, on the fossil fuel indicators, the crowd is pushed toward the top of the scale by the outliers at the bottom of the scale. That is to say, the very great losses/low scores of former major fossil fuel exporters, such as Qatar and Saudi Arabia, put the majority of the countries, which are former fossil fuel importers, near the top of the scale.

For RES, the situation is the opposite. Most countries have a certain renewable energy resource base, but a few have much more than the others, for example, Australia, Canada, and Iceland. These exceptionally endowed countries squash the rest together at the bottom of the scale. Consequently, the average country has much higher scores on the fossil fuel indicators than on the renewable energy indicator. As the sensitivity analysis is carried out in terms of the relationship between percentage of change in the indicators and percent change in the index, it appears that the fossil fuel scores play a much bigger role in the index because 1% of a high score is more than one 1% of a low score. Thus, it is the asymmetry of the outliers that differentiates the impact of the indicators in Fig. 2.

This brings us back to the question of what to do about the outliers. We have already removed countries such as Greenland and (temporarily) Iceland. What about Australia, Canada, Kuwait, Qatar, and Saudi Arabia? Should they also be removed to give the distribution of countries on the indicators a more even shape and reduce the impact of the fossil fuel indicators? That would make little sense. Australia and Canada are important countries that happen to have very large renewable energy endowments which could be major geopolitical advantages in a world running on renewable energy. To exclude them would stop the index from doing precisely what it is meant to do: identify the countries that would experience large gains or losses.

Similar arguments can be made about the fossil fuel outliers. Saudi Arabia is a regional power and ally of the United States involved in many relationships and conflicts. Kuwait and Qatar are small but geopolitically important countries. Iraq invaded Kuwait, and in response the United States invaded Iraq, with Kuwait's oil resources playing a pivotal role in both events. Qatar plays an important role in the conflict between the other Gulf Arab states and Iran and as the host of American military forces and the Al Jazeera television channel, and all of this is related to its income from natural gas.

Another option for dealing with this issue would be to take the logarithm of the indicators to change their distribution without removing the outliers. Although the former outlier countries would still be in the dataset, they would no longer have extreme values. However, that would be problematic because it is precisely the losing of massive advantages of some countries and gaining of major advantages of other countries that we are interested in. If we suppress the scale of difference, the index will no longer do what it is supposed to.

A final option for dealing with the effect of differing indicator distribution on the index would be to give RES extra weight to compensate for its lower bulge. However, the different distribution of the fossil fuel indicators also reflects something important about the world: renewable energy resources are more evenly distributed across countries than are fossil fuels. A world running on renewable energy will be flatter in geopolitical terms than one based on fossil fuels. To understand this, one has to look beyond the histograms and bear in mind that the values have been normalized and, importantly, in the cases of FFR and FFD, inverted. The bulge of countries at the top are all the former importers,

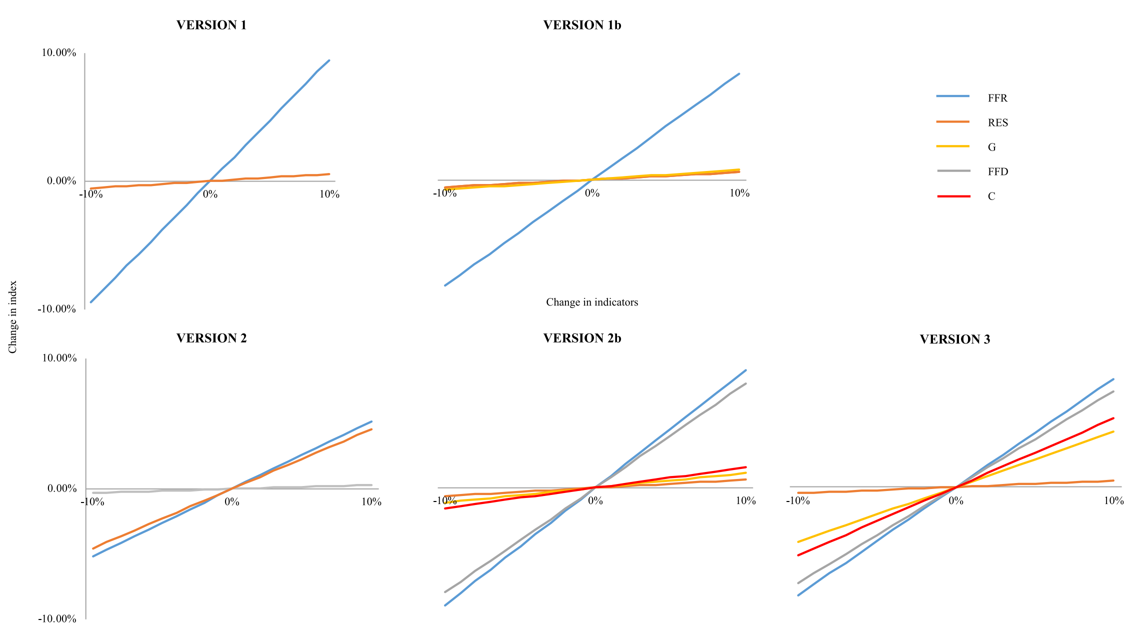

Fig. 2. Sensitivity graphs.

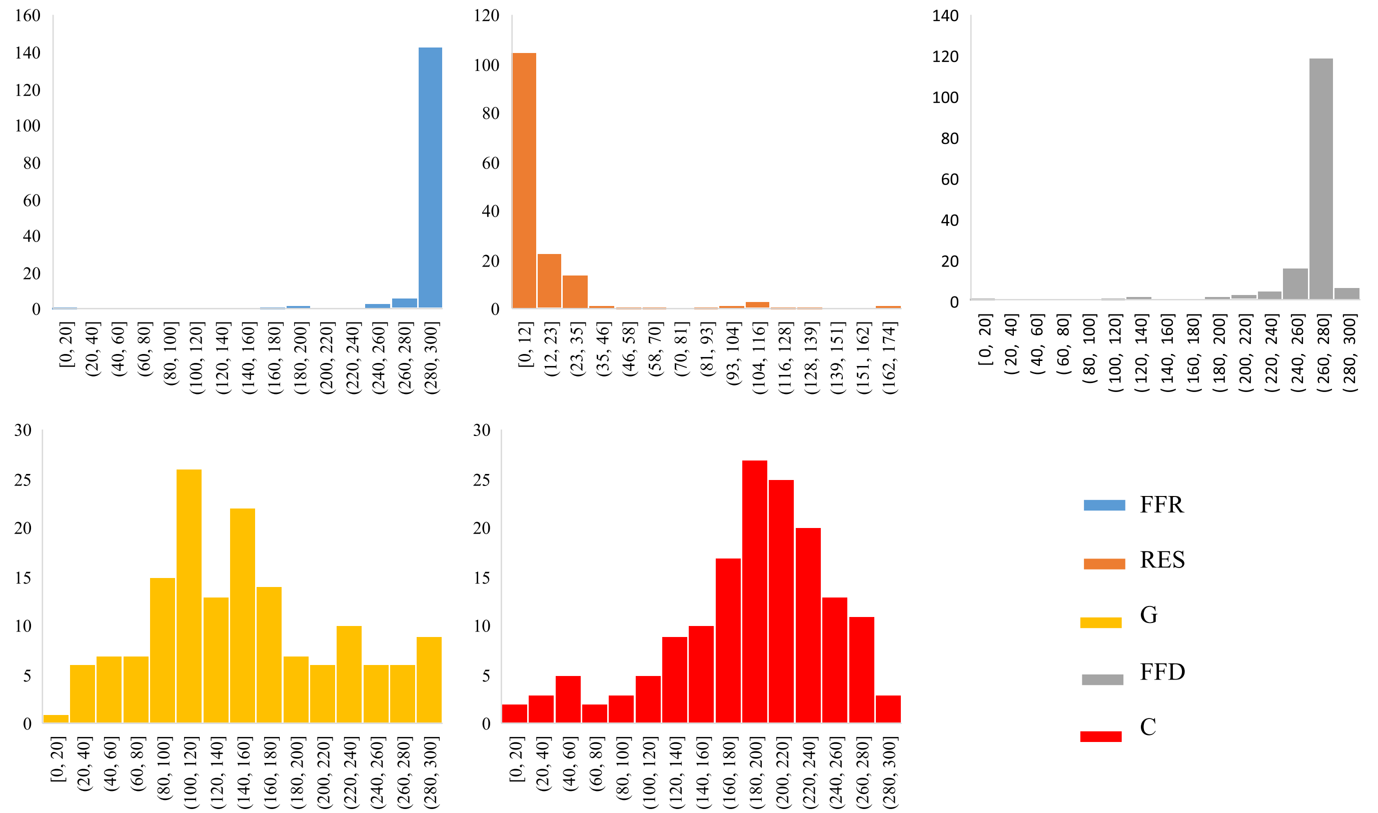

Fig. 3. Distribution of countries on indicators.

which have come a long way by getting rid of a significant burden. By contrast, RES is not inverted: all countries have some renewable energy resources, though a few countries have a lot more than the rest. The main geopolitical changes and drama brought on by a transition to renewables will therefore be related to the winding down of fossil fuels, not the introduction of renewables. Accordingly, rather than increasing the weighting of renewables, one can increase the weight of fossil fuels to capture more of the interesting geopolitical dynamics. We have done this in versions 1b, 2b, and 3 of the index by including both FFR and FFD.

9. Results

The full country rankings for all five index versions are presented in Appendix 2. In order to compare how the five versions play out, we selected 17 countries and tracked how their ranks change from one version of the index to another (see Fig. 4). The 17 countries were divided into six rough groups, each sharing a color.

Some tendencies are consistent across all five index versions and can thus be considered robust. First, major fossil fuel importers, such as Chile, New Zealand, and Sweden, are likely to experience major geopolitical gains. Second, most of the world's major oil exporters, such as Iraq, Russia, and Saudi Arabia, will experience a weakening of their energy-related geopolitical positions. Third, and more unexpectedly, also China and the United States do not fare well. Especially in versions 1 and 2 of the index, these two countries are near the bottom, mingling with the major oil exporters. In versions 1b, 2b, and 3, their outlook is somewhat better, but still not particularly good. This finding is noteworthy as it contrasts with those of other studies (see discussion in the next section).

For some other countries, the results are less consistent across the five index versions. Poor, unstable countries without fossil fuels, such as Afghanistan, Eritrea, and Somalia, do well in all versions except 3, where they are suddenly sent straight to the bottom. This is because version 3 applies the governance and conflict indicators to all countries (not just net fossil fuel exporters), and these countries have some of the lowest scores on these indicators. Governance and conflict are also included in versions 1a and 2b, but only applied to net fossil fuel exporters. We find it makes little sense that countries such as Afghanistan, Eritrea, and Somalia are placed among countries such as Iraq, Nigeria, and Saudi Arabia, when the former will benefit from no longer having to spend their scarce funds on fossil fuel imports, while the latter stand to lose massively from the discontinuation of fossil fuel exports.

Two other countries for which the results vary are Japan and the Netherlands. Japan comes out low in versions 1 and 1b because it has relatively small renewable energy resources compared to its population density, but rises when its considerable current fossil fuel imports and strong scores on the governance and conflict indicators are taken into account in versions 2, 2b, and 3. The Netherlands follows a similar pattern, but scores a bit lower because of its domestic natural gas production and reserves. However, in version 3, the difference between Japan and the Netherlands disappears as the governance and conflict indicators come to dominate. Again, we see that the results of version 3 are not entirely convincing, as the Netherlands' gas production and reserves logically should play some role, however depleted they are.

10. Discussion

Each version of the GeGaLo index has its own strengths and weaknesses. Which one works best depends on what one wants to use it for. This article is meant to be an exploratory exercise and the point is to show different options and approaches. Including an index version does not necessarily mean that we think it is correct. Readers and people carrying out further research in this area can choose the version that fits their purposes best and how to further develop it.

Version 1 is closest to a purely geopolitical and physical geography

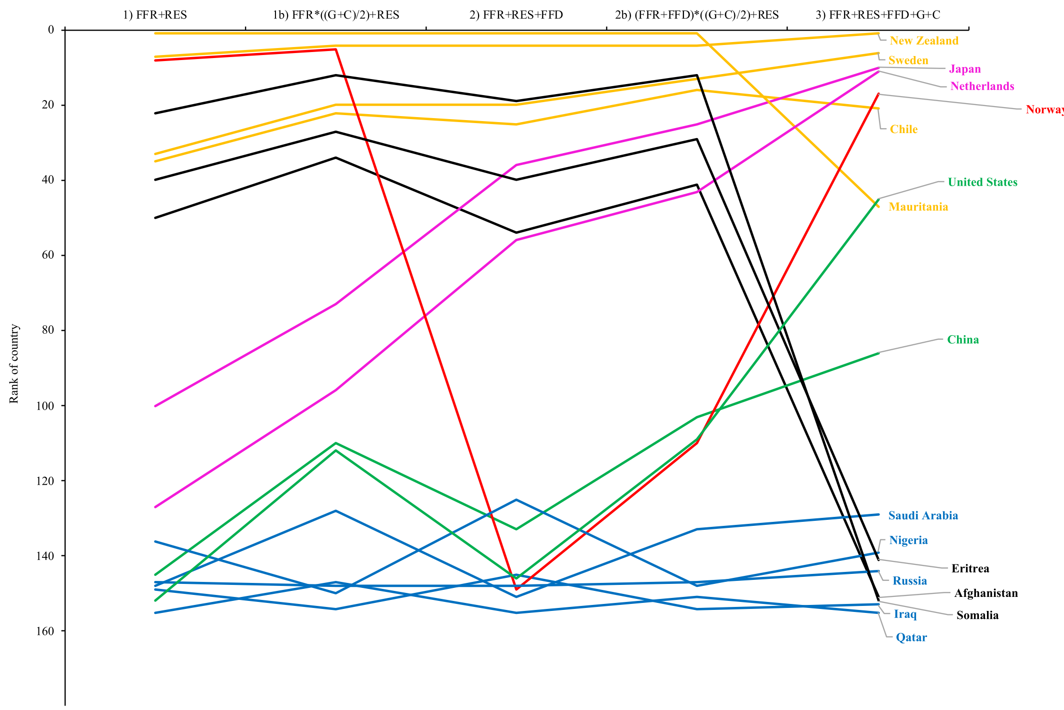

Fig. 4. Selected countries compared across five index versions.

approach. It is most transparent and suitable for a very long-term perspective, as it simply includes the fossil fuel and renewable energy resources of countries without mixing these with indicators linked to the current socio-political situation. Countries with limited fossil fuels and a lot of wind, sun, and/or rivers naturally score highest, while the countries traditionally considered resource-wealthy go to the bottom. Also, population size influences the result: countries with large fossil fuel resources and small populations stand to lose a lot, such as Qatar (156th place), Kuwait (155th), and the UAE (154th).

Version 1 also highlights the importance of space, including maritime space for offshore wind turbines. Countries poor in fossil fuels, but with low population density, tend to score high, for example, Mauritania (2nd place) and Mongolia (3rd place). Countries with low population density have greater sun and wind resources per capita, as well as more space for the equipment to harvest those resources. Conversely, despite its high fossil fuel import dependency and total lack of reserves, Singapore scores low (142nd place) in version 1 of the index because it also lacks renewable energy resources. This is one of the main strengths over the other index versions, which place Singapore unrealistically high.

However, in its simplicity, version 1 also misses out on things such as the role of governance in the ability of major fossil fuels producers to handle their decline. Version 1b remedies this, but still one might argue that it also makes sense to take into account the role of the current fossil fuel industries. After all, countries such as Russia and Saudi Arabia are not buoyed today mainly by their fossil fuel reserves but by their current fossil fuel production and exports. The inclusion of the FFD indicator in versions 2 and 2b ensures that this is taken into account. But, like version 1, version 2 fails to take into account the vast differences in the ability of fossil fuel-rich states to handle their decline. Thus, out of versions 1, 1b, 2, and 2b, it is 2b that proves to be the most versatile.

Version 3 is based on an entirely different approach, where all the indicators are simply added up. This gives greater weight to governance and conflict and the advantage of having high scores on these indicators, but the index ends up being more about these things than about energy geopolitics. For some this will be a fundamental weakness and render version 3 unusable.

A possible weakness shared by versions 2, 2b, and 3 is that they rank Singapore too high. This is because Singapore has high scores on all indicators except RES, where it has the lowest score possible as it has hardly any space for solar panels or wind turbines, or any hydropower resources. The more indicators that are included, the more Singapore's low RES score is drowned out, and its rank goes up. Although the numbers do add up, one could argue that Singapore's almost total lack of renewable energy resources is a fundamental weakness, and that an index that gives the country a high rank is faulty. In that case, version 1 of the index, where Singapore is ranked 142nd, gives a more accurate result. However, one could also argue that the other indicators remain relevant whatever the renewable energy endowment of a country and that it is therefore not wrong for Singapore to have a high rank, even if it might be surprising. Another solution would be to say that Singapore is an extreme outlier on the RES indicator and is therefore not comparable to the other countries and should not be included in the index. What conclusion one draws depends on what one wants to achieve with the index.

Summing up, we find that version 2b is the most nuanced and useful version of the index for all-round purposes. The second-best alternative is the simplest one, version 1. In the next section, we compare it to some of the rankings in the existing literature.

10.1. Comparison with other indexes

As noted in the introductory part of the article, the main previous attempts at assessing the effects of energy transition on the geopolitical positions of countries are those of Smith Stegen [56], Sweijs et al. [57], and Van de Graaf [55]. In Tables 7 and 8, we compare version 2b of the GeGaLo index to their assessments. Countries where the other indexes diverge significantly from ours are marked with italics.

Smith Stegen diverges from GeGaLo on 9 out of 24 countries, Sweijs et al. on 4 out of 7, and Van de Graaf on 3 out of 9. In sum, our index produces significantly different results from the existing indexes on the geopolitics of the energy transition. Particularly notable is the divergence on China and the United States, which both Smith Stegen and Van de Graaf categorize as geopolitical winners, while our index places them among the lower half of countries. These two countries may be thought of as energy transition winners because people have in mind

Table 7
Comparison of GeGaLo version 2b with Van de Graaf and Smith Stegen.

	Van de Graaf	GeGaLo	Smith Stegen
GAINERS	*China*** Europe Japan *USA*	Bhutan (4)* Brazil (27) Finland (22) France (37) Georgia (24) Honduras (52) Japan (26) Jordan (57) Kenya (64) Mali (11) Nicaragua (31) Slovakia (53) Sweden (14) Uruguay (6)	*Algeria* *China* Finland France Honduras *India* Jordan Kenya Mali *Mongolia* Nicaragua *Sri Lanka* Sweden *USA* Uruguay
LOSERS	*Brazil* Nigeria Russia Saudi Arabia Venezuela	Algeria (132) Bahrain (130) Bangladesh (96) China (104) Gabon (122) India (97) Kuwait (146) Mongolia (113) Nigeria (149) Qatar (152) Russia (148) Saudi Arabia (134) Sri Lanka (83) Timor-Leste (103) Trinidad and T. (125) USA (110) Venezuela (151)	Bahrain Bangladesh *Bhutan* Gabon *Georgia* Kuwait Qatar *Slovakia* Timor-Leste Trinidad and T.

Notes: Countries marked with italics diverge significantly from GeGeLo index. Numbers in parentheses represent ranks in GeGaLo.

Table 8
Comparison of GeGaLo with Sweijs et al.

GeGaLo (ranks in parentheses)	Sweijs et al. (from least to most exposed to EU energy transition)
Egypt (74)	*Saudi Arabia*
Kazakhstan (116)	*Qatar*
Algeria (132)	Kazakhstan
Saudi Arabia (134)	*Egypt*
Libya (147)	Libya
Russia (148)	Russia
Qatar (152)	*Algeria*

Notes: Countries with italics diverge significantly from GeGaLo. Numbers in parentheses represent ranks in GeGaLo.

their status as the world's major oil importers, but are less conscious that they also depend heavily on rich domestic oil, gas, and, especially, coal deposits. Both China and the United States rely heavily on domestic coal supplies for electricity generation. Coal is the basis for many of China's energy-intensive goods and the lifeblood of its export-oriented industrial economy.

With regard to Russia and Saudi Arabia, however, our results match those of Sweijs et al. [57] and Van de Graaf [55]. Combined with the consistently low scores for these two countries across all five versions of GeGaLo, the message is clear: for Russia and Saudi Arabia, energy transition is a driver for geopolitical decline. This is important. Russia is a major diplomatic player, one of the world's greatest and most active military powers, the possessor of the world's second largest nuclear arsenal, and the world's largest country by surface area. Saudi Arabia is the center of Islam, a major US ally, and a key player in the volatile Gulf region.

11. Conclusion

In this article, we have explored the design of an index of the geopolitical gains and losses that countries may experience after a transition to renewable energy: GeGaLo. There is a growing body of literature that speculates about the geopolitical consequences of the growth of renewable energy, but few attempts have been made to bring quantitative data into the analysis. Compared to the most sophisticated of these attempts, that of Smith Stegen [56], our analysis increases the level of detail, uses a different set of indicators, applies a different method of index aggregation, focuses on the situation after energy transition rather than on the transition as such, and results in a different ranking of countries.

We carried out a sensitivity analysis across five different versions of the index and found that version 2b works best for general purposes. It includes all our indicators and gives extra weight to fossil fuels, while differentiating between the differing capacities of fossil fuel-rich states to handle a weakening of their geopolitical position. However, there is no perfect design for such an index. Each approach has strengths and weaknesses and even the best index remains an abstraction of the real world.

Nonetheless, GeGaLo can still play a supportive role for energy and foreign policy, especially in countries that risk their main sources of wealth and power becoming stranded geopolitical assets as a result of the transition to renewable energy. It may help raise their awareness of the risks and induce them to implement strategic measures to secure their position in the international state system. If one includes governance and conflict indicators in the index design, it shows how some countries can reduce their geopolitical risks by avoiding conflict, especially major oil exporters.

Some results are consistent across the five versions of the index. First, most major fossil fuel importers are likely to experience major geopolitical gains when they rid themselves of this burden. Second, most of the world's major oil exporters will experience a weakening of their energy-related geopolitical positions. This includes Russia, currently the world's biggest energy exporter and one of its most geopolitically important countries. Third, and more unexpectedly, China and the United States are ranked lower in our analysis than in others, especially in the purely resource-based iterations of our index (versions 1 and 2). The upbeat geopolitical assessments of China and the United States in other analyses may be due to an overfocus on their dependency on oil imports, and a lack of attention to the large-scale domestic oil, gas, and coal production from which they currently benefit. Especially coal dependency is overlooked.

Several components that are not included in the current versions of GeGaLo could be included in future iterations. It could be expanded to include bioenergy and geothermal energy, especially if there are major advances in the development of third-generation biofuels. Likewise, nuclear fuel resources could be included. One could also try to include critical materials for renewable energy technologies, such as cobalt, lithium, and copper. An attempt in this direction would, however, have to consider the fact that it is difficult to predict which minerals will be needed and in what volumes in the future, as that depends on rapidly evolving technologies [65].

It would also be possible to introduce weighting to differentiate among the different fossil fuels according to their contribution to global warming. The rationale for doing this would be that the most polluting fuels are likely to be phased out more quickly. Thus, coal would be weighted most heavily, oil second most, and natural gas least. This would however change the premise for the index, as it would no longer be about what happens after a completed energy transition, but more about the dynamics of the energy transition process itself.

The emphasis in the current index is on physical energy resources. However, one could also consider innovation as a resource and include data on a country's capacity for innovation, reducing the emphasis on physical geography. That would likely strengthen the positions of China and the United States, but also those of countries such as Finland, Germany, Japan, Korea, and Sweden.

Acknowledgements

This article is a product of the Kodak Moment project, which is funded by the NORRUS Pluss program of the Research Council of Norway (project number 287937). We thank Javlon Juraev for his extensive support handling the indicator data and carrying out calculations.

Appendix 1. Index calculation formulas

R_{coal}, R_{gas}, R_{oil}	Fossil fuel resources
$D_{coal} = (p_{coal} - (i_{coal} - e_{coal})$ $D_{gas} = p_{gas} - (i_{gas} - e_{gas})$ $D_{oil} = p_{oil} - (i_{oil} - e_{oil})$	Fossil fuel production minus (imports minus exports)
E_{hydro}, E_{wind}, E_{solar}	Renewable energy resources
G	Governance
C	Conflict

Each resource indicator is calculated as per capita units by dividing the resource by the population of the country:

$$x_j = \frac{X_j}{N} \tag{A.1}$$

where x_j is the per capita indicator x of country j, X_j is the indicator X of country j in absolute terms, and N is the population size. Subsequently, each sub-indicator is normalized to the range of 0–100 using the following formula, where $\hat{}$ means normalized:

$$\hat{x_j} = \frac{x_j - \min(x)}{\frac{\max(x) - \min(x)}{100}} \tag{A.2}$$

In the next step, the indicators are summed up:

$$FFR = (100 - \hat{r_{coal}}) + (100 - \hat{r_{gas}}) + (100 - \hat{r_{oil}}) \tag{A.3}$$

$$RES = \hat{e_{hydro}} + \hat{e_{wind}} + \hat{e_{solar}} \tag{A.4}$$

$$FFD = (100 - \hat{d_{coal}}) + (100 - \hat{d_{gas}}) + (100 - \hat{d_{oil}}) \tag{A.5}$$

where FFR is fossil fuel resources, RES is renewable energy sources, and FFP is fossil fuel production. Sub-indicators for fossil fuel resources and fossil fuel production are obtained by inverting them (subtracting them from 100), as the former privileges of having fossil fuels are lost when the world transitions to renewable energy.

Subsequently, the governance and conflict indicators are averaged:

$$k_j = \frac{G_j + PI_j}{2} \tag{A.6}$$

The final index value of country j is calculated using the following formulas for the five different versions of the index:

1. $Index_j = (FFR_j + RES_j)$ (A.7)

1b. $Index_j = k_{j*}FFR_j + RES_j$ (A.8)

2. $Index_j = (FFR_j + FFD_j + RES_j)$ (A.9)

2b. $Index_j = k_{j*}(FFR_j + FFD_j) + RES_j$ (A.10)

3. $Index_j = (FFR_j + FFD_j + RES_j + G_j + P_j)$ (A.11)

Appendix 2. Index results

Iceland was excluded from our calculations because it is an outlier that distorts the results for other countries. However, Iceland comes out at the top in all versions of the index if it is included in calculations and has been reinstated in the table below.

Rank	1) FFR + RES	1b) FFR*([G + C]/2)+RES	2) FFR + RES + FFD	2b) (FFR + FFD)*([G + C]/2)+RES	3) FFR + RES + FFD + G + C
1	Iceland	Iceland	Iceland	Iceland	Iceland
2	Mauritania	Mauritania	Mauritania	Mauritania	N. Zealand
3	Mongolia	Bhutan	Guyana	Guyana	Singapore
4	Bhutan	Guyana	Bhutan	Bhutan	Switzerland
5	Guyana	N. Zealand	N. Zealand	N. Zealand	Canada
6	Libya	Norway	Congo	Uruguay	Finland
7	Congo	Australia	Libya	C. African Rep.	Sweden
8	N. Zealand	Canada	Mongolia	Mauritius	Austria
9	Norway	Argentina	Chad	Singapore	Denmark

10	Australia	C. African Rep.	Sudan	Argentina	Ireland
11	Gabon	Uruguay	Uruguay	Mali	Japan
12	Canada	Mali	C. African Rep.	Ireland	Netherlands
13	Kazakhstan	Somalia	Mauritius	Somalia	Bhutan
14	Chad	Mauritius	Singapore	Sweden	Portugal
15	Sudan	Mongolia	Argentina	Cyprus	Germany
16	Argentina	Ireland	Mali	Paraguay	Belgium
17	C. Afr. R.	Tajikistan	Gabon	Chile	Mauritius
18	Uruguay	Paraguay	Ireland	Tajikistan	Norway
19	Mali	Montenegro	Niger	Panama	Estonia
20	Bolivia	Cyprus	Somalia	Costa Rica	Slovenia
21	Oman	Sweden	Sweden	South Korea	Czechia
22	Niger	Costa Rica	Cyprus	Finland	Chile
23	Somalia	Chile	Bolivia	Estonia	Taiwan
24	Mauritius	Brazil	Peru	Georgia	UK
25	Papua N. G.	Georgia	Paraguay	Djibouti	Latvia
26	Algeria	Madagascar	Chile	Japan	Spain
27	Peru	Finland	Tajikistan	Brazil	South Korea
28	Ireland	Eritrea	Panama	Latvia	Lithuania
29	Tajikistan	Latvia	Costa Rica	Madagascar	France
30	Paraguay	Djibouti	South Korea	Eritrea	Slovakia
31	Montenegro	Zambia	Finland	Nicaragua	Uruguay
32	Laos	Nicaragua	Papua N. G.	Montenegro	Hungary
33	Cyprus	Kyrgyzstan	Laos	Zambia	Cyprus
34	Sweden	Estonia	Estonia	Austria	Australia
35	Costa Rica	Afghanistan	Georgia	Taiwan	Malaysia
36	Chile	Nepal	Djibouti	Kyrgyzstan	Croatia
37	Brazil	Bosnia and H.	Japan	France	Guyana
38	Georgia	Tunisia	Brazil	Spain	Costa Rica
39	Madagascar	Panama	Latvia	Belgium	Italy
40	Finland	Guinea-Bissau	Madagascar	Portugal	Romania
41	Eritrea	Austria	Eritrea	Lithuania	Poland
42	Latvia	Albania	Nicaragua	Afghanistan	Bulgaria
43	Djibouti	Denmark	Montenegro	Nepal	Mongolia
44	Zambia	Morocco	Zambia	Netherlands	Panama
45	Nicaragua	Greece	Austria	Croatia	Georgia
46	Kyrgyzstan	Lithuania	Taiwan	Morocco	USA
47	Estonia	Zimbabwe	Algeria	Tunisia	Montenegro
48	Angola	Croatia	Kyrgyzstan	Switzerland	Mauritania
49	DRC	Honduras	DRC	Guinea-Bissau	Argentina
50	Colombia	Mexico	France	Belarus	Ghana
51	Afghanistan	Liberia	Spain	Italy	Albania
52	Nepal	Ethiopia	Belgium	Honduras	Peru
53	Bosnia & H.	Switzerland	Portugal	Slovakia	Greece
54	Tunisia	Cambodia	Lithuania	Jamaica	Senegal
55	Panama	Kenya	Afghanistan	Albania	Jamaica
56	Cameroon	Belarus	Nepal	Liberia	Serbia
57	Guinea-B.	Egypt	Netherlands	Jordan	Jordan
58	Yemen	Senegal	Croatia	Armenia	Vietnam
59	Mozamb.	Spain	Morocco	Zimbabwe	Sri Lanka
60	Austria	Armenia	Tunisia	Cambodia	Indonesia
61	Albania	Burkina Faso	Switzerland	Ethiopia	Zambia
62	Denmark	Portugal	Canada	Senegal	Kazakhstan
63	Morocco	Turkey	Guinea-Bissau	Denmark	Tunisia
64	Greece	Timor-Leste	Belarus	Kenya	Macedonia
65	Lithuania	France	Italy	Togo	Morocco
66	Zimbabwe	Tanzania	Yemen	Dominican R.	Rwanda
67	Croatia	Slovenia	Honduras	Lebanon	Israel
68	Honduras	Jamaica	Cameroon	Burkina Faso	Oman
69	South Africa	Jordan	Slovakia	Israel	Laos
70	Mexico	Macedonia	Jamaica	Tanzania	Moldova
71	Liberia	Cuba	Albania	Bosnia and H.	Tanzania
72	Myanmar	Bulgaria	Liberia	Mexico	Malawi
73	Ethiopia	Côte d'Ivoire	Jordan	Guatemala	Thailand
74	Switzerland	Japan	Armenia	Egypt	Paraguay
75	Cambodia	Syria	Zimbabwe	Moldova	Madagascar
76	Guinea	Serbia	Cambodia	Cuba	Brazil
77	Kenya	Romania	Ethiopia	Côte d'Ivoire	Bosnia and H.
78	Belarus	Dominican R.	Senegal	Slovenia	Dominican R.
79	Egypt	Thailand	Denmark	El Salvador	Nicaragua
80	Senegal	Gambia	Kenya	Turkey	Armenia
81	Uzbekistan	Moldova	Togo	Syria	Gambia
82	Spain	Guatemala	Guinea	Gambia	Burkina Faso
83	Armenia	Italy	Myanmar	Sri Lanka	Sierra Leone
84	Burkina F.	Taiwan	Dominican R.	Sierra Leone	Benin
85	Portugal	Sierra Leone	Lebanon	Thailand	UAE
86	Turkey	Ukraine	Burkina Faso	Malawi	Congo
87	Timor-Leste	El Salvador	Israel	Philippines	China
88	France	Slovakia	Tanzania	Uganda	Gabon
89	Tanzania	South Korea	Bosnia and H.	Ukraine	South Africa

90	Malaysia	Togo	Mexico	Haiti	Papua N. G.
91	Slovenia	Malawi	Guatemala	Pakistan	Uganda
92	Jamaica	Uganda	Egypt	Hungary	Cuba
93	Jordan	Hungary	Moldova	UK	Bolivia
94	Indonesia	Sri Lanka	Mozambique	Burundi	Ecuador
95	Macedonia	UK	Cuba	Rwanda	Nepal
96	Cuba	Philippines	Côte d'Ivoire	Bangladesh	Belarus
97	Bulgaria	Netherlands	Slovenia	India	Bahrain
98	Côte d'Iv.	Haiti	El Salvador	Vietnam	Trinidad and T.
99	Eq. Guinea	Pakistan	Turkey	Romania	Cambodia
100	Ecuador	India	Syria	Greece	Kyrgyzstan
101	Japan	Burundi	Benin	Macedonia	Timor-Leste
102	Syria	Vietnam	Kazakhstan	Germany	Kenya
103	Serbia	Lebanon	Gambia	Timor-Leste	Liberia
104	Romania	Israel	Sri Lanka	China	Bangladesh
105	Dominic. R.	Belgium	Sierra Leone	Bulgaria	Côte d'Ivoire
106	Benin	Rwanda	Thailand	Serbia	El Salvador
107	Thailand	Bangladesh	Uzbekistan	Czechia	Mozambique
108	Gambia	Singapore	Malawi	Canada	Niger
109	Moldova	Czechia	Philippines	Poland	India
110	Trinid. & T.	Germany	Uganda	USA	Guatemala
111	Guatemala	China	Ukraine	Norway	Togo
112	Italy	Poland	Ghana	Australia	Algeria
113	Taiwan	USA	Haiti	Mongolia	Philippines
114	Ghana	Kazakhstan	Pakistan	Malaysia	Honduras
115	Sierra Leone	Malaysia	Hungary	Ghana	Djibouti
116	Ukraine	Oman	UK	Kazakhstan	Mexico
117	El Salvador	Congo	Burundi	Peru	Guinea
118	Slovakia	Peru	Rwanda	Oman	Angola
119	South Korea	Gabon	Bangladesh	Indonesia	Uzbekistan
120	Togo	UAE	India	Laos	Tajikistan
121	Malawi	Ghana	Vietnam	UAE	Myanmar
122	North Korea	Indonesia	Romania	Gabon	Azerbaijan
123	Uganda	Laos	Greece	Congo	Colombia
124	Hungary	Trinidad and T.	Malaysia	South Africa	Mali
125	Sri Lanka	South Africa	Ecuador	Trinidad and T.	Ethiopia
126	UK	Papua N. G.	Nigeria	Benin	Haiti
127	Philippines	Bolivia	Angola	Papua New G.	Turkey
128	Netherlands	Libya	North Korea	Bolivia	Cameroon
129	Haiti	Saudi Arabia	Macedonia	Ecuador	Chad
130	Pakistan	Bahrain	Germany	Bahrain	Saudi Arabia
131	India	Benin	Timor-Leste	Mozambique	Iran
132	Azerbaijan	Algeria	Indonesia	Algeria	Egypt
133	Burundi	Ecuador	Colombia	Niger	Guinea-Bissau
134	Vietnam	Niger	China	Saudi Arabia	Zimbabwe
135	Lebanon	Mozambique	Bulgaria	Angola	Lebanon
136	Israel	Angola	Serbia	Guinea	Eq. Guinea
137	Nigeria	Colombia	South Africa	Uzbekistan	Burundi
138	Belgium	Azerbaijan	Czechia	Azerbaijan	Turkmenistan
139	Rwanda	Guinea	Iran	Colombia	Ukraine
140	Bangladesh	Uzbekistan	Azerbaijan	Myanmar	Nigeria
141	Turkmenist.	Chad	Poland	Iran	Pakistan
142	Singapore	Eq. Guinea	Venezuela	Eq. Guinea	Eritrea
143	Czechia	Myanmar	Bahrain	Cameroon	Sudan
144	Bahrain	Iran	Turkmenistan	Chad	Libya
145	Germany	Turkmenistan	Oman	Turkmenistan	Russia
146	China	Kuwait	Iraq	Kuwait	Kuwait
147	Iran	Cameroon	USA	Libya	Venezuela
148	Russia	Qatar	Eq. Guinea	Russia	C. African Rep.
149	S. Arabia	Russia	Russia	Nigeria	North Korea
150	Iraq	Sudan	Norway	Sudan	DRC
151	Poland	Nigeria	Trinidad and T.	Venezuela	Yemen
152	Venezuela	Venezuela	Saudi Arabia	Qatar	Afghanistan
153	USA	DRC	Australia	North Korea	Somalia
154	UAE	North Korea	UAE	DRC	Iraq
155	Kuwait	Iraq	Kuwait	Iraq	Syria
156	Qatar	Yemen	Qatar	Yemen	Qatar

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