Impacts of energy transition on country-level: vulnerability index

Elizaveta Smolovik

PhD student

Junior research fellow at Laboratory for climate change economics, HSE

Laboratory for climate change economics

Relevance

- Increasing gap between mitigation policies and the required level of emissions to limit global warming well below 2°C in line with the Paris Agreement
- Active development of national climate policies, carbon pricing mechanisms are introduced in 75 jurisdictions
- Changing conditions of inter-fuel competition, renewables are replacing conventional fuels
- **Our contribution:** lack of studies considering a broader set of assets (carbon intensity, critical minerals, adaptation)

Source: World Bank (2024)

Exposure to energy transition: transition risks

Market risks

Decarbonization worldwide will lead to a slowdown in growth, and further to a reduction in demand for fossil fuels.
In the 2000s, demand grew by an average of 2.4% per year, in the 2010s - 1.3%, in the 2020-2030s - 0.5–0.9% per year (IEA 2023)

This is a threat to exporting countries and their budget revenues, "stranded assets"

Regulatory risks

New barriers to carbon-intensive products (aluminum, steel, fertilizers, electricity, etc.) are emerging on international markets. The most striking example is the EU CBAM (European Commission 2024)

Weakening of the competitive position of exporters of carbon-intensive products

Technological risks

Technological lag and lock-in with insufficient support for knowledge–intensive industries (Unruh 2000), lack of integration of climate policy into industrial policy (Inflation Reduction Act in the U.S. 2022 - 369 billion dollars)

Weakening of competitive positions of exporters, investment stagnation

Source: TCFD (2017)

Methodology

- Sample: 133 countries with population more than 1 million people.
- The index comprises 2 parts: energy transition assets (4 different types of assets) and adaptation potential.
- The impact can be positive and negative. Depending on this, the values are normalized with a positive or negative sign.
- For a negative impact, the higher the value, the lower vulnerability to energy transition.
- In order to make values comparable, they are pre-adjusted to the population or GDP of the country.
- The values are normalized so that they are in the range [0, 1]:

For positive impacts:

$$\hat{x} = \frac{x_j - \min(x)}{\max(x) - \min(x)}$$

For negative impacts:

$$\hat{x} = -1 * \left(\frac{x_j - \min(x)}{\max(x) - \min(x)}\right)$$

Review of indicators

Exposure:

- FF – fossil fuels (production, exports, reserves of oil, gas and coal)
- CIP – carbon-intensive production (exports, carbon intensity of economy)
- CES – clean energy sources (potential and capacities of hydro, solar, wind and nuclear energy)
- CM – critical materials (reserves and processing capacities of 6 most demanded minerals + uranium)

Adaptation potential:

- RD – R&D investment (% of GDP, 10-year average)
- GDPpC– GDP per capita PPP
- Ed – education expenses (% of GDP, 10-year average)
- GE – government effectiveness

Choice of critical materials

Cumulative demand for selected critical materials by 2050 in Net Zero scenario, kt, ktU

Mineral	2023	2050 Net Zero
Copper	6372	19239
Cobalt	64	323
Lithium	92	1573
Nickel	478	3094
Magnet rare earth elements	16	80
Graphite (all grades: natural and synthetic)	1292	7879
Uranium	65,65	130*

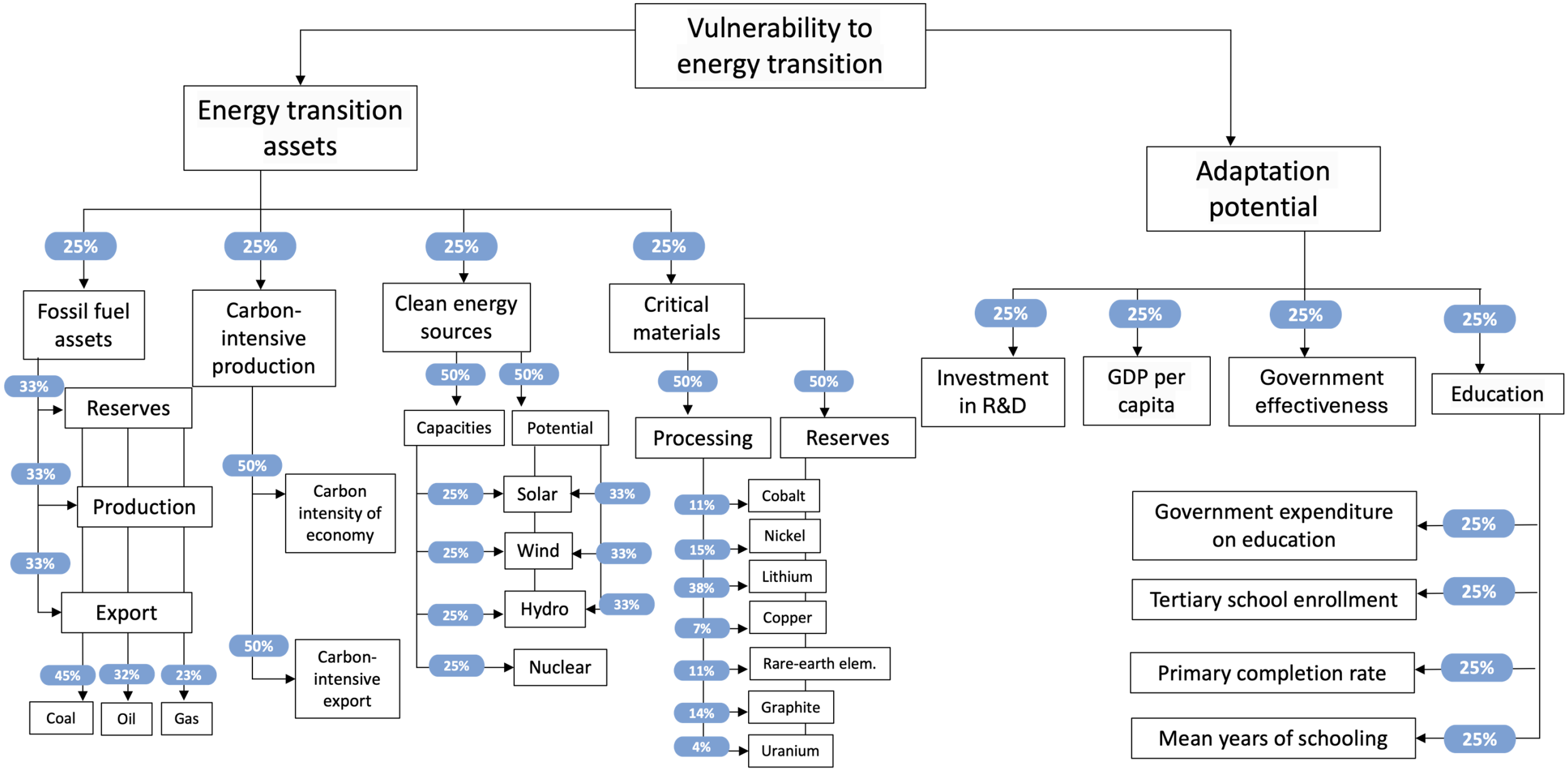
*Data for uranium is considered for 2040 as the reference value at highest demand

Source: IEA 2024

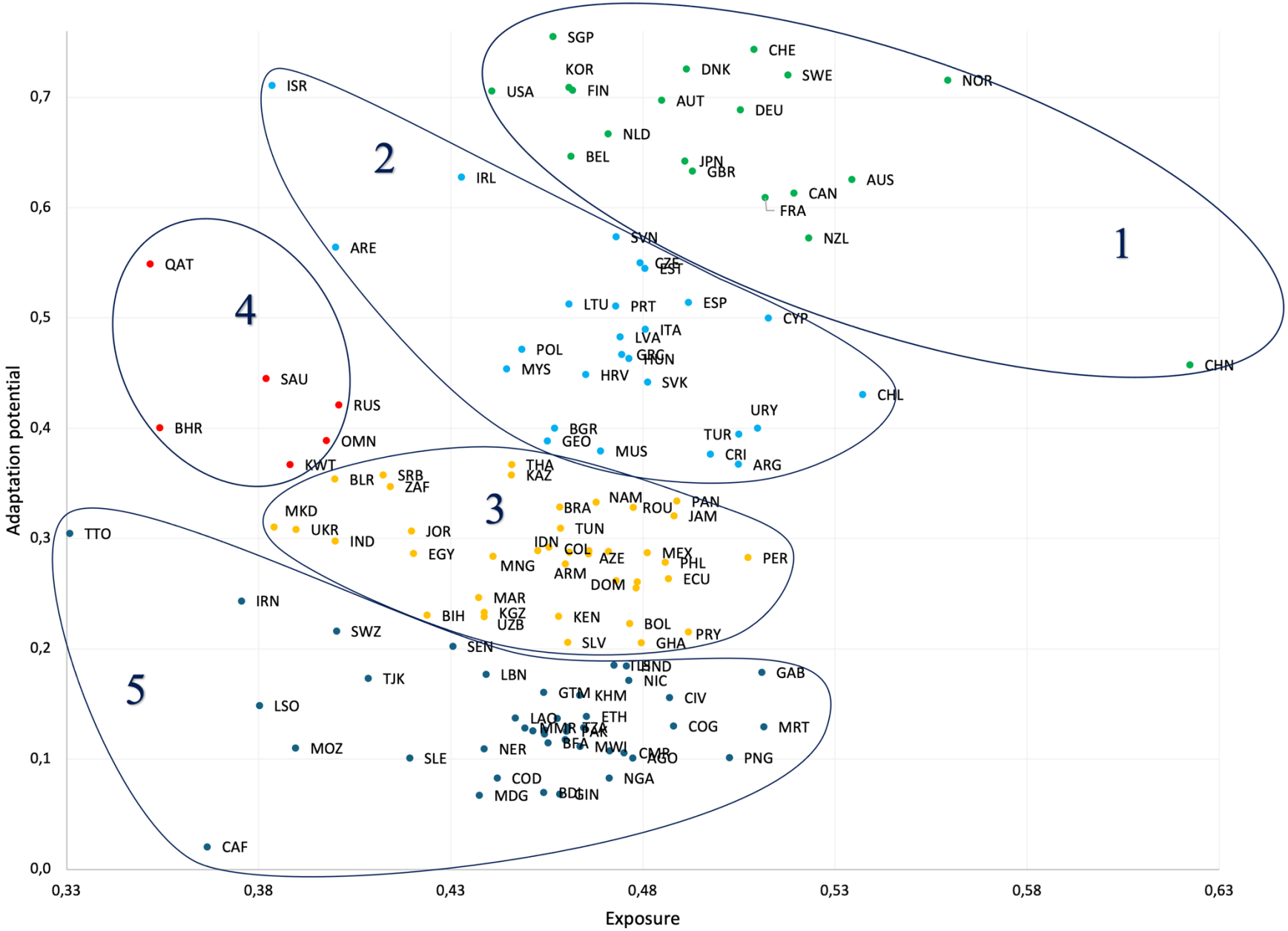
Final index formula

The final index is calculated as the average proportional between energy transition assets and adaptation potential

$$V = \sqrt[2]{(FF + CIP + CES + CM)/4 * (RD + GDPpC + Ed + GE)/4}$$


Vulnerability to energy transition
Energy transition assets
Adaptation potential
25%
Fossil fuel assets
Carbon-intensive production
Clean energy sources
Critical materials
33%
Reserves
33%
Production
33%
Export
45%
32%
23%
Coal
Oil
Gas
50%
Carbon intensity of economy
50%
Carbon-intensive export
50%
Capacities
Potential
25%
Solar
33%
25%
Wind
33%
25%
Hydro
33%
25%
Nuclear
50%
Processing
50%
Reserves
11%
Cobalt
15%
Nickel
38%
Lithium
7%
Copper
11%
Rare-earth elem.
14%
Graphite
4%
Uranium
Investment in R&D
GDP per capita
Government effectiveness
Education
Government expenditure on education
Tertiary school enrollment
Primary completion rate
Mean years of schooling

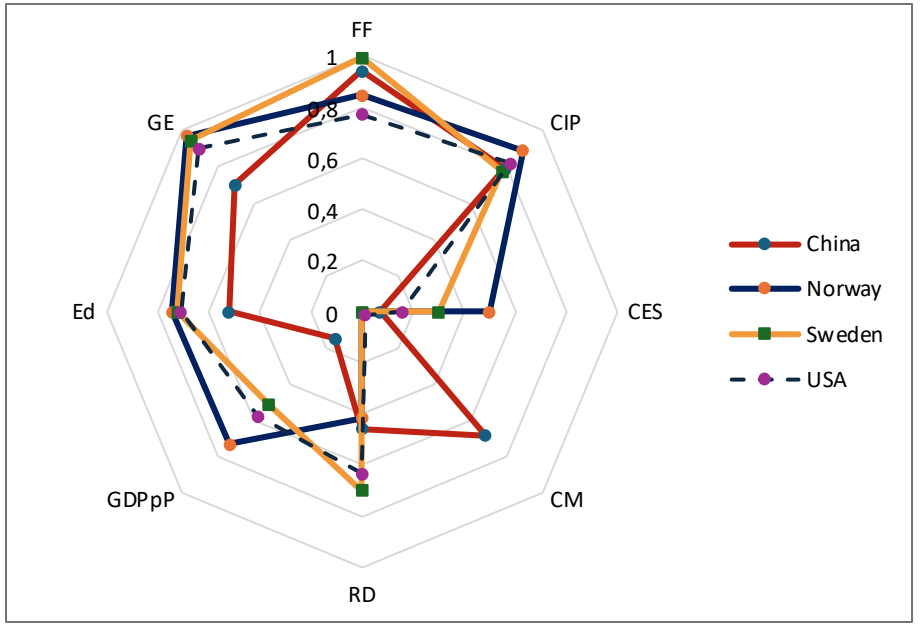
Distribution of countries



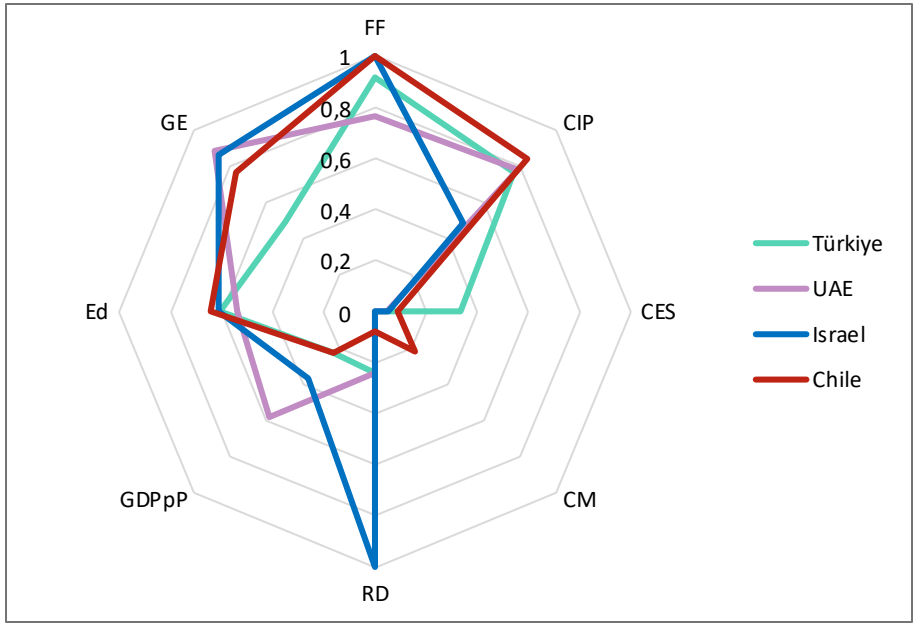
Country groups 1,2

- **Group 1:** advanced G20 countries, some European countries (Norway (1), Sweden (3), Denmark (4), Finland 10). High adaptation potential.
- Norway (1), USA (16), Australia (8) and Canada (11), though being fossil-fuel exporters, can compensate for the losses through the development of clean energy capacities.
- China (19) is among the top 3 countries in terms of ETA thanks to its investment into renewable energy sources (solar PV, wind turbines) and solid reserves of critical materials and processing capacities.
- **Group 2:** advanced economies with high adaptation potential, but more vulnerable because of less capacities in clean energy sources and critical materials.
- Chile (30) - one of the top producers of copper and lithium in the world
- UAE (32) is less vulnerable to energy transition among the OPEC states thanks to developing clean energy capacities and economic diversification

Distribution of energy transition assets (group 1)



Distribution of energy transition assets (group 2)



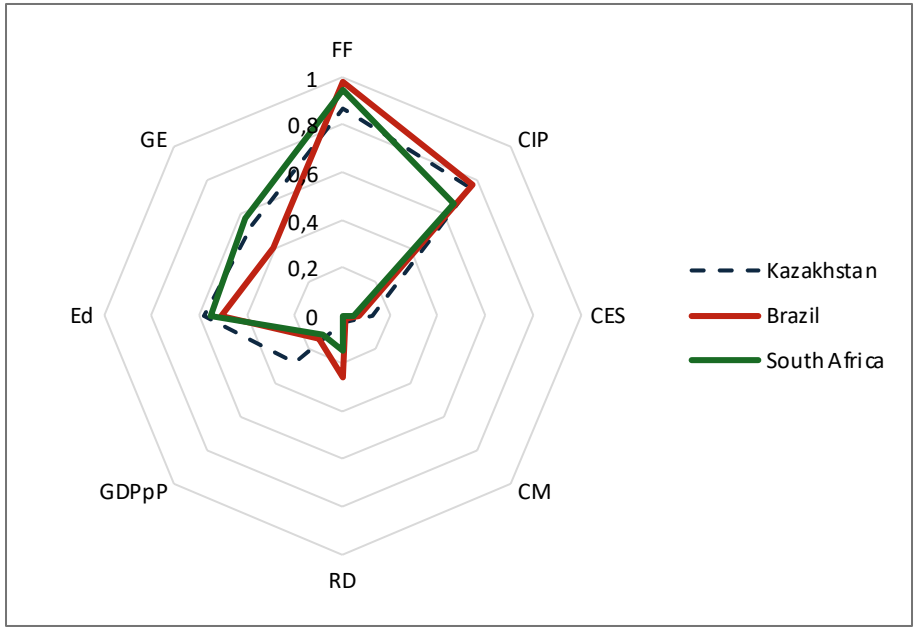
Country groups 3,4

- **Group 3:** emerging economies which due to low adaptation potential and lack of renewable energy capacities bear high costs in energy transition.
- South Africa's (54) advantage in providing critical metals is being offset by its low share of renewables and low R&D investment and GDP per capita.
- Brazil (56) and Kazakhstan (51) lack potential in renewable energy sources in per capita terms, though Brazil is rich with hydropower capacities.

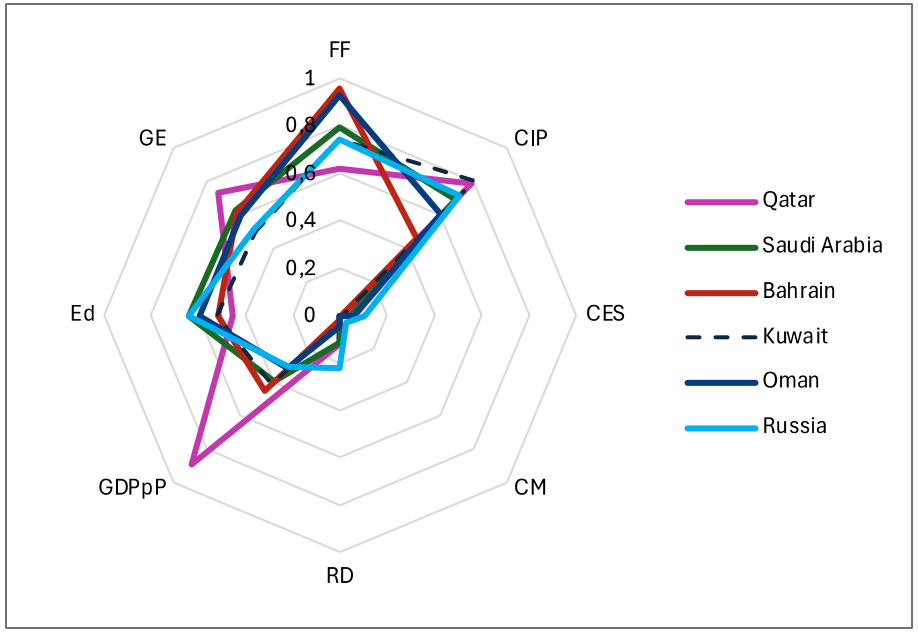
- **Group 4:** six countries of the Gulf Cooperation: Saudi Arabia (47), Bahrein (50), Qatar (41), Kuwait (60) and Oman (55) + Russia (48)
- Adaptation potential values are almost close to the group 2 countries'. However, the values of assets impacted by energy transition is very low, which indicates high exposure of fossil fuel assets given very low clean energy sources capacities and critical materials reserves.

- Russia (48), despite its advantages in renewables and reserves of critical materials, is among the vulnerable countries, which is related to its fossil fuel dependency and carbon-intensive export.

Distribution of energy transition assets (group 3)



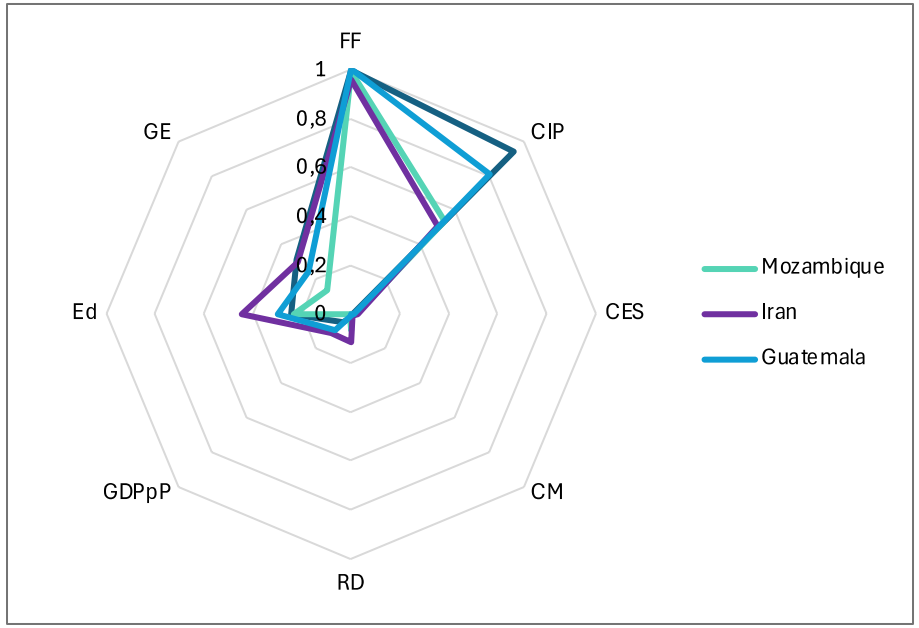
Distribution of energy transition assets (group 4)



Country group 5

- **Group 5:** the most exposed to energy transition low and lower-middle countries that lag behind technological progress, lack educational and institutional capacities.
- The largest number of countries (Global South countries): Central Asia (Kyrgyzstan (87), Uzbekistan (89)), Latin America (Nicaragua (99), Guatemala (103)), Africa (Ethiopia (114), Mozambique (126)), South Asia (Nepal (109)), MENA region (Iran (93)).
- Belong to the bottom of the rating with the lowest value in adaptation potential, insignificant share of renewables in energy mix and abundance with critical minerals.
- Received low scores in carbon intensive production which indicates high carbon intensity of these economies.

Distribution of energy transition assets (group 5)



Comparison of index results with other estimations

	Our index	Overland et al. (2019)	Van de Graaf (2018)	Stegen (2018)
Gainers	Norway (1) Switzerland (2) Singapore (6) Australia (8) Canada (11) USA (16) New Zealand (17) China (19) UAE (32)	Singapore (3) Canada (5) Finland (6) Sweden (7) Bhutan (13) Mauritius (17) Norway (18) Uruguay (31) Australia (34) USA (46)	China European countries Japan USA	Algeria China Finland France Honduras India Jordan Kenya Mali Mongolia Nicaragua USA Uruguay
Losers	Qatar (41) Saudi Arabia (47) Russia (48) Kuwait (60) Iran (93) Ethiopia (106) Central African Republic (133)	Qatar (156) Venezuela (147) Kuwait (146) Russia (145) Iran (131) Saudi Arabia (130) China (87)	Brazil Nigeria Russia Saudi Arabia Venezuela	Bahrain Bangladesh Bhutan Gabon Georgia Kuwait Qatar Slovakia Timor-Leste

Implications

- ✓ Trade specialization coupled with natural factors (resource abundance), relatively cheap labor and scarcity of high technologies determine countries' capabilities to adapt to energy transition.
- ✓ Developed economies that implement ambitious climate policies are not exposed to transition risks but create them to developing economies. It conflicts with ensuring just energy transition: fossil fuel dependent states as well as low and lower middle-income economies require much effort than developed economies to adjust.
- ✓ Vulnerable countries should not be ‘blamed’ for their specialization but rather be considered as part of a global solution to the climate problem.
- ✓ Dialogue is needed between those who gain and and those who loose, including within the framework of just energy transition

Thank you for your attention!

esmolovik@hse.ru

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Review of indicators – Fossil fuel assets

Indicator	Description
Fossil fuel production (FFP)	Production of natural gas, coal, and crude oil (cubic meters/tones/ billion bl/day per capita) Normalized negatively [0, 1] $$FFP = 0{,}45P_C + 0{,}23P_G + 0{,}32P_O$$
Export of fossil fuels (FFE)	Share of exports of natural gas, coal, and crude oil in total exports (%) Normalized negatively [0,1] $$FFE = 0{,}45E_C + 0{,}23E_G + 0{,}32E_O$$
Fossil fuel reserves (FFR)	Total reserves of natural gas, coal, and crude oil (cubic meters/tones/ billion bl/day per capita). Normalized negatively [0,1] $$FFR = 0{,}45R_C + 0{,}23R_G + 0{,}32R_O$$
Fossil fuel assets (FF)	$$FF = \frac{FFP + FFE + FFR}{3}$$

Review of indicators – Carbon-intensive production

Indicator	Description
Carbon intensity of economy (CI)	Total greenhouse gas emissions per unit of GDP Normalized negatively [0,1]
Share of carbon-intensive export in total export (CIE)	Exports of cement, iron and steel, aluminum, fertilizers, lime glass, ceramic, pulp, paper in total export (%) Normalized negatively [0,1]
Carbon-intensive production (CIP)	$CIP = \frac{CI + CIE}{2}$

Review of indicators – Potential in critical minerals

Indicator	Description
Critical minerals and materials (CMR)	Endowment with copper, lithium, cobalt, nickel, platinum-group metals, rare-earth elements, graphite, manganese, uranium (tones per capita) Normalized positively [0,1] ➢ Weights between materials are allocated based on the cumulative demand by 2050
Processing of critical minerals and materials (CMP)	Processing capacities for copper, lithium, cobalt, nickel, platinum-group metals, rare-earth elements, graphite, manganese, uranium (production at <USD 130/kgU) (% from world capacities) Normalized positively [0,1]
Potential in critical materials (CM)	$CM = \frac{CMR + CMP}{2}$

$$CMR = Cob * 0{,}11 + Nick * 0{,}15 + Lit * 0{,}38 + Cop * 0{,}07 + REM * 0{,}11 + Gr * 0{,}14 + Ur * 0{,}04$$

$$CMP = Cob * 0{,}11 + Nick * 0{,}15 + Lit * 0{,}38 + Cop * 0{,}07 + REM * 0{,}11 + Gr * 0{,}14 + Ur * 0{,}04$$

Review of indicators – Clean energy sources

Indicator	Description
Clean energy sources (CES)	Hydro, solar and wind power capacity (MW per capita) Nuclear supply (GW/h per capita) Normalized positively [0,1] $CES = \frac{hydro + solar + wind + nuclear\ capacities}{4}$
Energy transition assets (ETA)	$ETA = \frac{FF+CIP+CES+CM}{4}$

Approaches to evaluate countries' vulnerability to energy transition

- **GeGaLo Index :** covers geopolitical advantages of countries at the end of the energy transition. Indicators: dependence on fossil fuels, fossil fuel reserves, renewable energy capacities, participation in military conflicts, quality of political institutions (Overland et al. 2019)

- **Losses and gains of oil exporters and importers:** assesses countries' vulnerability to energy transition. Indicators: economic diversification, the share of oil export revenue in GDP, and OPEC membership (Van de Graaf 2018)
  - High share of oil export revenue in GDP, low diversification of assets

- **Vulnerability to energy transition:** exposure (share of fossil energy sources in the energy balance, fossil fuel revenue), sensitivity (per capita energy consumption, inequality, unemployment), adaptation potential (investment in R&D, quality of education, quality of political institutions) (Shen et al. 2023)
  - Low adaptation potential, high proportion of hydrocarbons in the energy balance