Food and Agriculture
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NATURAL RESOURCE-DRIVEN FRAGILITY

MAPPING GLOBAL VULNERABILITY

Natural resource-driven fragility

Mapping global vulnerability

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Foreword

In an increasingly interconnected world, we are confronted with formidable global challenges stemming from resource depletion, unsustainable production and consumption patterns, and the alarming consequences of climate change. Extractive industries such as mining, and farming bear significant responsibility, accounting for half of the world's carbon emissions and over 80 percent of biodiversity loss. The escalating material weight of our economies exerts unprecedented strain on climate and natural life–support systems, surpassing previous estimations.

Annually, our planet consumes a staggering 92 billion tonnes of materials, encompassing biomass, metals, fossil fuels, and minerals. This figure continues to grow at a concerning rate of 3.2 percent per year. The scientific consensus is clear: the current models of production and consumption are pushing our planet towards unsustainable limits. Moreover, without swift and substantial global action, average global temperatures are projected to rise beyond a critical threshold of 2 °C, at which point significant and potentially irreversible environmental changes will be unleashed. Concurrently, the strain on resources will intensify exponentially. By 2030, the demand for food, water, and energy is estimated to surge by approximately 35 percent, 40 percent, and 50 percent, respectively, compared to 2017 levels, aggravating environmental degradation (Lluberas and Shorrocks, 2019). The intricate interplay between climate change and resource scarcity will exacerbate these challenges, potentially reducing agricultural productivity by up to a third across vast regions of Africa within the next six decades.

Recognizing the inherent complexities, we acknowledge that the ability of impoverished communities to manage natural resources hinges upon both internal and broader institutional frameworks, as well as the distinctive characteristics of the resources themselves. While there is growing awareness of the political processes that transform environmental concerns into social issues and policy development, the absence of reliable indicators on access to natural resources hampers the integration of water, energy, and food security into the sustainable development agenda.

This report endeavours to define and map natural resource-driven fragility, aiming to lay the foundation for the development of a visualization tool – a global map highlighting vulnerable areas acutely exposed to natural resource-driven fragility. By providing empirical evidence, this tool will serve as a compass, guiding decisions regarding geographical and thematic areas of intervention, thereby alleviating the burden of natural resource-driven fragility faced by the most vulnerable nations. We hope that this report, elaborated through the fruitful collaboration between FAO and the Imperial College of London, sparks collective action and inspires diverse stakeholders to unite in addressing these pressing challenges. Through interdisciplinary collaboration, innovative solutions, and a shared commitment to sustainability, we can forge a path towards a more resilient and equitable future.

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Abbreviations

AQUASTAT	FAO's Global Information System on Water and Agriculture
CCKP	The Climate Change Knowledge Portal
CGLS	Copernicus Global Land Service
CMIP	Coupled Model Intercomparison Project
EPI	Environmental Performance Index
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization - Food and agriculture data
GDP	gross domestic product
HDI	Human Development Index
IBNET	International Benchmarking Network
IEA	International Energy Agency
IRWR	Internal Renewable Water Resources
IUCN	International Union for Conservation of Nature
LCOE	Levelized Cost of Electricity
MCA	multicriteria analysis
OECD	Organization for Economic Co-operation and Development
PC	Pairwise Comparisons
PCA	principal components analysis
SDG	Sustainable Development Goal
SEEA	System of Environmental–Economic Accounting
SPEI	The Standardized Precipitation–Evapotranspiration Index
SSP3	Shared Socioeconomic Pathways – Regional Rivalry (A Rocky Road)
TFWW	Total Freshwater Withdrawal
UN	United Nations
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNSD	United Nations Statistics Division
USD	United States dollar
WEF	Water–Energy–Food
WHO	World Health Organization
WIPO	World Intellectual Property Organization
WSM	weighted sum model

Units

°C	degree Celsius
GJ	gigajoule (10^9 joules)
km^2	square kilometre
kWh	kilowatt hour
mm	millimetre
m^3	cubic metre
TJ	terajoule (10^{12} joules)

Executive summary

This report presents a framework for estimating natural resource-driven fragility as an indicator based on the water, energy, and food nexus (WEF). This dimension of nations' fragility is framed in the context of their ability to meet their demand (consumption) based on their own resources' availability. The publication illustrates the conceptual approach employed for the mapping of areas worldwide subject to vulnerability driven by natural resources, according to current availability and patterns of use.

The methodology elaborated and applied to selected case studies is broadly illustrated in the second chapter. The methodology employed involves a multicriteria approach to identify and analyze the confounding factors contributing to fragility, along with the development of indicators to measure these factors. The report also incorporates multivariate analysis and stakeholder input to enhance the accuracy of the assessment.

The tool implementation section outlines the specific components examined within the WEF nexus framework, including water, energy, and food. For each resource, various aspects such as availability, demand, and reserve/deficit are evaluated and adjusted to provide a comprehensive understanding of the fragility associated with them.

The report then introduces the WEF nexus integrated score, which combines the normalized values of different indicators and confounding factors to quantify fragility. The weighted sum model (WSM) and pairwise comparison are employed to calculate the integrated scores, while the results of the multicriteria analysis of confounding factors further enhance the assessment.

The application of the approach is hence illustrated through selected case studies from various countries, such as Argentina, Bangladesh, Cameroon, Costa Rica, Kazakhstan, Kenya, Slovenia, and Zambia. These cases demonstrate the employment of the assessment methodology and provide economic equivalents for the assessed regions in terms of water, food, and energy as a way of validating the approach.

Finally, the report concludes by summarizing the key findings and insights gained from the assessment. It highlights the importance of considering the WEF nexus framework and its integrated approach in understanding and addressing natural resource-driven fragility.

The report represents a supporting tool to guide decisions over geographical and thematic areas of intervention for reducing the natural resource-driven fragility of the most vulnerable countries. Overall, the publication provides a comprehensive assessment of natural resource-driven fragility using the WEF nexus framework and offers valuable insights for policymakers, researchers, and stakeholders involved in the broad domain of resource management and sustainability.

1. Introduction

The world faces global challenges and constraints due to resource depletion, wasteful and harmful production and consumption, and the emerging impacts of climate change. Extractive industries (mining and farming) are responsible for half of the world's carbon emissions and more than 80 percent of biodiversity loss, while the increasing material weight of the world's economies is imposing more dangerous levels of stress on climate and natural life–support systems than previously thought. Each year, the world consumes more than 92 billion tonnes of materials, composed of biomass (mostly food), metals, fossil fuels and minerals, and this figure is growing at 3.2 percent per year. While the scientific debate continues, all evidence points to the direction of a planet unable to support current models of production and consumption (Voulvoulis, 2022).

Moreover, without significant global action, average temperatures are predicted to increase by more than 2 °C, a threshold at which significant and potentially irreversible environmental changes will occur. At the same time, the pressure on resources will increase dramatically. Demand for food, water and energy is expected to increase by 2030 by approximately 35 percent, 40 percent and 50 percent compared to 2017 levels, along with increasing environmental degradation. The interconnectivity between trends in climate change and resource scarcity will further amplify these challenges. Climate change could reduce agricultural productivity by up to a third across large parts of Africa in the next 60 years.

It is generally accepted that the conditions under which the poor can manage natural resources depend on internal and wider institutional structures, as well as on the specific character of the natural resources themselves (Baumann, 2002). While there is a heightened awareness of the political process, through which environmental problems become issues of social concern and policy development, the absence of indicators on access to natural resources impedes the integration of water, energy, and food security into the sustainable development agenda.

This report, therefore, aims to define and map natural resource-driven fragility to support the development of a visualization tool (global maps of vulnerable areas, particularly exposed to natural resources fragility) that will provide evidence to guide decisions over geographical and thematic areas of intervention for reducing the natural resource-driven fragility of the most vulnerable nations.

2. Methodology

2.1. The natural resource-driven fragility concept

Fragility has been conceptualized by the Organization for Economic Co-operation and Development (OECD) as the combination of exposure to risk and the insufficient coping capacity of a state, system and/or community to manage, absorb and mitigate those risks. Today, it is seen as an emergent property of a complex system, where reformers will not be able to predict impact or behaviours linearly, but will instead have to rely on best guesses, fast feedback, and adaptation to get results (OECD, 2022a).

Issues related to natural resources directly shape the drivers of fragility. Although environmental factors are rarely, if ever, the sole cause of conflicts and social unrests, the exploitation of natural resources and related environmental stresses can be implicated in all phases of the conflict cycle, from the outbreak and perpetuation of violence to undermining prospects for peace. For example, the Near East and North Africa region, which historically has coped with water scarcity, finds its water management systems already plagued by weak governance, limited resources, and degraded infrastructure, failing, as conflict is taking a severe human and economic toll, fuelling massive displacements of populations (FAO and World Bank, 2018).

While some of these issues are often nominally included via the conflict risk indicators used in indices like the Fragile States Index, (i.e. the description of demographic pressure and refugees and Internally Displaced Persons indicators), natural resources and their management are often overlooked or misdiagnosed in analyses of state fragility, leading to missed opportunities when designing effective responses. There is, therefore, a need for the inclusion of natural resources and environmental issues as both contributors to fragility and potentially critical to effective responses. Fair access to and effective management of natural resources, such as land and water, is essential to public health, state legitimacy, livelihood security, and economic prosperity – all necessary components to countering fragility and fostering stability (United States Department of State, 2020). The effective management of natural resources for agricultural production, for example, is a key strategy not only to reduce food insecurity, but also to prevent historical frailties from turning into violence and conflict. Cooperation over environmental issues and awareness of natural resources driven fragility can also facilitate broader trust, strengthen social cohesion, and provide an entry point for engagement between conflict parties (Voulvoulis and Burgman, 2019).

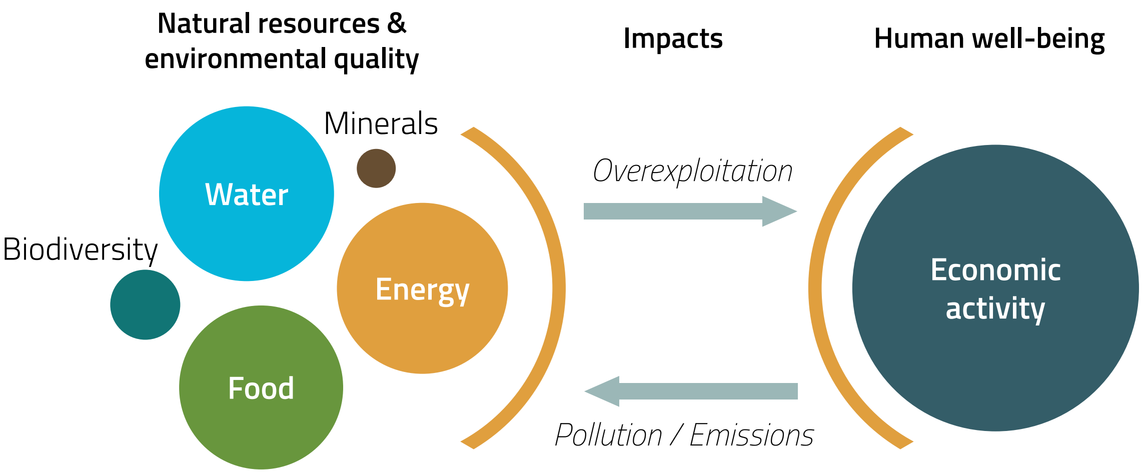
The link between environmental issues and fragility is further demonstrated by climate change as a driver that may exacerbate these challenges. Climate change is increasingly recognized as a destabilizing force. Its connection to conflict and stability is important not only in terms of the environment and natural resource management but also in the context of political fragility and peace. When fragile contexts experience multiple hazards, the diverse threats and required responses can significantly strain a country's limited resources. And when governments are forced to prioritize one issue over another due to lack of resources, the cycle of fragility just keeps going.

2.2. Water–Energy–Food nexus fragility framework

Access to natural resources and healthy ecosystems is essential for human well-being, dignity and sustainable livelihoods. Natural resource-driven fragility is a complex and multidimensional issue. While there exists a plethora of indicators that could inform some aspects of global fragility, their potential to improve its assessment is limited due to the complex interrelationships and interdependencies between water, energy, and food systems. However, natural resource-driven fragility can be conceptualized, assessed, compared, and monitored using water, energy, and food as a nexus and a set of indicators as confounding factors of fragility. Fragility can be the result of resource deficit or stress, both as the impact of resources overexploitation to support economic activities, as well as a reduction in resource availability due to pollution and emissions from these activities (Figure 1).

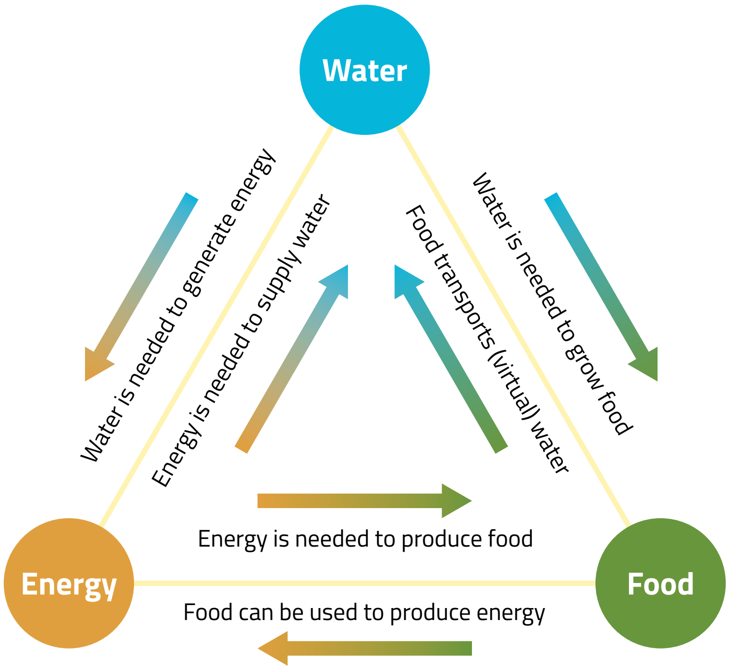
The Water–Energy–Food nexus (Figure 2) is a valuable approach to building on, defining fragility conditions based on accessibility and availability of natural resources and food security, as defined by scientifically proven methods (UN-Water, 2013; FAO, IFAD, UNICEF, WFP and WHO, 2021). This approach can capture how fragile a state is, based on its availability and demand of natural resources, considering nexus interactions and confounding factors such as economic development and access to technology.

Figure 1. The dual relationship between economic activity and natural resources and environmental quality



Source: Authors' own elaboration.

Figure 2. The Water–Energy–Food nexus conceptual approach



Source: Authors' own elaboration, based on IBM (2009).

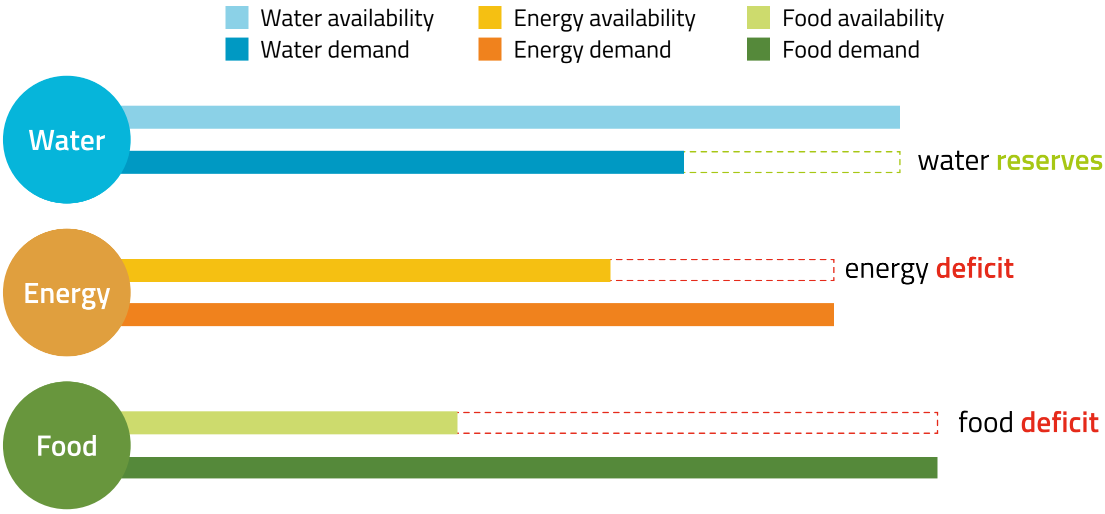
Since natural resource-driven fragility is a complex issue, the approach developed delivers its assessment based on a composite multidimensional structure. Following the workflow to calculate composite indicators proposed by the OECD (2008), the methodological steps for natural resource-driven fragility assessment are based on the following components:

- Natural resources surplus/deficit: Looking at water, energy, and food surplus/deficit per country on an annual basis as the difference between availability and demand per country.
- Recalculated sustainable natural resources surplus/deficit: Looking at water, energy, and food security per country on an annual basis assuming a sustainable level of resource use per person.
- A WEF nexus integrated surplus/deficit score (using multicriteria analysis methods).
- A multicriteria assessment of confounding factors of natural resources driven fragility, using indicators selected and scored through stakeholder engagement.

The basic component of natural resource-driven fragility is captured as integrated natural resources, looking at water, energy, and food separately first as the difference between availability and demand per country (Figure 3) and then through their integration. Resource security per country is estimated looking at water, energy and food separately and calculating the difference between availability and demand as explained in Table 1.

However, the amount of water, energy and food a country consumes (resources demand) depend on the size of its population as well as its level of development amongst other factors (i.e. climate and geography). There are inter and intragenerationally (as well as inter- and intranationally) equitable issues in terms of fair share distribution of the world's resources which are not distributed equally where the demand takes place.

Figure 3. WEF resource surplus/deficit conceptual diagram



Source: Authors' own elaboration.

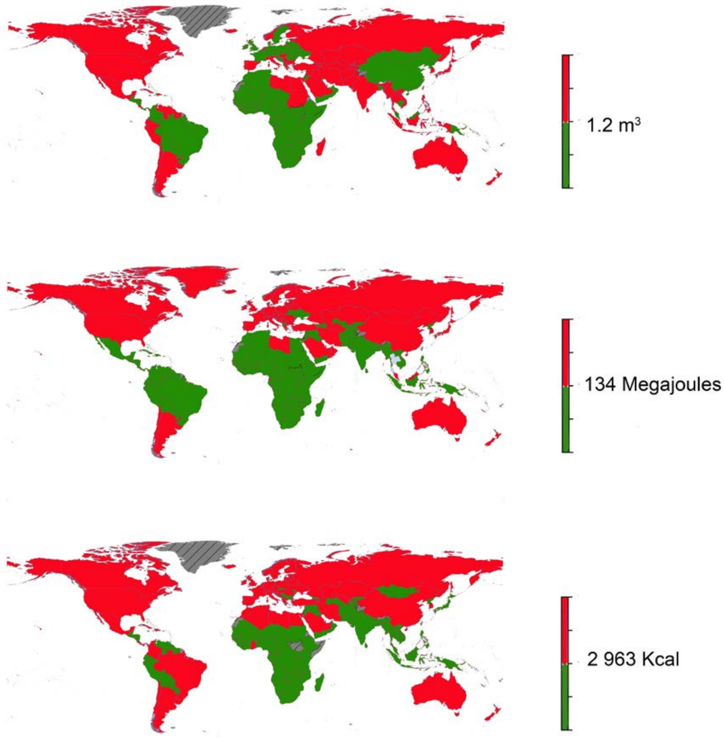
Table 1. Water, energy and food indicators of the resource-driven fragility (definitions)

Water	Energy	Food
Difference between **Total Internal Renewable Water Resources** (IRWR) and **Total Freshwater Withdrawal** (TFWW)	Difference between **Primary Production** and **Final Energy Consumption**	Difference between **Food Production** and **Food Consumption**
IRWR is a long-term average annual flow of rivers and recharge of aquifers generated from endogenous precipitation and expressed in cubic meters per year **TFWW** is the volume of freshwater extracted from a country's sources (rivers, lakes, aquifers) for its agriculture, industries, and services	**Primary Production** is defined as the capture or extraction of fuels or energy from natural energy flows, the biosphere, and natural reserves of fossil fuels within the national territory in a form suitable for use **Final Energy Consumption** refers to the consumption of primary and secondary energy by manufacturing, construction, and non-fuel mining, by transport, and by others (agriculture, forestry and fishing, commerce and public services, households, and other consumers)	**Food Production** is the total domestic production, whether inside or outside the agricultural sector. Unless otherwise indicated, production is reported at the farm level for crop and livestock products **Food Consumption** refers to the total amount of the commodity available as human food during the reference period. Tonnes of Production and Food were converted to kilocalories using FAOSTAT conversion values per crop per country per year
Indicators: IRWR, TRWR, Total/Agricultural/ Industrial/Municipal Freshwater Withdrawal, Level of Water Stress	**Indicators:** United Nations Statistics Division (UNSD) Primary Energy Production, Imports, Exports, Total Energy Supply, Final Energy Consumption	**Indicators:** Production, Domestic Supply and Food Supply

Source: Author's own elaboration with data from AQUASTAT (2022a), UNSD Environmental Indicators (2022) and OECD iLibrary (2022) for water data; UNSD Energy Statistics (2022) and IEA (2020) for energy data; FAOSTAT (2022a) for food data.

Differences between country averages for daily water, energy and food consumption per person across the globe in 2019 are shown in Figure 4. In the maps, with Red are indicated those countries with resource consumption per person per day above world average, and with Green those below, with significant variation in their distance from that average. This means that measuring the difference between availability and current demand as an indicator of fragility, those countries that consume above the world average would seem more fragile and those below, less fragile than they really are. Indeed, the developed world has a significant resource sustainability gap (the difference between what it currently consumes and what its entitlement should be if it consumed its fair share) (Voulvoulis *et al.*, 2022).

Figure 4. Global daily water, energy and food consumption per capita



Source: Author's own elaboration with 2017 data from AQUASTAT (2022a), 2019 data from FAOSTAT (2022b) and UNSD (2022) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

From a sustainability perspective and in terms of living within planet boundaries, and considering the current level of development, it is important for the difference between availability and demand to capture the resource reserves or deficit of a country after that country meets the water, energy and food demand for all its population. By recalculating, therefore, the amount of water, energy and food that a country consumes based on its population and using the same level of consumption per capita across countries, the new difference between availability and demand offers a much better indicator of natural resource-driven fragility. These new differences for water, energy, and food per country can then be integrated through the different multicriteria nexus methods to support fragility decision-making. A multicriteria analysis (MCA) approach is used to bring together the findings of all components and calculate a WEF nexus integrated security score.

MCA is a well-developed decision-making methodology applied for complex multidimensional questions as it comprises various techniques and tools which explicitly consider multiple objectives and criteria (or attributes) in decision-making problems. It is used here both for the WEF nexus integrated security score and for capturing the role of confounding factors to fragility (discussed later in this report). MCA frameworks are relatively easy to understand and allow the direct involvement of multiple experts, interest groups, and stakeholders. The analysis is transparent to participants and includes mechanisms for continuous feedback. It provides a systematic approach to ranking against a range of certain criteria weighted by their relative importance. It can also incorporate factors that are seen by stakeholders as critical to the process but are difficult to reliably express in quantitative terms. For example, the values of human life or natural biodiversity do not have to be reduced to a single unit equivalent (e.g. dollars). Indicators are selected based on their relevance, analytical soundness, timeliness, accessibility, and geographic coverage, with a preference for indicators with the widest global coverage.

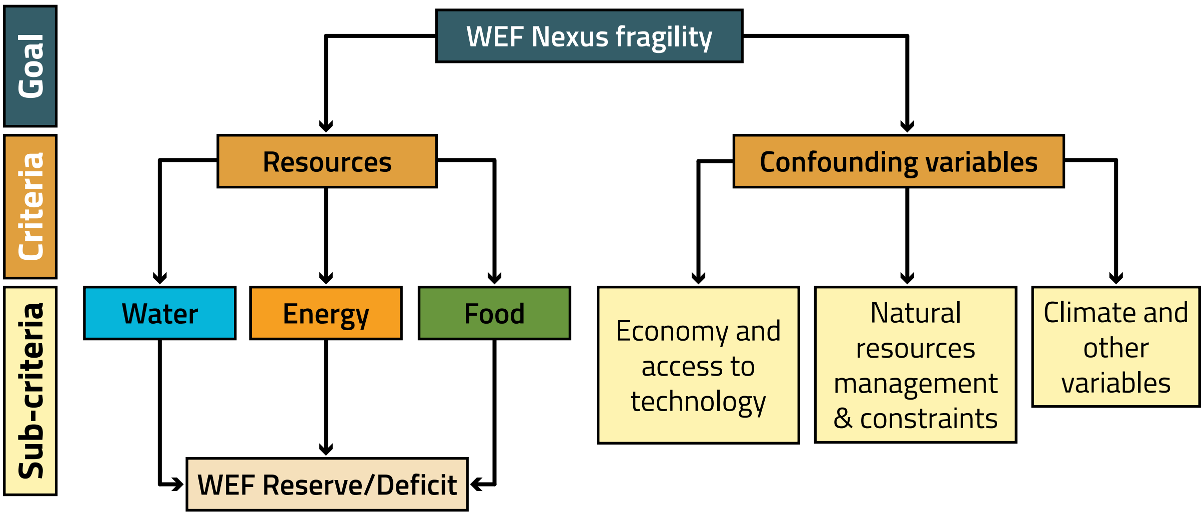
There are several dozens of MCA methods, all of which differ in the way they weigh and relate criteria and variables. Based on the logical soundness, the robustness of implementation, consistency, transparency and ease of application and interpretation, two well-developed and widely applied methods are applied: Pairwise Comparisons (PC, to compare countries against each other), and Weighted Sum Model (WSM, to relate and combine indicators). These are first used for integrating water, energy, and food resource surplus/deficit per country, and then for including additional indicators to capture countries' socioeconomic development, technology, natural resources management, and climate risks as confounding factors to natural resources driven fragility.

2.3. Multicriteria approach to confounding factors of fragility

Several indicators are also considered to better capture a country's natural resource-driven fragility that perhaps can be easier understood as confounding factors to that fragility (Figure 5). These include countries' socioeconomic development, access to technology, natural resources management practices, and climate risks. Natural resource management and governance are highly complex and significant components to countering fragility and fostering stability.

Worldwide, scarce natural resources and the environment are increasingly exploited while at the same time the demand for freshwater, agricultural products and energy is rising particularly in countries still developing. Inequalities in the distribution and access to water, energy and food are exacerbated by the impacts of climate change. For example, precipitation changes from climate change will affect the dry tropics and subtropics, where most rainfed production takes place, leading to a reduction in yields, compared to the large swathes of temperate cereal production in the northern hemisphere, where even an expansion nudged by global warming may be seen. A multicriteria approach is used to create an overall fragility score that ranks countries based on the selected indicators, informing their WEF nexus scores. Inferences or judgements are made with respect to the indicators' current condition relative to their desired future condition or target value so that the MCA supports the development both of a visualization and decision support tool (Figure 5). An initial set of indicators for confounding factors was identified based on recent reviews of global natural resources and their management, including FAO, World Bank, EIA, and UNSD. In total, 47 indicators were selected and classified by natural resources availability and demand; socioeconomic and technological development; environmental management; and climate risks following the natural resource-driven fragility framework. The weights of criteria and sub-criteria, which express the relevance of the identified indicators to characterizing and assessing the fragility of countries to lack of natural resources, were estimated through participatory engagement of relevant experts and stakeholders.

Figure 5. Fragility through WEF nexus assessment and confounding variables



Source: Authors' own elaboration.

2.4. Indicators for confounding factors

This report uses a framework that ranks countries from high to low levels of natural resources driven fragility. The highest rank can, therefore, indicate a stronger level of resilience to potential water, energy and food resources shortages. Moving from fragility to resilience has gained some attention in recent years (Desai and Forsberg, 2020) as it embraces the approach that identifies risks to fragility and strengthening coping capacities. Resilience emerges from positive interactions between the elements of environmental management, socioeconomic and technological dimensions. Here, a high-level concept of fragility is reflected in the multidimensional approach of the framework to guide the transition from fragility to resilience, taking into account both the WEF nexus and confounding factors to fragility. Overall natural resource-driven fragility rankings should indicate which countries are best addressing the resources challenges that every nation faces. This granular view and comparative perspective can assist in understanding the determinants of fragility progress and in refining policy choices. The final set of indicators was checked against: (1) timeliness of the data source and the frequency of its updates; (2) geographic coverage, with a preference for indicators as close to global coverage as possible; and (3) quality of the data.

Table 2. Indicators for confounding factors

Indicator	Link to resilience	Definition	Relevance	Source
		Resource availability and management		
Number of earths required	Inverse (-1)	How many earths would be needed if everyone lived like the residents of a given country. An indicator of the Ecological Footprint, which reflects the demands of a country (a group of people) on global natural resources.	Resources demand directly relates to natural resource-driven fragility.	Global Footprint Network, 2021
Emissions *Thousand metric tons of carbon dioxide*	Inverse (-1)	Carbon dioxide emissions are caused by the burning of fossil fuels. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels, and gas flaring.	Due to worsening climate change trends, high carbon dioxide emissions can exacerbate natural resource-driven fragility, as more consumers have to switch to alternative energy sources and develop new infrastructure based on carbon-neutral or net-zero solutions. As a result, high emissions have an inverse relationship with countries resource resilience.	United Nations Data, 2022a
Total natural resources rents *Percentage of GDP*	Inverse (-1)	The estimates of natural resources rents are calculated as the difference between the price of a commodity and the average cost of producing it.	The overreliance of economies on natural resources limits their resilience. This metric is directly linked to fragility.	World Bank, 2022a
Fishing grounds *Biocapacity, global hectares per person*	Direct (+1)	The fishing grounds footprint is calculated based on estimates of the maximum sustainable catch for various fish species. These sustainable catch estimates are converted into an equivalent mass of primary production based on the various species' trophic levels. This estimate of maximum harvestable primary production is then divided among the continental shelf areas of the world.	Higher capacity of fishing grounds is likely to improve natural resources driven resilience through food supplies, transport, and trade links. Therefore, this metric is inversely linked to fragility.	Global Footprint Network, 2021
Built-up land *Biocapacity, global hectares per person*	Direct (+1)	The built-up land footprint is calculated based on the area of land covered by human infrastructure - transportation, housing, industrial structures, and reservoirs for hydropower.	A well-developed infrastructure supports the socio-economic development and resilience of countries.	Global Footprint Network, 2021

Table 2. Indicators for confounding factors *(cont.)*

Indicator	Link to resilience	Definition	Relevance	Source
Threatened species: vertebrates *Number of species*	Inverse (-1)	Vertebrates consist of mammals, birds, reptiles, amphibians, and fish. Invertebrates consist of molluscs and other invertebrates.	A greater number of threatened species indicates that natural resource management strategies are either underdeveloped or severely compromised, directly related to fragility.	IUCN, 2022
Environmental Performance Index (EPI) *Score*	Direct (+1)	The EPI provides a data-driven summary of the state of sustainability around the world. Using 32 performance indicators across 11 issue categories, the EPI ranks 180 countries on environmental health and ecosystem vitality.	High EPI indicates a country is closer to rich established environmental policy targets, which is a sign of resilience.	Wolf *et al.*, 2022
Total biocapacity *Global hectares per person*	Direct (+1)	Biocapacity serves as a lens, showing the biosphere's capacity to regenerate and provide natural resources and services for life. It allows researchers to add up the competing human demands, which include natural resources, waste absorption, water renewal, and productive areas dedicated to urban uses.	Increase in total capacity by definition reduces natural resource-driven fragility.	Global Footprint Network, 2021
Total Ecological Footprint *Global hectares per person*	Inverse (-1)	The Ecological Footprint is derived by tracking how much biologically productive area it takes to provide for all the competing demands of people. These demands include space for food growing, fibre production, timber regeneration, absorption of carbon dioxide emissions from fossil fuel burning, and accommodating built infrastructure.	The more biologically productive areas are needed for food, fibres, timber regeneration, carbon dioxide emission absorption and built infrastructure, the lower the country's resilience. This metric is directly related to fragility and is inversely related to resilience.	Global Footprint Network, 2021
Number of countries required	Inverse (-1)	An indicator of the Ecological Footprint, which reflects the demands of a country (a group of people) on global natural resources.	The greater the demand for natural resources, the lower the resilience of the country (even if the country is sufficiently supplied with external resources).	Global Footprint Network, 2021
Agricultural land *1 000 ha*	Direct (+1)	Land used for cultivation of crops and animal husbandry. The total of areas under "cropland" and "permanent meadows and pastures."	Agricultural land is a resource availability indicator.	FAOSTAT, 2022c

Table 2. Indicators for confounding factors *(cont.)*

Indicator	Link to resilience	Definition	Relevance	Source
Forest land *1 000 ha*	Direct (+1)	Land spanning more than 0.5 hectares, with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. Excludes land predominantly under agricultural or urban land use.	Forest land is a resource availability indicator.	FAOSTAT, 2022d
Artificial surfaces *1 000 ha*	Direct (+1)	Artificial surfaces are composed of any type of areas with a predominant artificial surface. Any urban or related feature is included in this class, for example urban parks (parks, parkland and laws). The class also includes industrial areas, and waste dump deposit and extraction sites.	Artificial surfaces are an indicator of infrastructure availability. A well-developed infrastructure supports socio-economic development and resilience.	FAOSTAT, 2022e
Inland water *1 000 ha*	Direct (+1)	Inland water includes any geographical area covered most of the year by inland water bodies. In some cases, the water can be frozen for part of the year (less than 10 months).	Inland water is a resource availability indicator.	FAOSTAT, 2022f
Coastal water *1 000 ha*	Direct (+1)	Coastal water is defined based on geographical features of the land in relation to the sea (coastal water bodies, i.e. lagoons and estuaries) and abiotic surfaces subject to water persistence (intertidal areas, i.e. coastal flats and coral reefs).	Coastal water is a resource availability indicator.	FAOSTAT, 2022g
Agriculture, forestry, and fishing, value added *Percentage of GDP*	Inverse (-1)	Agriculture, forestry, and fishery correspond to forestry, hunting, and fishing, as well as cultivation of crops and livestock production.	Large percentage of agriculture, forestry and fishery in the nation's GDP is a sign of high reliance on natural resources, which is directly tied to fragility.	World Bank, 2022b
Mortality rate attributed to unsafe water, unsafe sanitation, and lack of hygiene *Rate per 100 000 population*	Inverse (-1)	Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene is deaths due to unsafe water, sanitation and hygiene, focusing on inadequate Water, sanitation and hygiene (WASH) services per 100 000 population.	Water pollution is inversely related to resilience.	WHO, 2022a
Mortality rate attributed to household and ambient air pollution, age-standardized *Rate per 100 000 population*	Inverse (-1)	Mortality rate attributed to household and ambient air pollution is the number of deaths due to the joint effects of household and ambient air pollution in a year per 100 000 population. The rates are age-standardized.	Air pollution is inversely related to resilience.	WHO, 2022b

Table 2. Indicators for confounding factors *(cont.)*

Indicator	Link to resilience	Definition	Relevance	Source
Climate change				
Nitrogen leaching **SSP3: Regional rivalry** **Time horizon: 2050** *Percentage of total area or km²*	Inverse (-1)	Nitrate leaching from cropland-applied mineral fertilizer has direct effects on water quality and can lead to eutrophication (algal blooms) and water supply toxicity.	Aquatic nitrate pollution is inverse to resilience and directly related to fragility.	Byers *et al.*, 2018
Peak flows risk index **SSP3: Regional rivalry** **Time horizon: 2050** *Percentage of total area or km²*	Inverse (-1)	Peak flows risk indicates locations where the risk of extreme high river flows is expected to increase.	Flood risk has a negative impact on water supply, food and energy production, and is therefore directly related to fragility.	Byers *et al.*, 2018
Projections of future renewable water resources by the country for different climate change scenarios **Time horizon: 2070-2090** *Percentage of change from 2019*	Direct (+1)	Relative changes in internal and inflowing water resources by country, resulting from Representative Concentration Pathway RCP 8.5 scenario for 2070/2090 horizon. The pixel-based data from six hydrological models considered in the ISI-MIP project, driven by 5 climate models, were routed through a river network.	An increase in internal renewable water resources toward the end of the century increases potential water availability for agricultural, industrial, and municipal uses, which is directly linked to a country's resilience, while a decline in water availability is indicative of a country's fragility.	FAO, 2018
Habitat degradation **SSP3: Regional rivalry** **Time horizon: 2050** *Percentage of total area or km²*	Inverse (-1)	Estimated as a percentage change from the share of land area within a pixel being converted from natural land to agricultural land in the future, as simulated by the Global Biosphere Management Model (GLOBIOM) model, and further downscaled to 0.5°C.	Habitat degradation occurs when human activities exert pressure on local ecosystems, particularly in rural areas where agricultural land and natural habitats meet. Habitat degradation eventually leads to land capacity degradation, which is directly linked to fragility.	Byers *et al.*, 2018

Table 2. Indicators for confounding factors *(cont.)*

Indicator	Link to resilience	Definition	Relevance	Source
Agricultural water stress index **SSP3: Regional rivalry** **Time horizon: 2050** *Percentage of total area or km²*	Inverse (-1)	The Agricultural Water Stress Index identifies areas where agricultural operations, especially irrigation, cause environmental water stress. To identify locations where monthly irrigated water demand exceeds sustainable supply, it measures the fraction of environmental flow requirement (EFR) required to meet agricultural demands.	Areas with more water available for irrigation are likely to be more adaptable to adverse climatic conditions.	Byers *et al.*, 2018
Drought intensity change **SSP3: Regional rivalry** **Time horizon: 2050** *Percentage of total area or km²*	Inverse (-1)	Change in drought intensity indicates locations where the intensity of droughts is increasing – both duration and water deficit. Calculation: the proportion between daily water volume deficit (m^3/s) below the 10th percentile daily discharge (Q90) and drought event duration (days).	Current and future droughts reduce national water supply and increase risks to food supply. This metric is therefore directly linked to fragility.	Byers *et al.*, 2018
Water stress index **SSP3: Regional rivalry** **Time horizon: 2050** *Percentage of total area or km²*	Inverse (-1)	Water stress index compares water demands to available water supply. High water stress means a high proportion of the available water is being used. Calculation: fraction of net human demands (domestic, industrial, irrigation) divided by renewable surface water availability, as known as the withdrawal to availability ratio.	The future water stress metric indicates risks to both the water and food sectors and is directly associated with fragility.	Byers *et al.*, 2018
Crop yield change **SSP3: Regional rivalry** **Time horizon: 2050** *Percentage of total area or km²*	Inverse (-1)	Climate change impact on crop yield indicates where a changing climate will negatively impact crop yields, primarily through high temperatures and reduced water availability.	Future negative impacts on crop yields directly link to food resource fragility.	Byers *et al.*, 2018
Number of Hot Days (T_{max} > 45°C) **SSP3: Regional rivalry** **Time horizon: 2080-2099**	Inverse (-1)	Annual number of hot days anomaly from reference period 1995-2014. Median value of Coupled Model Intercomparison Project (CMIP) 6 multimodel ensembles. Average by country.	Increase in the number of days with maximum daily temperature exceeding 45°C is directly linked to fragility.	Clark *et al.*, 2003

Table 2. Indicators for confounding factors *(cont.)*

Indicator	Link to resilience	Definition	Relevance	Source
The Standardized Precipitation Evapotranspiration Index (SPEI) **SSP3: Regional rivalry** **Time horizon: 2080-2099**	Indirect (-1)	The Standardized Precipitation Evapotranspiration Index (SPEI), or Mean Drought Index, calculated for a 12-month period, has been found to be closely related to drought impacts on ecosystems, crop, and water resources. The SPEI is designed to take into account both precipitation and potential evapotranspiration (PET) in determining drought Metric: SPEI anomaly from reference period 1995-2014. Median value of CMIP 6 multimodel ensemble. Average by country.	SPEI is widely used today as a global measure for drought monitoring over various cumulative time intervals. Positive values indicate positive water balance (or wet) conditions and negative values indicate negative water balance (or dry) conditions. It is a metric for determining the onset, duration and magnitude of drought events with respect to normal conditions in natural and managed systems such as crops, ecosystems, rivers, water resources, etc.	Clark *et al.*, 2003
Days with precipitation higher than 50mm **SSP3: Regional rivalry** **Time horizon: 2080-2099**	Inverse (-1)	Precipitation > 50mm anomaly from reference period 1995-2014. Median value of CMIP 6 multimodel ensemble. Average by country.	Extreme precipitation occurrences directly relate to the vulnerability of water, food, and energy resources.	Clark *et al.*, 2003
Growing Season Length **SSP3: Regional rivalry** **Time horizon: 2080-2099**	Direct (+1)	Growing Season Length anomaly from reference period 1995-2014. Median value of CMIP 6 multimodel ensemble. Average by country.	Future length of growing season is an indicator of the agricultural resource. This metric is inversely related to fragility.	Clark *et al.*, 2003
		Economy and access to technology		
Ores and metals exports *Percentage of merchandise exports*	Inverse (-1)	Ores and metals comprise the crude fertilizer, minerals, metalliferous ores, scrap, and non-ferrous metals.	Large percentage of crude minerals and ores in the total merchandise ties economies to raw natural resources, which is a sign of fragility inversely associated with resilience.	World Bank, 2022c
Merchandise exports *Current USD*	Direct (+1)	Merchandise exports show the value of goods provided to the rest of the world valued in current U.S. dollars. Exports are recorded as the cost of the goods delivered to the frontier of the exporting country for shipment - the free on board (f.o.b.) value.	High merchandise exports generally stimulate economic growth and nation's resilience, which are inversely related to fragility.	WTO, 2022

Table 2. Indicators for confounding factors *(cont.)*

Indicator	Link to resilience	Definition	Relevance	Source
Manufactures exports *Percentage of merchandise exports*	Direct (+1)	Manufactures include chemicals, basic manufactures, machinery and transport equipment, and miscellaneous manufactured goods, excluding division non-ferrous metals.	Manufacturers' exports are signs of technological advances and economic diversity, which support the nation's resilience and reduce natural resource-driven fragility.	World Bank, 2022d
Fuel exports *Percentage of merchandise exports*	Inverse (-1)	Fuels comprise the mineral fuels, lubricants and related materials.	Large percentage of fuel in the total merchandise is a sign of fragility.	World Bank, 2022e
Exports of goods and services *Current USD*	Direct (+1)	Exports of goods and services represent the value of all goods and other market services provided to the rest of the world. They include the value of merchandise, freight, insurance, transport, travel, royalties, license fees, and other services, such as communication, construction, financial, information, business, personal, and government services.	Growth in merchandise, freight, insurance, transport, travel, royalties, license fees, and other services promotes economic development and reduces reliance on natural resources. As a result, this metric is positively correlated with resilience and inversely linked to fragility.	World Bank, 2022f
Food exports *Percentage of merchandise exports*	Inverse (-1)	Food comprises food and live animals, beverages and tobacco, animal and vegetable oils, fats and oil seeds, oil nuts, and oil kernels.	Large percentage of food in the total merchandise indicates a nation's dependence on natural resources, which makes countries less resilient. Hence, this is a direct sign of fragility.	World Bank, 2022g
Insurance and financial services *Percentage of commercial service exports*	Direct (+1)	Insurance and financial services cover freight insurance on goods exported and other direct insurance, such as life insurance; financial intermediation services, such as commissions, foreign exchange transactions, and brokerage services; and auxiliary services, such as financial market operational and regulatory services.	Insurance and financial services support economic resilience. This metric is negatively related to the natural resources driven fragility.	IMF, 2022a
GDP per capita *Current USD*	Direct (+1)	GDP per capita is a gross domestic product divided by midyear population. GDP is the sum of the gross value added by all resident producers in the economy, plus any product taxes and minus any subsidies not included in the value of the products.	High GDP is a metric of resilience, which is inversely related to fragility.	World Bank, 2022h

Table 2. Indicators for confounding factors *(cont.)*

Indicator	Link to resilience	Definition	Relevance	Source
High-technology exports *Current USD*	Direct (+1)	High technology products are the sum of the Aerospace, Computers-office machines, Electronics-telecommunications, Pharmacy, Scientific instruments, Electrical machinery, Chemistry, Non-electrical machinery, Armament.	High technology products directly relate to development and resilience, which reduce fragility.	United Nations Comtrade, 2022
Human Development Index (HDI) *Score*	Direct (+1)	The Human Development Index (HDI) is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable, and having a decent standard of living. The HDI is the geometric mean of normalized indices for each of the three dimensions.	A decent standard of living, good education, and healthy life inversely relate to fragility.	UNDP, 2022
Grants of patents *Number*	Direct (+1)	Patents Resident filings (per million population), grants and patents in force	This metric is positively linked to the nation's technological advances, freedom of intellectual expression and developed legal system, which reduce global fragility.	WIPO, 2023
ICT goods exports *Percentage of total goods exports*	Direct (+1)	Information and communication technology goods exports include computers and peripheral equipment, communication equipment, consumer electronic equipment, electronic components, and other information and technology goods (miscellaneous).	ICT offer vast opportunities for economic growth, improved health, better service delivery, learning through distance education, social and cultural advances, etc. This indicator is positively related to resilience and inversely associated with fragility.	UNCTAD, 2022
ICT service exports *Balance of Payment, current USD*	Direct (+1)	Information and communication technology service exports include computer and communications services (telecommunications and postal and courier services) and information services (computer data and news-related service transactions).	This is a strong indicator of high technological advances, which is inversely linked to fragility.	IMF, 2022b
Gross domestic expenditure on research & development *Percentage of GDP*	Direct (+1)	The gross domestic expenditure on R&D indicator consists of the total expenditure (current and capital) on R&D by all resident companies, research institutes, university and government laboratories, etc. It excludes R&D expenditures financed by domestic firms but performed abroad.	This is a strong indicator of a technologically advanced economy, which is inversely related to fragility.	United Nations Data, 2022b

2.5. Multivariate analysis

The underlying patterns across data were studied using principal components analysis (PCA). The objective of the PCA is to reveal how different indicators change in relation to each other and how they are associated.

Principal components try to capture as much of the variance in the dataset as possible. Factor loading indicates how much a given indicator correlates with a component, ranging from -1 to 1. For each identified component, some indicators have more weight than others. Largest factor loadings are assigned to the individual indicators that have the largest variation across countries, a desirable property for cross-country comparisons, as individual indicators that are similar across countries are of little interest and cannot possibly explain differences in performance.

The provisional criteria must be assessed against various qualities, such as:

- Completeness: Have we included all the main criteria and sub-criteria?
- Redundancy: The relatively unimportant criteria or duplicates can be removed. These decisions can be based on the statistical structure of the dataset (multivariate analysis) and expert opinion (stakeholder engagement).
- Mutual independence of preferences: Straightforward applications of MCA require that criteria are independent. Can we assign preference scores for the options on one criterion without knowing what the options' preference scores are on any other criteria? If the answer is yes, then the criteria are considered mutually independent. If independence is violated, more advanced MCA procedures may be adopted.

2.6. Stakeholder forum

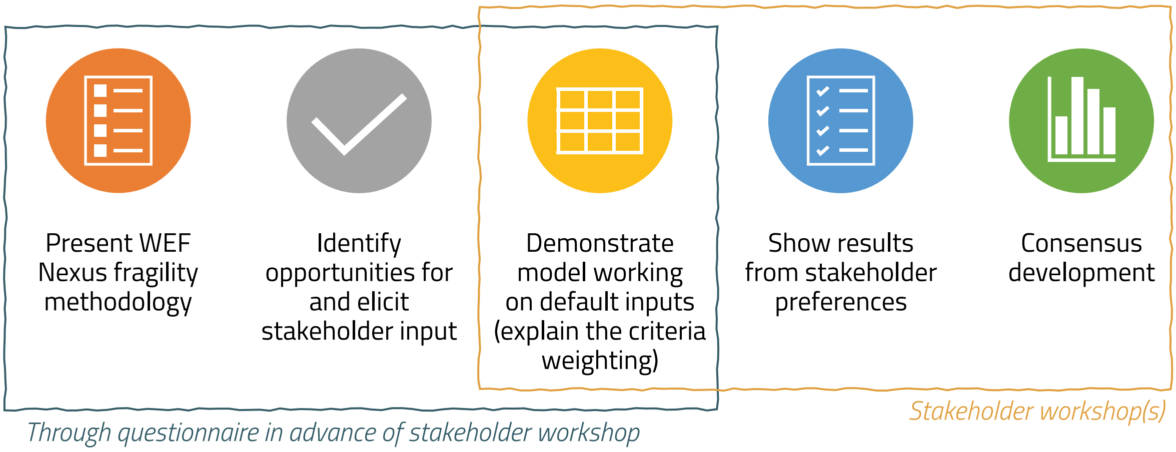
To simplify, quantify, analyse, and disseminate otherwise complicated information, the natural resource-driven fragility mapping tool was developed based on a participatory process using multicriteria analysis. MCA involves the engagement of multiple experts and stakeholders to consider all viewpoints and reach a consensus regarding the set of sub-criteria, indicators and their related weights (Mendoza *et al.*, 1999). Such participatory approaches support the production of rigorous and objective composite indicators based on credible data, relationships, and weights. To facilitate this, MCA not only incorporates qualitative and quantitative information, but also contains feedback tools for evaluating the consistency of results (Grafakos *et al.*, 2010).

The stakeholder forum aimed to:

- develop a general agreement on the elements of the WEF nexus framework,
- receive feedback on the sources and availability of data,
- validate assumptions and corporate model inputs as stakeholder preferences, and
- collect information, ideas, opinions, and insights to complement research.

To achieve this, a set of objectives was defined. The initial task consisted of identifying and contacting stakeholders. The outcome of an MCA is as versatile or one-sided as the ideas of the participants, so the selection process must be inclusive and open to a wide spectrum of opinions. The second objective was to share a brief questionnaire that explains the goals, objectives and methodology, along with a number of questions with reasonable expectations about the indicators used and their potential importance. The third objective involved a virtual consultation, in which the collated responses were discussed, and initial results working on default inputs were demonstrated. The fourth and final objective was to apply the stakeholder preferences in the model, perform model sensitivity analysis, and share the final results, based on valuable opinion and feedback of stakeholders. The key steps of the stakeholder forum development are outlined in Figure 6.

Figure 6. Main steps in the stakeholder forum exercise



Source: Authors' own elaboration.

The stakeholders were selected based on the diversity of views and expertise. The final group included direct (FAO) and indirect internal stakeholders (UN representatives and national decision-makers), external stakeholders (academic experts, NGOs, the commercial sector) and other potential users. The experts carried the knowledge and experience in the following areas:

- Emergency and Resilience
- Emergency and Rehabilitation
- Food insecurity and economic drivers
- Yield gap and food insecurity
- Fragmentation of vegetation
- Drought
- Agroecological zoning
- Investment
- Geographic Information System (GIS)
- Land and water
- Water resources management
- Nature-based solutions
- Climate risk
- WEF Nexus

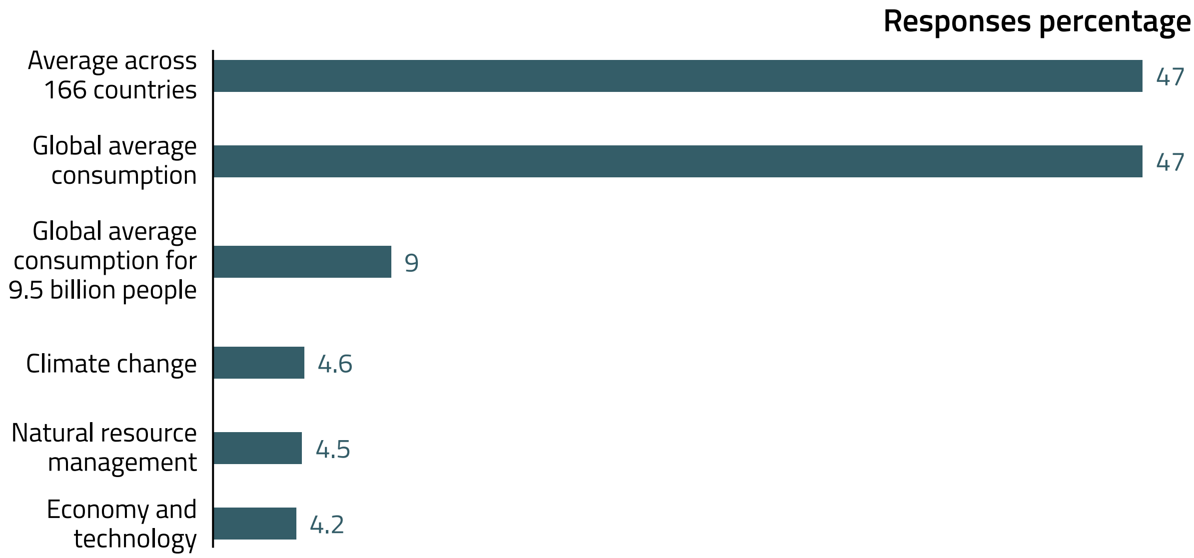
In order to minimize potential biases, the process included the validation of the water, energy and food consumption thresholds, the ranking and scoring of confounding indicators, supplemented by the invitations to provide further feedback on the process. For learning and validation purposes, there was a focus on identifying and discussing experts' disagreements, thereby adjusting the collective action framework.

2.7. Natural resource-driven fragility assessment outputs

Experts view

Unlike rigorous methods, the highly versatile approach adopted is a dynamic process that provides an opportunity for further amendment, completion, and weighting of criteria and sub-criteria. The approach can also encompass different geographic areas if comprehensive, reliable, and updated datasets are available. For example, for calculating the amount of water, energy and food a country consumes based on its population multiplied by the average person consumption, most experts selected the global average and the average across countries as more suitable (Figure 7), with a small number of participants choosing demand estimates based on a global population expected to reach 9.5 billion people.

Figure 7. Stakeholder survey results: recommended estimates of global threshold of water, energy and food consumption per capita

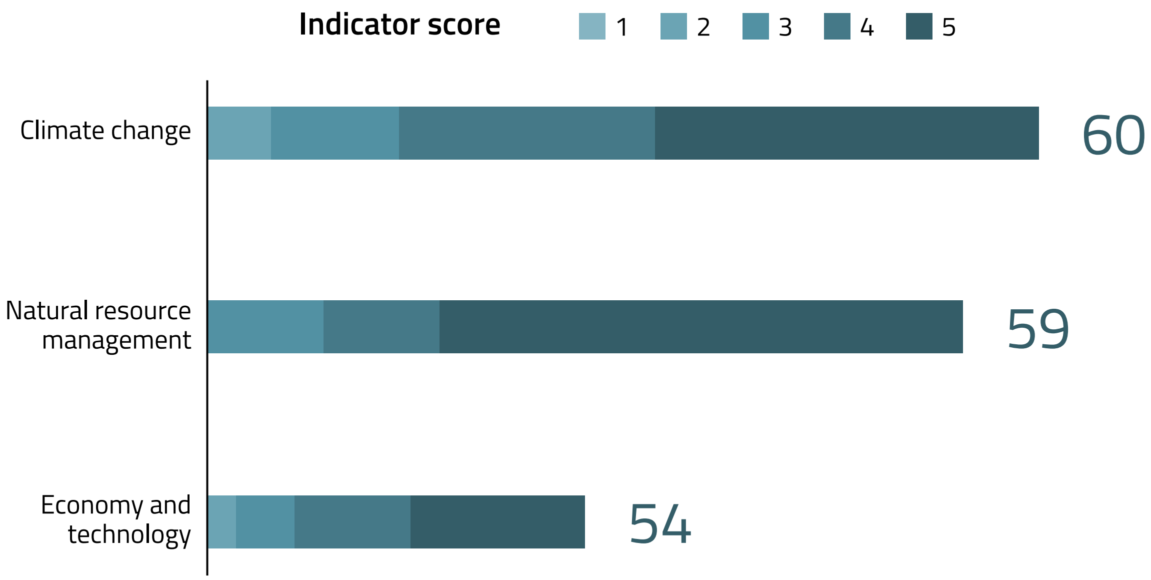


Source: Authors' own elaboration, based on survey output.

Figure 8 depicts the survey results for the evaluation of the economic and technological development, climate change and natural resource management components. Climate change received the highest scores from most respondents, followed by resource management and the dimensions of economy and technology.

Despite the initial questionnare results, throughout the discussions the majority of participants recommended and agreed that socioeconomic growth and the availability of technology play a critical role in the global natural resources security.

Figure 8. Stakeholders' survey results: the confounding variable indicators scores



Source: Authors' own elaboration, based on survey output.

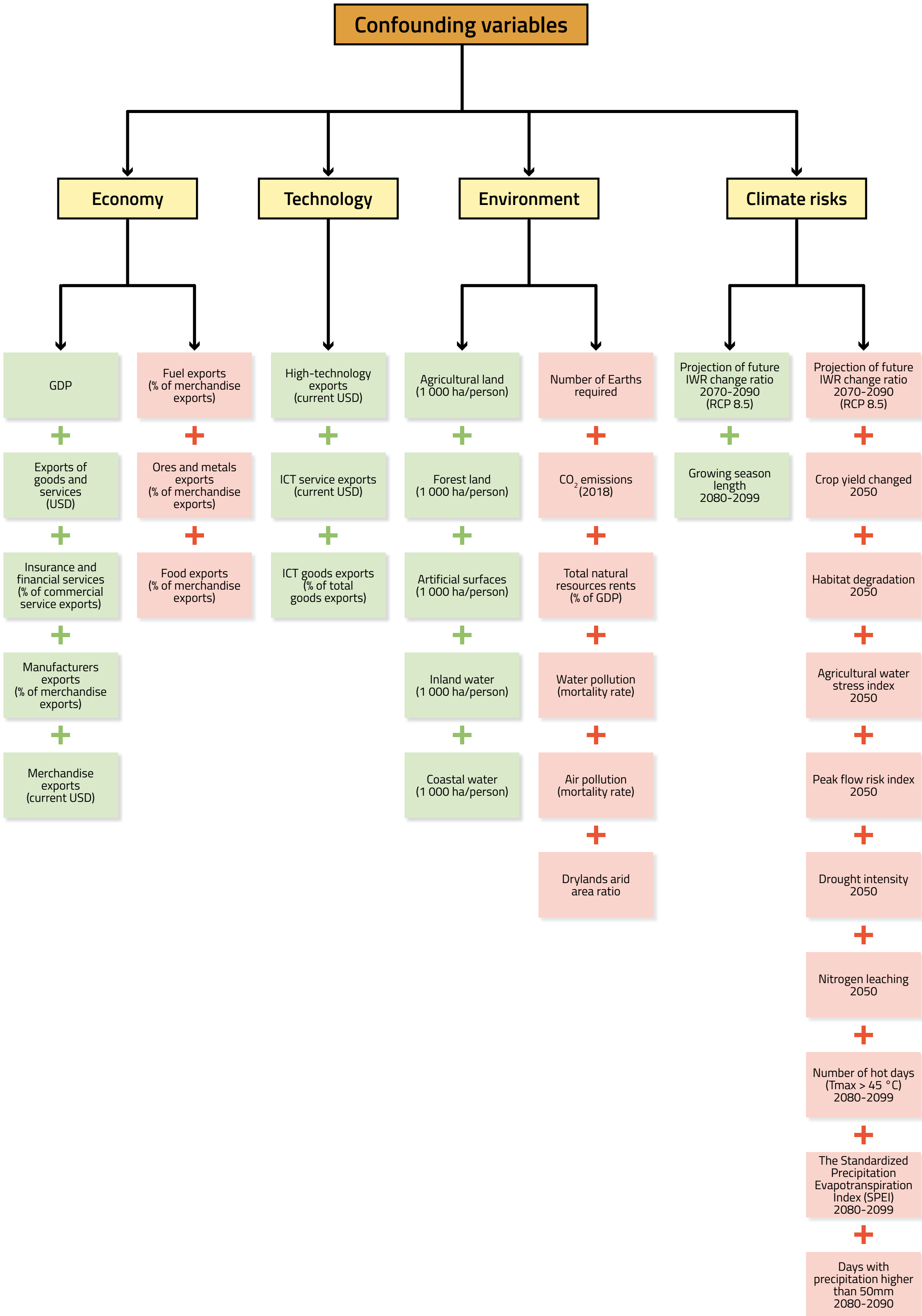
Principal component analysis

PCA was performed on groups of indicators within their individual criteria: economy and access to technology, natural resources management, and climate risks. In all three groups of indicators, the first component accounts for around a third of the explained variance, and a major share of observations distributes across more than one dimension. In the economy and access to technology group, the exports of goods and services (current USD), high-technology exports (current USD), and merchandise exports (current USD) are indicators that positively correlate with the first component (explained variance 0.33), while agriculture, forestry, and fishery, value added (percentage of gross domestic product, GDP) and food exports (percentage of merchandise exports)- negative. The second component is related to the population size of the countries (explained variance 0.16). In the natural resources management group, ecological (deficit) or reserve, forest land, total bio-capacity, and fishing ground are positively correlated with the first component (explained variance 0.3), in contrast to the total ecological footprint and number of earths required. Climate indicators are divided into two subsets with water-related risks: agricultural water stress and non-renewable groundwater stress on the one hand, and heat stress events and additional cooling days on the other.

Confounding indicators subset

WEF nexus natural resource-driven fragility identifies contexts that require greater attention from the international community through the data-driven approach based on water, energy, food resource surplus/deficit and 35 confounding indicators across economy, environmental management and climate dimensions, primarily sourced from independent, third-party institutions, as well as qualitative expertise. Thinking in integrated dimensions helps actors move beyond symptoms of fragility to target its root causes, thereby informing more holistic and effective policy responses. Such thinking goes beyond binary distinctions of fragile versus non-fragile and crisis versus non-crisis to recognize that different levels of fragility and resilience exist in all contexts. Indicators that inform access to information and communication, as well as high technology, were grouped into an individual category "technology". Figure 9 shows the subset of confounding indicators and their link to nations' resilience.

Figure 9. Final subset of confounding indicators and their link to resilience



Source: Authors' own elaboration.

The economical dimension measures resilience stemming from the diversity in production of goods and services, and minimal reliance on natural resources. Economic stability is a source of well-being and prosperity of individuals, households, and society. It influences the other components of resilience by increasing political and societal equalities that mitigate violence and unrest.

The technological dimension evaluates resilience based on high-tech, information and communication development. Technological solutions reduce vulnerability and improve coping capacity of the state. The environmental dimension evaluates the resilience associated with environmental footprint, pollution, and biological capacity. Environmental resilience reduces possibility of conflict over the distribution of resources, and influence major measures of economic and social well-being, consequently influencing other characteristics of fragility (Taherzadeh, 2021).

The climate dimension combines indicators of future heat, drought, and flood anomalies with multiple risks to agricultural and water sectors. Current and future climate hazard and potential climate resource are determined by the physical climate system and global greenhouse gas emissions, thus managing them is beyond capabilities of individual countries. The aspect of climate risk can better inform the fragility (Siderius *et al.*, 2021).

3. Tool implementation

3.1. Water

Water security is a rapidly growing concern around the world. This is analysed using the fundamental concept of availability and demand, which together indicates difficulties in satisfying the needs of a population based on available resources (Wan Roseley and Voulvoulis, 2023).

Availability

Total Internal Renewable Water Resources (IRWR)

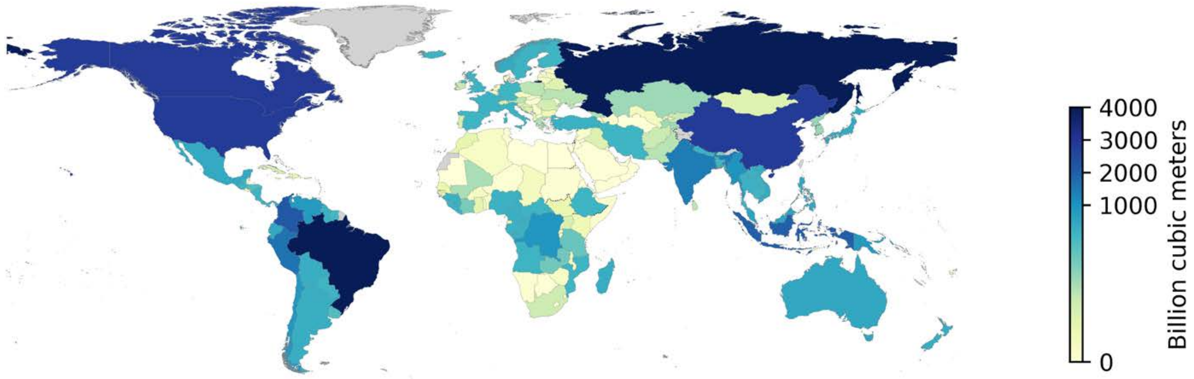
IRWR is a long-term average annual flow of rivers and recharge of aquifers generated from endogenous precipitation and expressed in cubic meters per year. It is calculated as follows:

IRWR = [Groundwater produced internally] + [Surface water produced internally] - [Overlap between surface water and groundwater]

The values for renewable water resources are annual averages of the 1961–1990 period of reference unless otherwise specified. They are not yearly values. FAO's Global Information System on Water and Agriculture (AQUASTAT) uses the 1961–1990 period of reference to provide internationally comparable information, as these renewable internal flows are an important indicator of water security or scarcity.

While some countries have an abundant supply of freshwater, others do not have as much. Figure 10 shows that over half of the renewable internal freshwater resources are available in eight countries: Brazil, Canada, China, Colombia, Indonesia, the Russian Federation, and the United States of America. Countries in the North Africa region and the Near East have a low water supply, putting them at dangerous risk of water scarcity.

Figure 10. Total internal renewable water resources



Source: Authors' own elaboration, based on data from AQUASTAT (2022b) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Demand

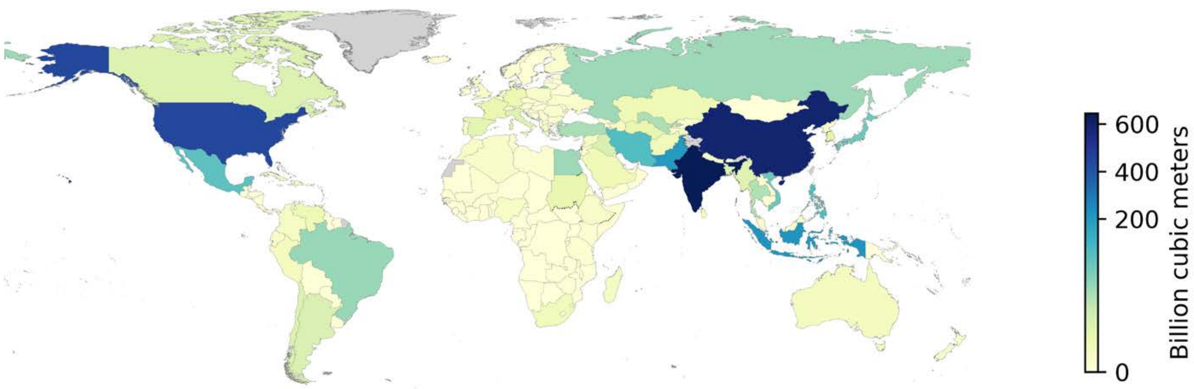
Total Freshwater Withdrawal (TFWW)

TFWW is the volume of freshwater extracted from a country's sources (rivers, lakes, aquifers) for its agriculture, industries, and services. It is calculated as follows:

Total freshwater withdrawal = [Total water withdrawal] - [Desalinated water produced] - [Direct use of treated municipal wastewater] - [Direct use of agricultural drainage water]

There is considerable variation in TFWW levels across the world. This depends on the population size, the importance of a country's agricultural or industrial sector, and climatic conditions. The most significant total freshwater withdrawals occur in China, India, and the United States of America (Figure 11).

Figure 11. Total freshwater withdrawal



Source: Authors' own elaboration, based on data from AQUASTAT (2022c) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

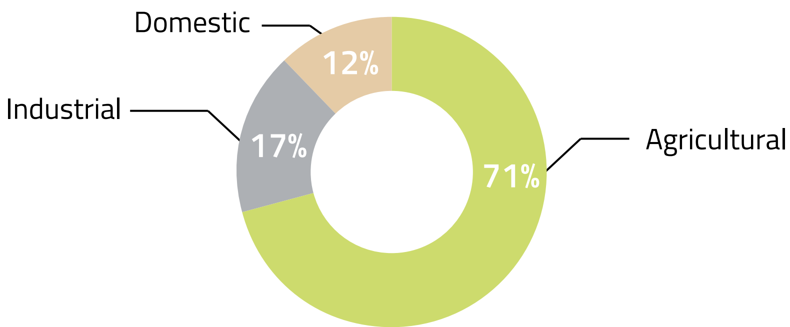
Types of freshwater withdrawal

AQUASTAT collects information on types of freshwater use and assigns them to three main categories, namely agricultural, industrial and municipal withdrawals so that the total withdrawal is equal to:

[withdrawals for agriculture] + [withdrawals for industry] + [withdrawals for municipal/domestic uses]

Globally, countries use over 71 percent of freshwater withdrawals for agriculture, but this share varies significantly by country (Figure 12). Agricultural water withdrawal (Annual quantity of self-supplied water withdrawn for irrigation, livestock and aquaculture purposes) can include water from primary renewable and secondary freshwater resources, as well as water from over-abstraction of renewable groundwater or withdrawal from fossil groundwater, direct use of agricultural drainage water, direct use of (treated) wastewater, and desalinated water. Water for the dairy and meat industries and industrial processing of harvested agricultural products is included under industrial water withdrawal (AQUASTAT 2022b, 2022c, 2022d, 2022e).

Figure 12. Global average share of freshwater withdrawal by use



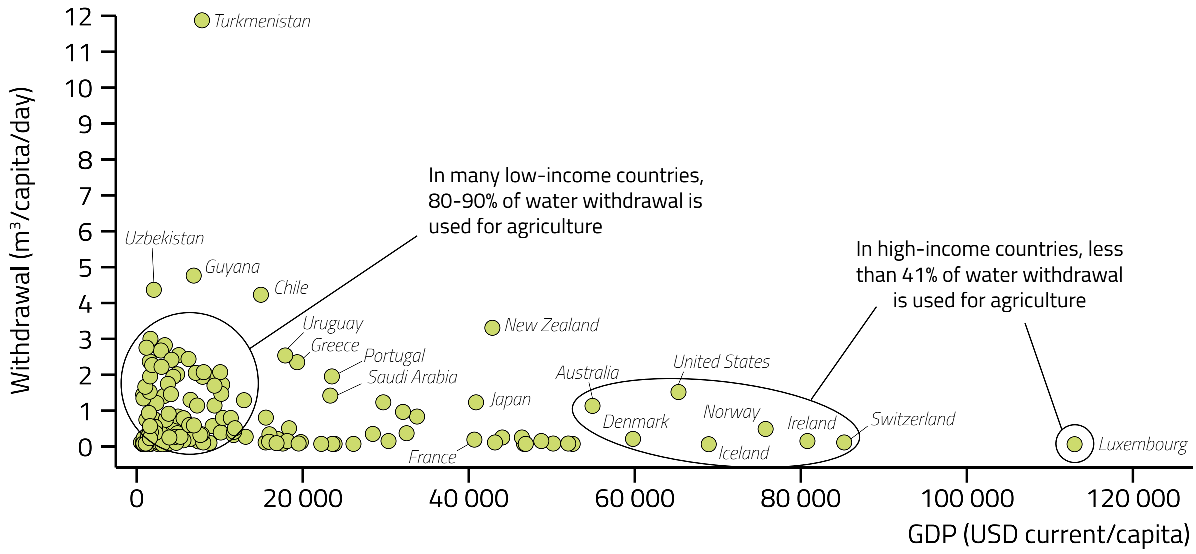
Source: Authors' own elaboration, based on data from AQUASTAT (2022e, 2022f, 2022g).

In many low-income countries, specifically from South America, West–East Africa, and West–South Asia, more than 80–90 percent of withdrawn water is used for agriculture, in particular for irrigation. Across the world, agricultural withdrawals account for a substantial part of total withdrawals in Central Asia, the Near East–Western Asia and Northern Africa. Globally irrigated agriculture represents 20 percent of the total cultivated land and contributes 40 percent of the total food produced worldwide. In high-income countries, however, less than 41 percent of withdrawals are used in agriculture (Figure 13).

Based on AQUASTAT types of water withdrawal, around 17 percent of global water withdrawals are used for industrial purposes, which dominate in high and middle-income countries (Figure 14). Industrial water withdrawal is defined as "annual quantity of self-supplied water withdrawn for industrial uses". It can include water from primary renewable and secondary freshwater resources, as well as water from over-abstraction of renewable groundwater or withdrawal from fossil groundwater, direct use of agricultural drainage water, direct use of (treated) wastewater, and desalinated water.

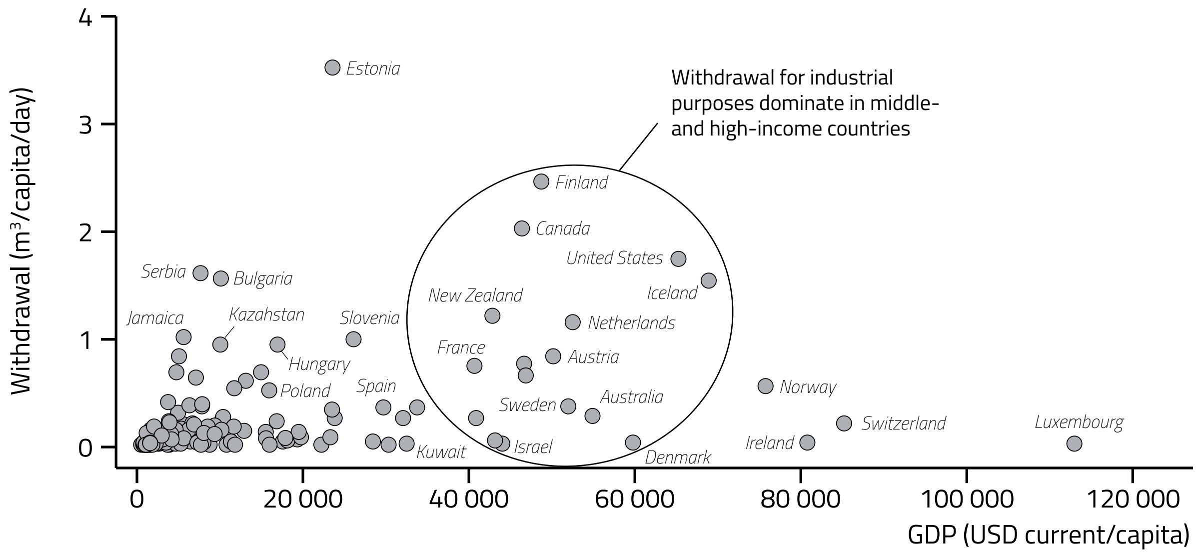
This sector refers to self-supplied industries not connected to the public distribution network. The ratio between net consumption and withdrawal is estimated at less than 5 percent. It includes water for the cooling of thermoelectric and nuclear power plants, but it does not include hydropower. Water withdrawn by industries that are connected to the public supply network is generally included in municipal water withdrawal".

Figure 13. Agricultural water withdrawal vs GDP per capita



Source: Authors' own elaboration, based on data from AQUASTAT (2022e) and World Bank (2022h).

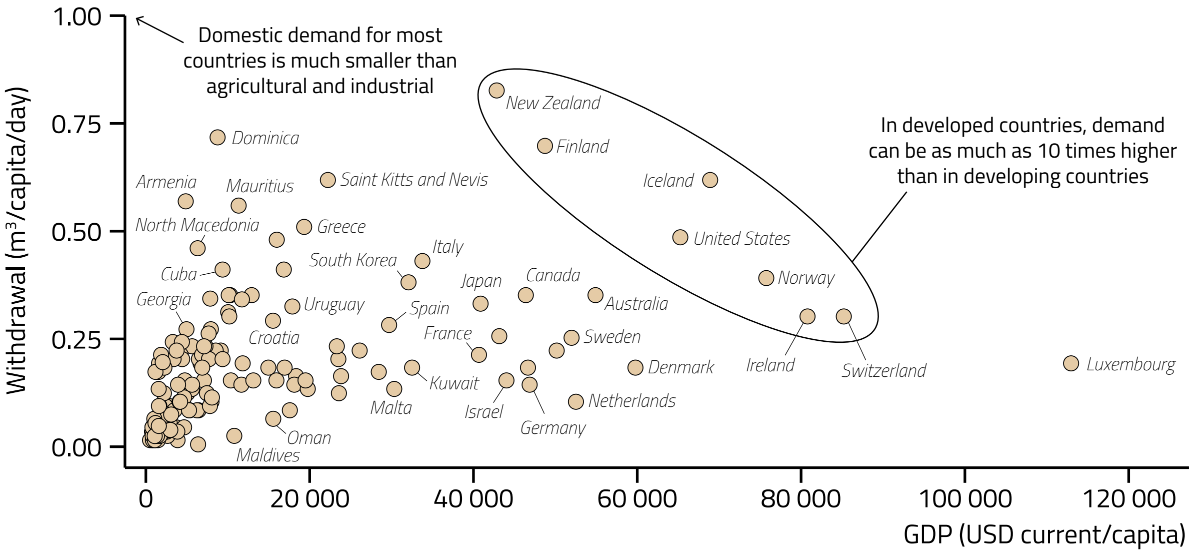
Figure 14. Industrial water withdrawal vs GDP per capita



Source: Authors' own elaboration, based on data from AQUASTAT (2022f) and World Bank (2022h).

Municipal (domestic) water withdrawal is defined as the "annual quantity of water withdrawn primarily for the direct use by the population". It can include water from primary renewable and secondary freshwater resources, as well as water from over-abstraction of renewable groundwater or withdrawal from fossil groundwater, direct use of agricultural drainage water, direct use of (treated) wastewater, and desalinated water. It is usually computed as the total water withdrawn by the public distribution network. It can include that part of the industries and urban agriculture, which is connected to the municipal network. The ratio between the net consumption and the water withdrawn can vary from 5 to 15 percent in urban areas and from 10 to 50 percent in rural areas" (AQUASTAT 2022f, 2022g).

Figure 15. Domestic water withdrawal vs GDP per capita



Source: Authors' own elaboration, based on data from AQUASTAT (2022g) and World Bank (2022h).

Domestic demands for most countries are much smaller than agricultural and industrial applications. Globally, only 12 percent of withdrawals are used for domestic purposes. UNESCO estimates that public water withdrawal in developing countries in Africa, Asia and Latin America represents just 0.05 – 0.1 m^3/person/day. This figure is even lower in the regions with insufficient water resources 0.020 – 0.060 m^3/person/day. In the developed world, however, people consume about 10 times more water daily than those in developing countries (Figure 15).

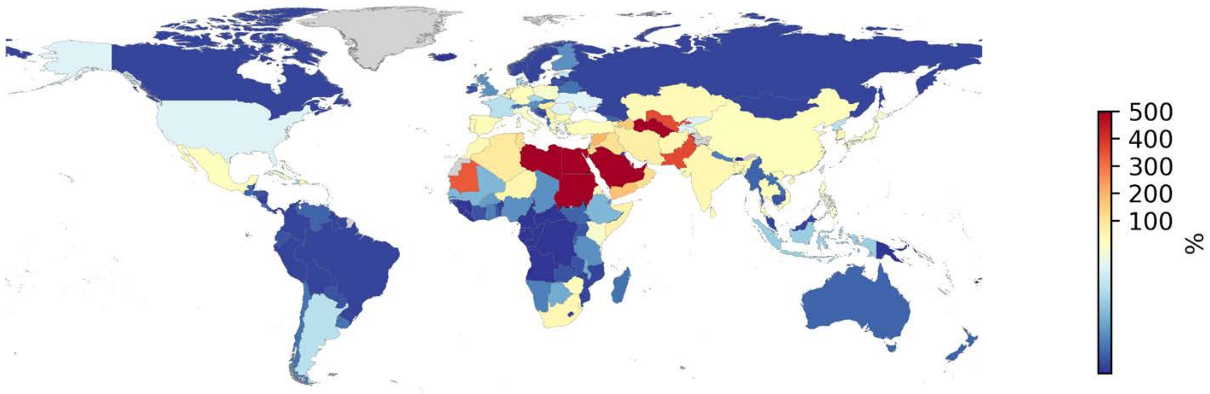
Due to the accelerated pace of population growth and the increase in the amount of water a single person uses, the global deficit in water resources is expected to rise. Therefore, developing countries' ability to provide more water for domestic, agricultural, industrial, and environmental purposes will depend on better management of water resources and more intersectoral planning and integration.

Water stress

As global water demand increases, water stress and the risk of water scarcity are now common concerns, especially in drylands with lower water resources and/or larger population pressures. Water stress is estimated as the ratio of freshwater withdrawals to renewable freshwater resources. This indicator does not directly insinuate that a country has water shortages but gives an indication of how close it may be to exceeding a water basin's renewable resources (Figure 16). If water withdrawals exceed available resources, a country is either extracting beyond the rate at which aquifers can be replenished, using non-renewable groundwater resources, or has high levels of desalination water generation (AQUASTAT 2022d).

Several countries across the Near East, North Africa and South Asia face extremely high levels of water stress. For example, Egypt, Iraq, Mauritania, Oman, Pakistan, Qatar, Saudi Arabia, the Sudan, Syria, Tunisia, Turkmenistan, United Arab Emirates, Uzbekistan, and Yemen have withdrawal volumes largely exceeding 100 percent of internal renewable resources. Although external renewable resources were not accounted for, high water stress values indicate that some countries may be producing water from desalination, using their fossil aquifers, or relying on external renewable freshwater resources, making them vulnerable to dams and water diversions.

Figure 16. Water stress - TFWW to IRWR ratio



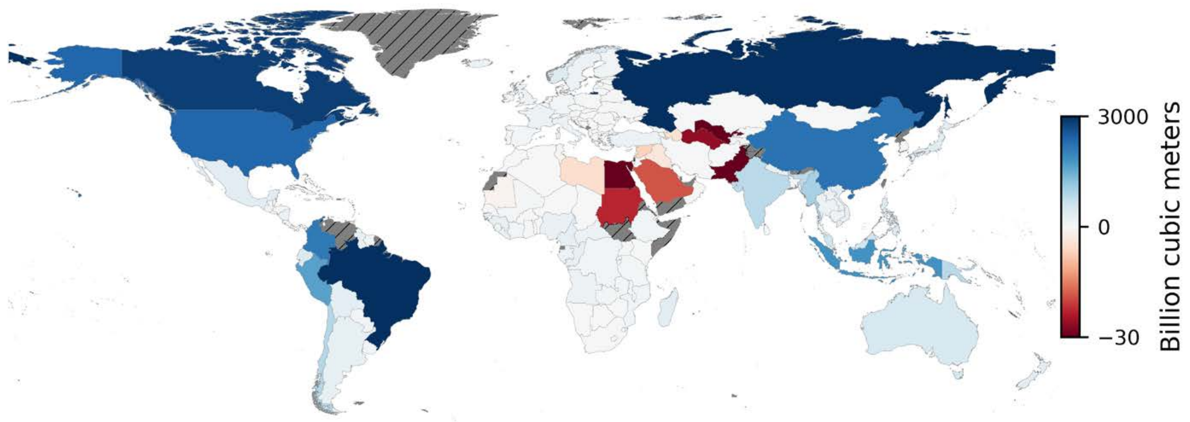
Source: Authors' own elaboration, based on data from AQUASTAT (2022d) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Reserve/Deficit

Difference between Total Internal Renewable Water Resources (IRWR) and Total Freshwater Withdrawal (TFWW)

IRWR – TFWW is the volume of water available after extraction from a country's internal renewable sources (rivers, lakes, and aquifers) for its agriculture, industries, and services. While some countries have an abundant freshwater supply, others do not have as much. A third of countries have IRWR and TFWW differences above 100 billion m^3, benefiting from rich freshwater resources within local river basins. However, in 37 of 176 countries this surplus is less than 10 billion m^3 and in further 20, water demand exceeds availability. These are countries in the Near East, North Africa and South Asia where a low water supply, puts population livelihood at dangerous risk from water scarcity. This situation is forecasted to worsen due to climate change, population growth, and increases in water consumption per person.

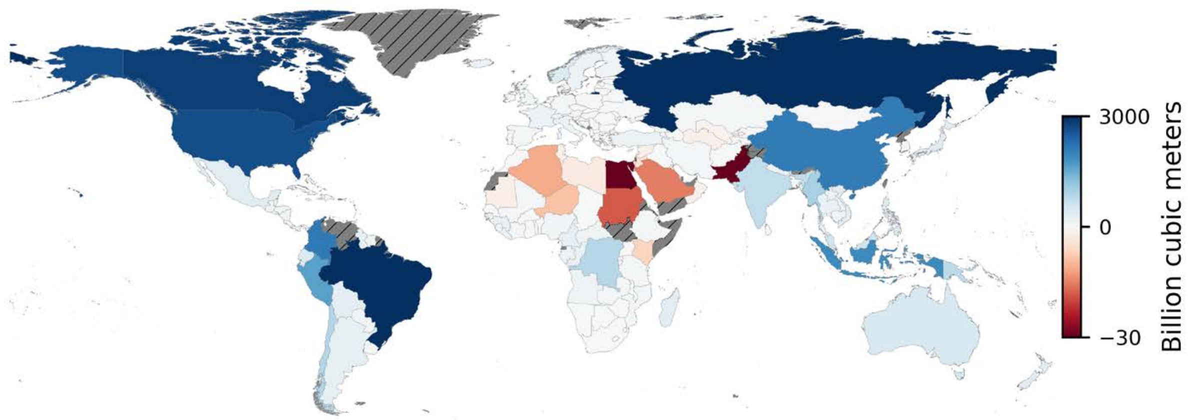
Figure 17. Water reserve/deficit: reserves (TFWW) minus resources (IRWR)



Source: Authors' own elaboration, based on data from AQUASTAT (2022b, 2022c) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Both water stress and the resource/deficit as a difference between availability and current demand, as indicators of water security, have some limitations, as they do not consider the size of the population and the level of withdrawal per capita (for their total food, potable water, and energy needs). TFWW levels in cubic meters per person per day are shown in Figure 4. These values vary between 0.02 and 12.66 cubic meters per person per day equivalent, with the global average at 1.45 cubic meters per capita per day, indicating that water security heavily depends on the equivalent amount of water withdrawn per capita per day in each country. For that reason, if we look again at the difference between water availability and demand as a water security indicator per country, by recalculating TFWW (new TFWW calculated by multiplying the population of the country by the global average of the Total Freshwater Withdrawal per capita), the results are shown in Figure 18.

Figure 18. Water reserve/deficit, adjusted



Source: Authors' own elaboration, based on data from AQUASTAT (2022b, 2022c) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Reserve/Deficit adjusted

Difference between total Internal Renewable Water Resources (IRWR) and Total Freshwater Withdrawal (TFWW) based on global average consumption

IRWR-TFWWadj is the volume of water available after extraction from a country's internal renewable sources (rivers, lakes, and aquifers) for its agriculture, industries, and services. It is calculated as:

IRWR – [Global Mean Consumption x Population]

After changing consumption (Figure 18) in line with the global average, the list of countries where water demand exceeds availability (in red) increased to 28 (from 20) and the group of countries with a resource surplus of about 100 billion m^3 reduced to 50 (from 52), with Ethiopia and Mozambique shifting to a more fragile status. It is also important to note that increased daily water consumption could significantly affect densely populated Bangladesh and Nigeria. Figure 18 suggests that renewable water resources are scares in many countries in Africa, and West–South Asia, as their total internal freshwater resources are not sufficient to meet even modest average consumption levels for domestic, agricultural, and industrial purposes combined.

3.2. Energy

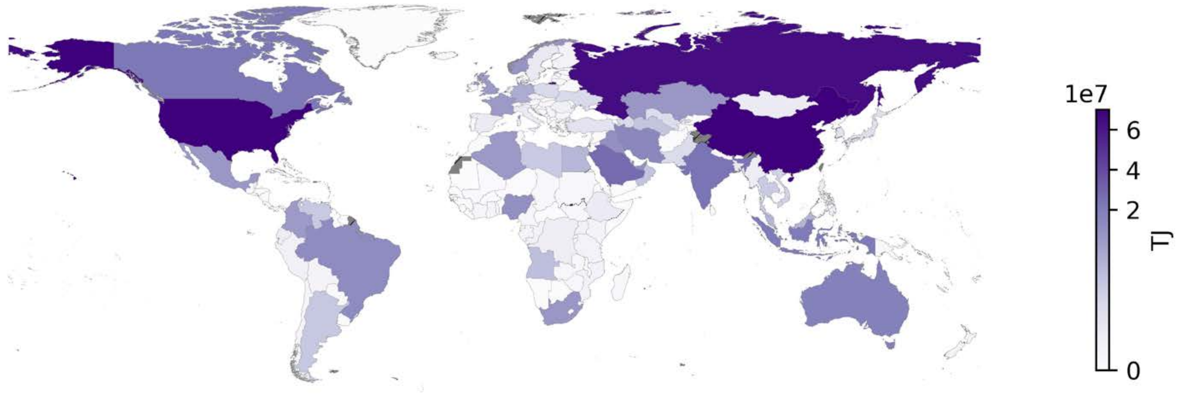
The provision of adequate and reliable energy is an essential element of sustainable development. Energy is vital for eradicating poverty, improving human welfare, and raising living standards.

Availability

Primary production

Primary production is defined as the capture or extraction of fuels or energy from natural energy flows, the biosphere, and natural reserves of fossil fuels within the national territory in a form suitable for use. Primary energy is the energy as it is available as a resource, for instance, the coal; the uranium; or the barrels of oil. The conversion of primary to secondary energy can lead to significant waste, which is particularly notable for fossil fuels (UNSD Energy Statistics, 2022).

Figure 19. Energy primary production



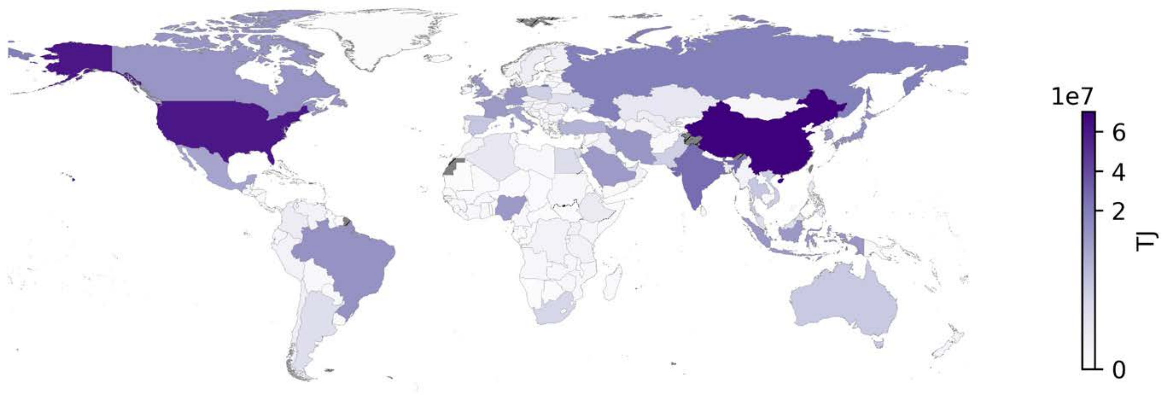
Source: Authors' own elaboration, based on data from UNSD Energy Statistics (2022) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Demand

Final energy consumption

Final energy consumption refers to the consumption of primary and secondary energy by manufacturing, construction, and non-fuel mining, by transport, and by others (agriculture, forestry and fishing, commerce and public services, households, and other consumers) (UNSD Energy Statistics, 2022). Brazil, Canada, China, Germany, India, Japan, the Russian Federation, and the United States of America are the top ten energy consumers in the world. Both China and the United States of America are leaders in global primary energy production and consumption. In contrast, most African countries (except Algeria, Egypt, Libya, Nigeria, and South Africa) report some of the lowest production and consumption annual values. When considering energy consumption per person, however, the list of leaders changes. The top-ten consumers are dominated by prosperous Canada, Finland, Iceland, Luxembourg, Oman, Norway, Saudi Arabia, United Arab Emirates, and United States of America. There is a strong correlation between energy consumption per person and individual wealth (Figure 21). An average citizen of high-income countries consumes up to ten times more energy than a citizen of low-income countries.

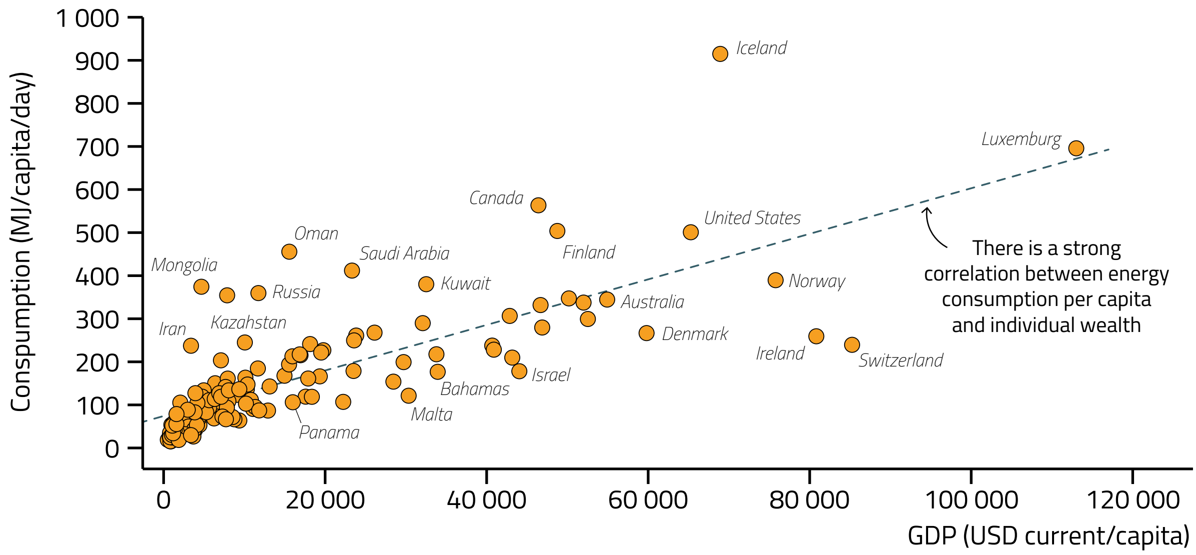
Figure 20. Energy total final consumption



Source: Authors' own elaboration, based on data from UNSD Energy Statistics (2022) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Today, governments in developed countries are increasingly aware of the need to better use energy resources, but reducing energy consumption in some parts of the world is a challenging process. Growth in energy consumption is closely linked not only to the growth in the industry, motorized transport, and urban areas – but also to climatic, geographical, and economic factors. Thus, Iceland, with a population of less than half a million inhabitants, consumes by far the most energy per person in the world. Canada, Norway, Qatar, and the United States of America also rank among the highest consumption rates.

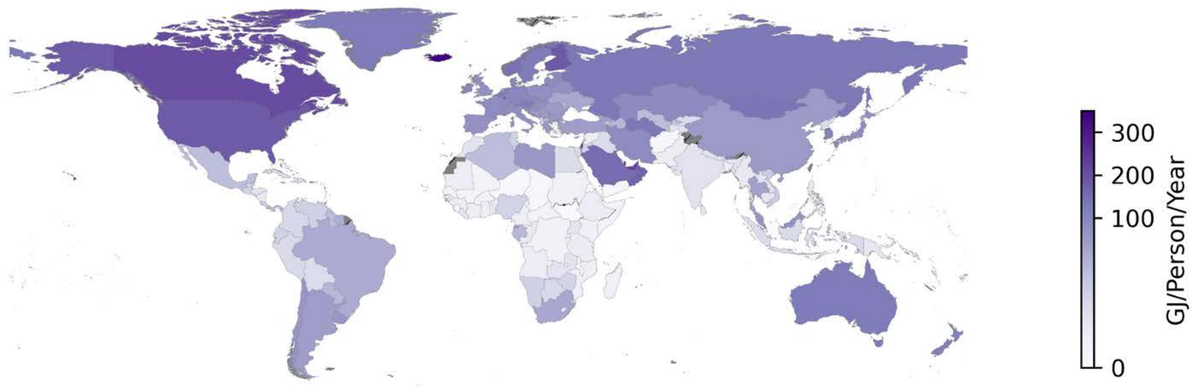
Figure 21. Energy consumption per capita vs GDP per capita



Source: Authors' own elaboration, based on data from UNSD Energy Statistics (2022) and World Bank (2022h).

Figure 22 shows differences in per capita energy use, which is inclusive of all dimensions of energy (electricity plus transport and heating). World energy consumption differs significantly, and for some low-income countries, the figures are so low that they are hardly registered, as beyond burning some solid fuels for cooking, people consume barely any energy at all. Increasing access to affordable energy in these countries is indispensable.

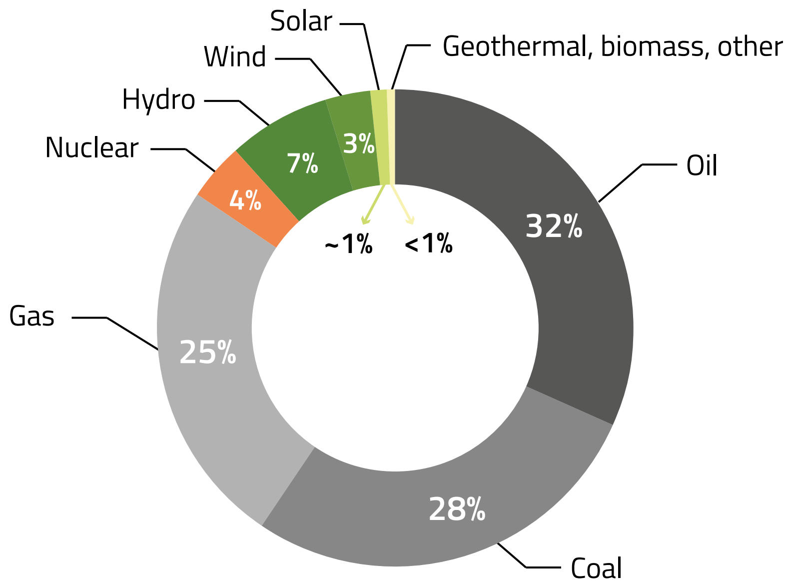
Figure 22. Energy consumption per capita



Source: Authors' own elaboration, based on data from UNSD Energy Statistics (2022) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Globally, the largest amount of energy comes from oil, followed by coal, gas, and then hydroelectric power, with around 80 percent produced from fossil fuels. In 2019, only 16 percent of global primary energy came from low-carbon sources (the sum of nuclear energy and renewables – which includes hydropower, wind, solar, bioenergy, geothermal, wave and tidal (Figure 23). Here traditional biofuels are not included).

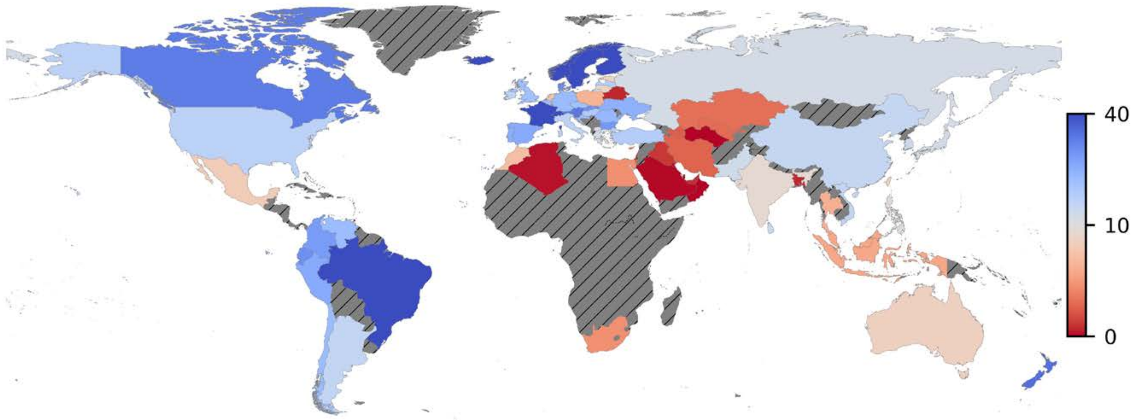
Figure 23. Primary energy consumption by source



Source: Authors' own elaboration, based on data from IEA (2020).

At the individual country level, however, the role of low-carbon and renewable sources in the energy mix significantly differs. For instance, Iceland gets over 2/3 of its energy from low-carbon sources – the highest in the world. Half of this is hydropower, followed by geothermal energy (24 percent). Sweden (69 percent), Norway (66 percent), Switzerland (49 percent), France (49 percent), Brazil (46 percent) and Finland (40 percent)

Figure 24. Low-carbon energy consumption



Source: Authors' own elaboration, based on data from BP (2021) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

also get significant amounts from nuclear or renewable sources, whereas many of the world's oil producing countries – Saudi Arabia, Kuwait and Oman – get less than 1 percent from low-carbon sources. Among the largest emerging economies, South Africa produces only 5 percent from low-carbon sources; India – 9 percent; and China – 15 percent (Figure 24).

When they transition to low-carbon energy resources, poorer countries face bigger challenges: they must grow their economies, provide sufficient access to energy and health care, and alleviate poverty while avoiding the carbon-intensive paths that today's rich countries have taken. Therefore, they need clean energy to be affordable, undercutting fossil fuel alternatives (Ritchie, Roser and Rosado, 2020).

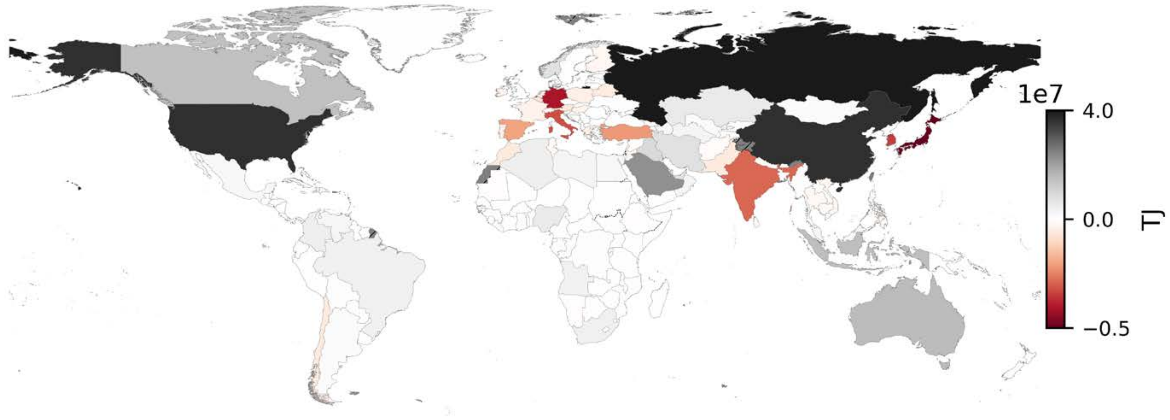
Reserve/Deficit

Difference between Primary Energy Production and Total Final Consumption

These are values of energy reserve/deficit estimated by extracting total final energy consumption from primary production. Of the 215 countries and territories provided by the UNSD Energy Balances, 132 experience an energy deficit. Austria, Belgium, Germany, India, Italy, Japan, Spain, the Republic of Korea, and Türkiye have the highest deficits per country, consuming on average 2–3 times more energy than produce (Figure 25). Japan has a large population and a relatively high per capita consumption. The country imports 89 percent of energy and has a per capita energy consumption of 83 GJ/capita versus the global average of 54 GJ/capita (IEA, 2020).

On the other side of the scale are big primary energy producers: Australia, Canada, China, Indonesia, Iraq, Qatar, the Russian Federation, Saudi Arabia, and the United States of America. It is important to note, however, that most of their current energy resources are fossil fuels. The difference between energy availability and demand as calculated above does not take into account the size of the population and global equality in energy consumption per capita.

Figure 25. Energy reserves/deficit



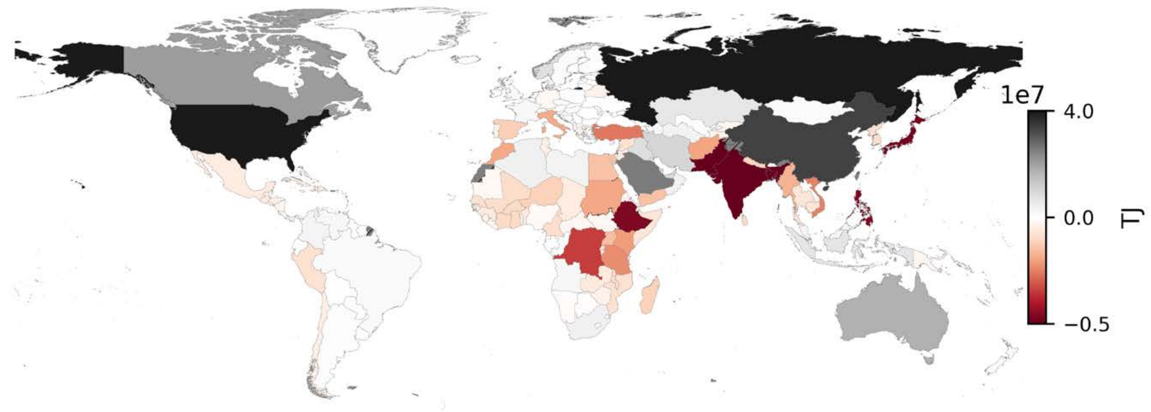
Source: Authors' own elaboration, based on data from UNSD Energy Statistics (2022) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Reserve/Deficit adjusted

Difference between Primary Energy Production and Total Final Consumption based on global average consumption

Total Final Consumption values were adjusted using the global average per capita energy consumption (54 GJ/cap/year) multiplied by the population of the countries. This scenario provided insights into the ability of countries to support demand if everyone consumed the same amount of energy and an initial sense of the threshold for sustainable energy consumption (Figure 26). These new energy consumption figures result in a deficit in 154 out of 195 countries/territories, with the largest deficits in Bangladesh, Ethiopia, India, Pakistan, Japan, Philippines, Türkiye, the United Republic of Tanzania and Vietnam. India looks most fragile, as it has a large population, whose current per capita energy consumption of 19 GJ/capita is 65 percent lower than the global average. China, the Russian Federation, and the United States of America remain at the top of the list of countries with significant energy production.

Figure 26. Energy reserves/deficit, adjusted



Source: Authors' own elaboration, based on data from UNSD (2022b) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

3.3. Food

Agriculture is one of the most significant sectors in the world, as agricultural productivity is important not only for a country's balance of trade but also for the security and health of its population. There are numerous ways to assess agricultural output, including sheer tonnage and the dollar value of the commodities produced. However, commodities critical to the food supply of less developed regions often have a lower dollar value than those of developed, high-income countries. For this reason, the total agricultural production and consumption are calculated from the list of commodities converted into kcal equivalents using FAO coefficients.

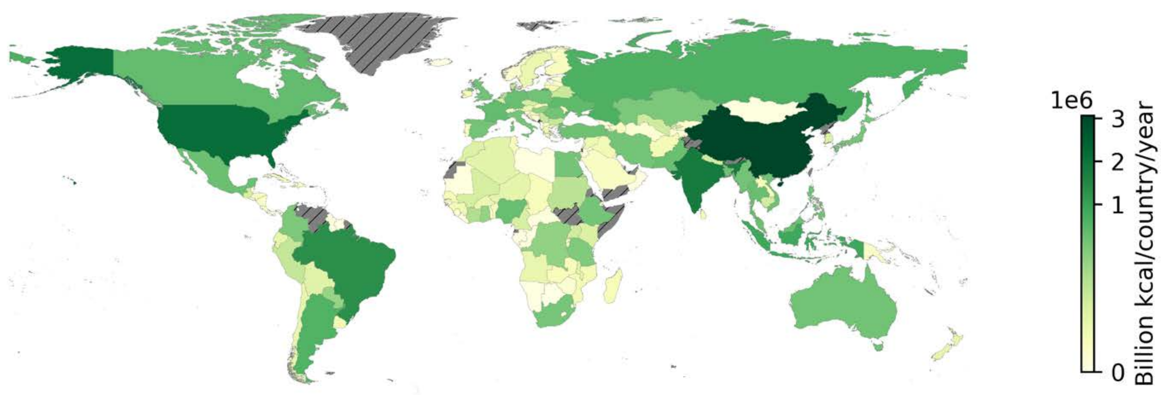
Availability

Food Production

FAO Statistics Divisions present Food Balances Production indicator which relates to the total domestic production within and outside the agricultural sector. Unless otherwise indicated, production is reported at the farm level for crop and livestock products, and in terms of live weight for fish products. All data shown relate to total meat production from both commercial and farm slaughter (Figure 27). Some key factors that influence the level of food production in a country include land area, size of the population, climate, and the quality of agricultural infrastructure and technology. FAO Statistics Divisions Production indicator values mapped across 166 countries (Figure 27) show that China is the largest food producer in the world, followed by the United States of America, India and Brazil. For China and India with their large population, producing enough to feed the nation from internal resources is a priority. China has a large territory and one of the world's greatest pools of agricultural labour. It produces a quarter of the global grain output and leads the planet in the production of cereals, fruit, vegetables, meat, poultry, eggs, fishery products and cotton. India is the largest producer of milk, pulses, and jute in the world. It is also the world's second-largest producer of rice, wheat, fruit, vegetables, sugarcane, cotton, and groundnuts.

The United States of America, despite employing a small fraction of the agricultural workforce of China or India, is ranked in the first three world's major food producers. Corn, soybeans, dairy, beef, and poultry are the top five United States of America agricultural commodities by value. Brazil was the world's fourth-ranked agricultural producer in 2019 and is the top global exporter of soybeans, raw sugar, frozen beef, and poultry.

Figure 27. Food production

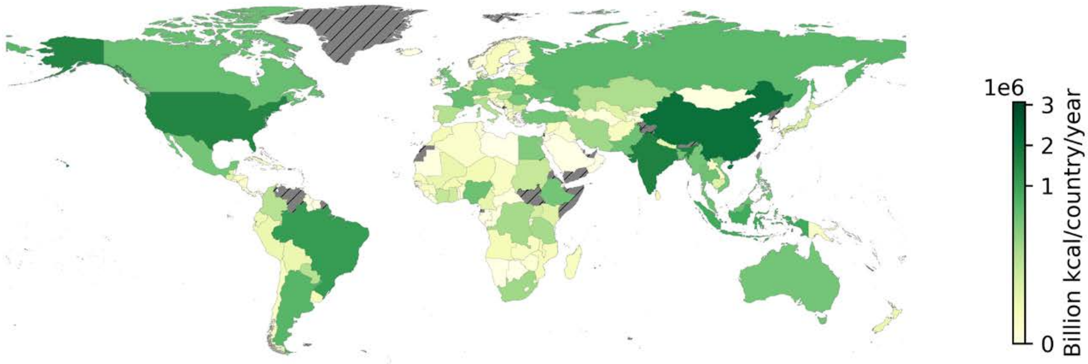


Source: Authors' own elaboration, based on data from FAOSTAT (2022h) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Food Production – Feed–Seed–Losses

Food production values need to consider feed, seed, and storage/transportation losses. Here, these quantities were extracted from the values of production (Figure 28). FAO Statistics Divisions Food Balances Feed indicator data refer to the quantity of a commodity available for feeding livestock and poultry during the reference period, whether domestically produced or imported. The indicator data include the amount of a commodity set aside for sowing or planting (or generally for reproduction purposes, such as sugar cane planted, potatoes for seed, eggs for hatching and fish for bait, whether domestically produced or imported) during the reference period.

Figure 28. Food production after extracting feed, seed, and losses



Source: Authors' own elaboration, based on data from FAOSTAT (2022b) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

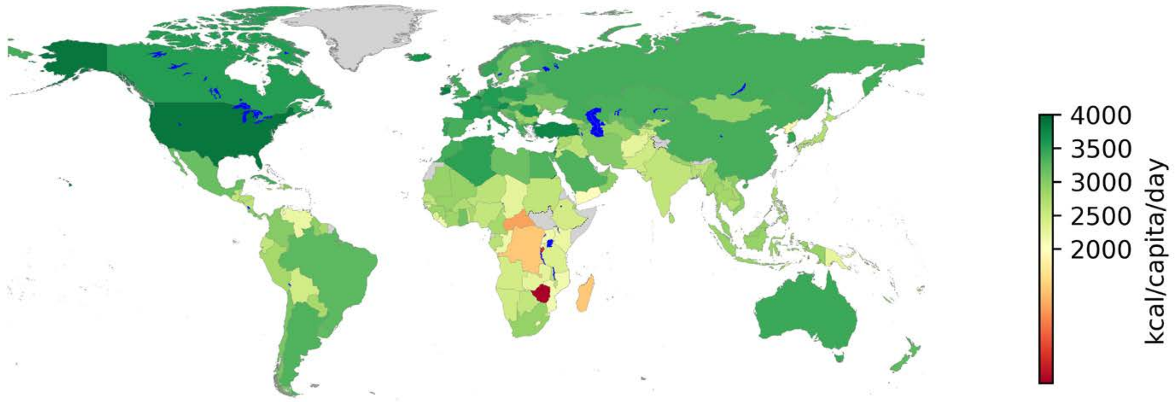
FAO Statistics Divisions Losses indicator represents the amount of a commodity lost during the year by waste at all stages between the level at which production is recorded and the household, i.e. storage and transport. Losses occurring before and during harvest are excluded. Waste from edible and inedible parts of household goods is also excluded. In countries with hot, humid climates, difficult transport, and inadequate storage or processing facilities, distribution waste tends to be considerable. This applies to the more perishable foods, especially those that must be transported or stored in a tropical climate for a long time. After extracting feed, seed and losses, Argentina, Brazil, China, India, Indonesia, and the United States of America remain global leaders in total food production. Israel, Jordan, Kuwait, Libya, and Saudi Arabia result in negative values, meaning that the total amount of feed, seed, and losses there exceed domestic production.

Demand

Food supply

FAO Statistics Divisions Food Supply indicator (caloric supply) refers to the total amount of human food available during the reference period. According to FAO definition, data include the commodity in question, as well as any commodity derived therefrom due to further processing (Figure 29). Food from maize, for example, comprises the amount of maize, maize meal and any other products derived therefrom available for human consumption. Food from milk relates to the amounts of milk as such, as well as the fresh milk equivalent of dairy products.

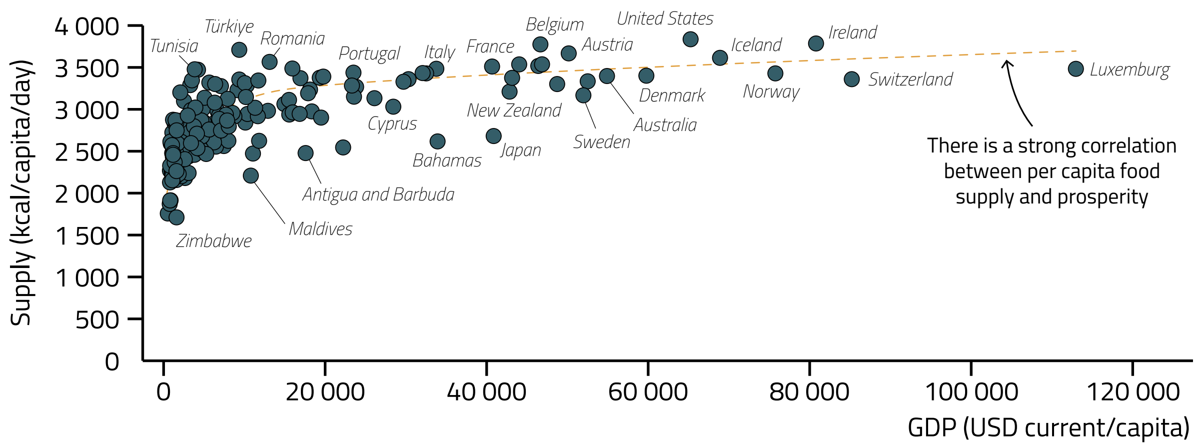
Figure 29. Food supply



Source: Authors' own elaboration, based on data from FAOSTAT (2022i) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

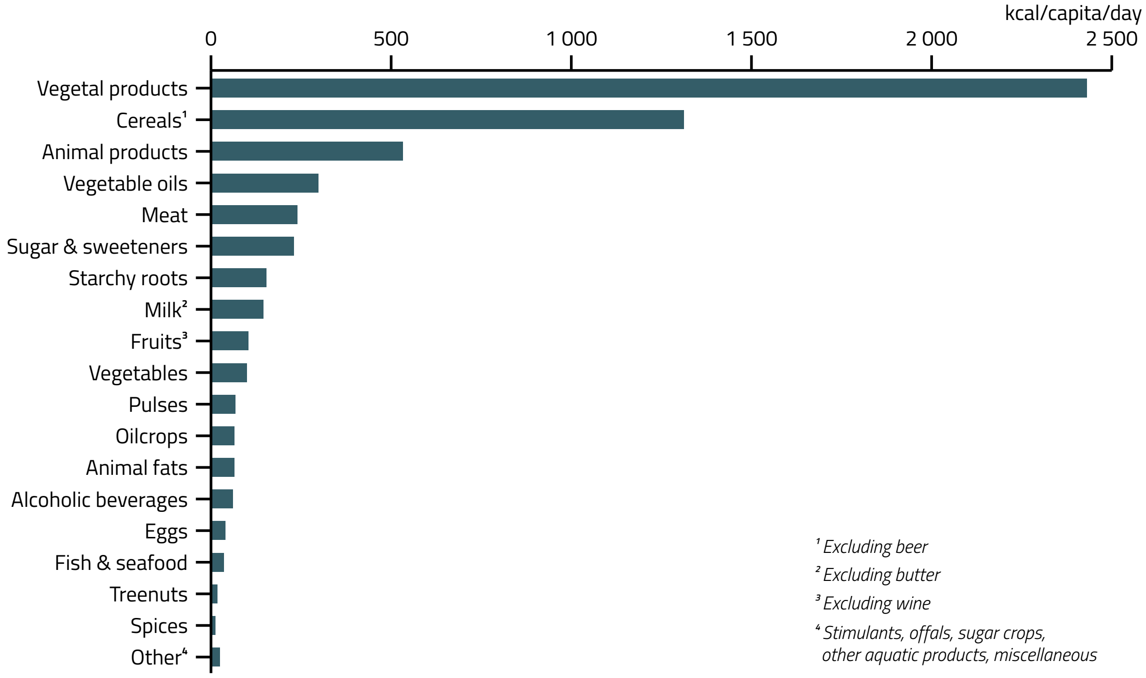
Globally, food supply figures vary from 1 707 kcal in Zimbabwe to over 3 800 kcal in Belgium, Ireland, and the United States of America. There is a strong correlation between per capita food supplies and prosperity. Higher-income regions tend to have higher levels of food supply relative to poorer regions (Figure 30). For example, in low middle-income India and upper-middle-income Brazil, daily food supply figures are below 3 000 kcal/person/day, even though these are global leading food-producing countries. The average human diet consists of mostly vegetables and derived products, followed by cereals and animal products. Both cereal and vegetal products require arable land and abundant water resources (Figure 31).

Figure 30. Food supply vs GDP per capita



Source: Authors' own elaboration, based on data from FAOSTAT (2022i) and World Bank (2022h).

Figure 31. Global food balance



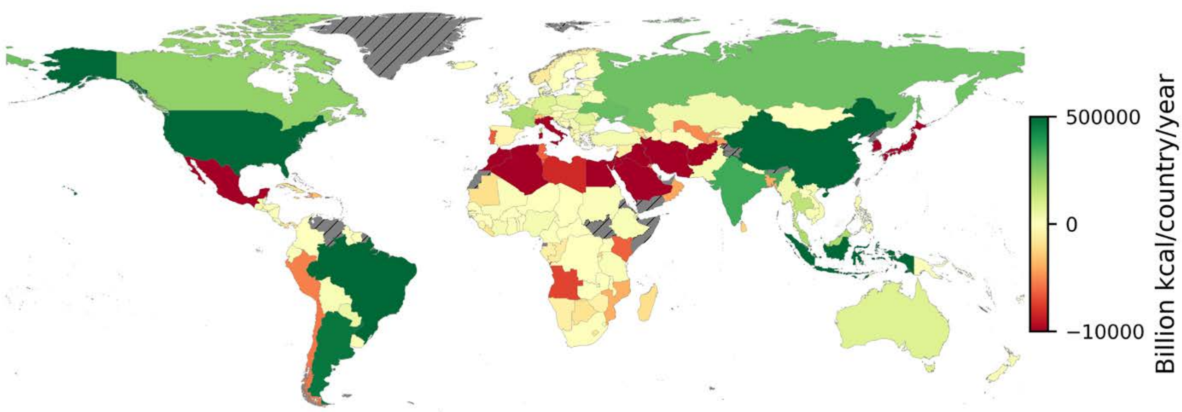
Source: Authors' own elaboration, based on data from FAOSTAT (2022b).

Reserve/Deficit

Difference between production and consumption

Most countries in the world, in theory, can meet their population demand even after extracting feed, seeds and losses, with larger food reserves in Brazil, China, India, the Russian Federation, and the United States of America. Currently, the deficit of food resources is observed in Afghanistan, Algeria, Angola, Bangladesh, Arabian Peninsula, Dominican Republic, Egypt, Haiti, Iran, Kenya, Libya, Madagascar, Mexico, Morocco, Mozambique, Peru, Sri Lanka, Tajikistan, Tunisia, and Uzbekistan. Italy, Japan, Portugal, and the Republic of Korea also do not produce enough to sustain their current population demands and must heavily rely on food imports (Figure 32).

Figure 32. Food reserve/deficit



Source: Authors' own elaboration, based on data from FAOSTAT (2022b) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

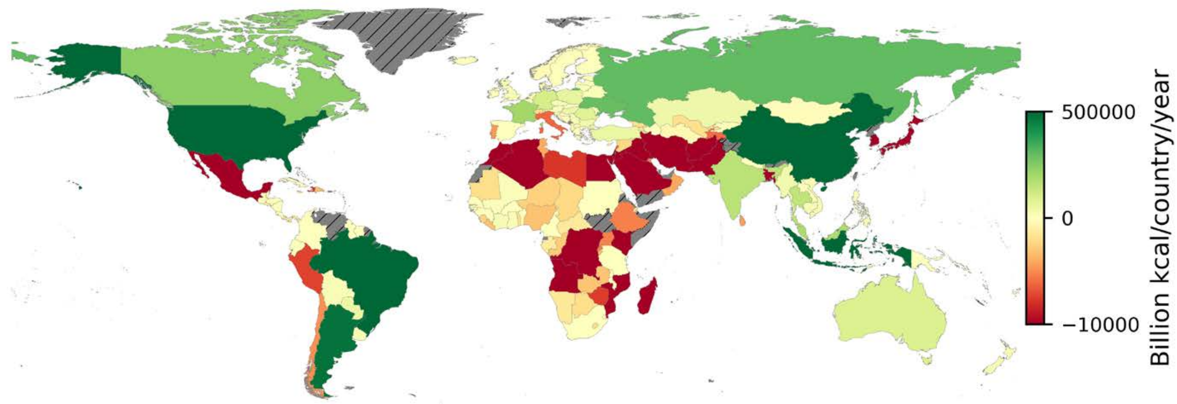
Reserve/Deficit adjusted

Difference between production and consumption in line with a global average consumption

Adjusting population consumption figures to match the global average demand increases the list of countries with food undersupply, covering most of Africa except Cameroon, Côte d'Ivoire, Ghana, Mali, South Africa, the Sudan, and the United Republic of Tanzania (Figure 33).

It can be argued, however, that current food production figures can inform only current food spare capacities, with some countries being able to improve their agricultural sector, producing more food, reducing storage and transportation losses, and boosting their population diet with more sustainable choices. There are also potential risks of land productivity losses associated with intensive farming in important food-producing countries such as Argentina, Brazil, China, the Russian Federation, the United States of America, etc.

Figure 33. Food reserve/deficit, adjusted



Source: Authors' own elaboration, based on data from FAOSTAT (2022b) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

4. WEF nexus integrated score

Water, energy, and food securities per country can be integrated through the different multicriteria nexus methods to support fragility decision making (Mendoza *et al.*, 1999). All MCA approaches begin with the performance matrix – a data set of selected countries and indicators. All countries are examined across water, energy, and food dimensions. Once any dominance analysis is concluded, the next stage is to determine whether trade-offs between variables are acceptable, so that good performance on one criterion can in principle compensate for weaker performance on another.

4.1. Normalization

Prior to MCA calculations, all indicators must be converted into one scale. There are several scaling techniques available (e.g. OECD, 2014). Here, three scaling methods were compared: standard score, min–max normalization, and percentage of the range.

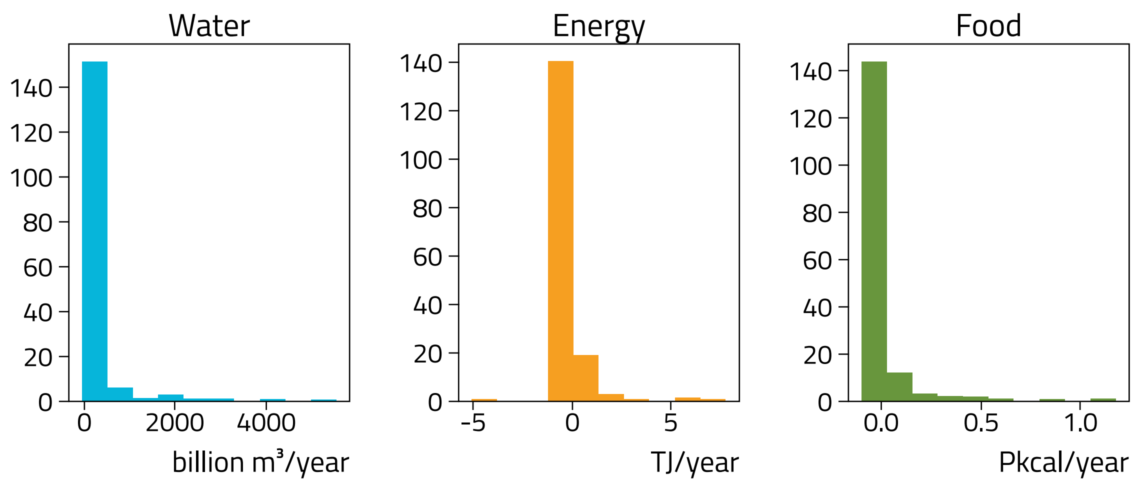
The values of water–energy–food reserve/deficit across the globe vary significantly, so the data are skewed, and there are several outliers (Figure 34). The numerical distances, however, carry meaningful information, and, therefore, no data transformation methods were considered. Thus, the standardization technique, where values are centred around the mean with a unit standard deviation, is potentially less suitable for this analysis. Min–Max method, on the other hand, does not preserve the negative values which inform resource deficit. The proportion of the min–max range approach results in the same fragility ranking order as the min–max data scaling technique but allows negative scores. Hence, data is scaled by dividing values of water, food, and energy spare capacities/deficit by their min–max range.

Table 3. Types of data scaling techniques

Technique	Description
Standardization (or z-scores) $z = (x - \mu) / \sigma$ *x:* original value *μ:* mean *σ:* standard deviation	Standardization is a technique where the values are centred around the mean with a unit standard deviation. This means that the mean of the attribute becomes zero and the resultant distribution has a unit standard deviation.
Min-Max normalization $norm = (x - min(x)) / (max(x) - min(x))$	Normalization is a scaling technique in which values are shifted and rescaled so that they end up ranging between 0 and 1. It is also known as Min-Max scaling.
Min-Max range proportion $P = x/(max(x) - min(x))$	The percentage of the min-max range converts indicators to a common scale by dividing by the range of the indicator values.

Source: Authors' own elaboration.

Figure 34. Water, energy, and food reserve/deficit data



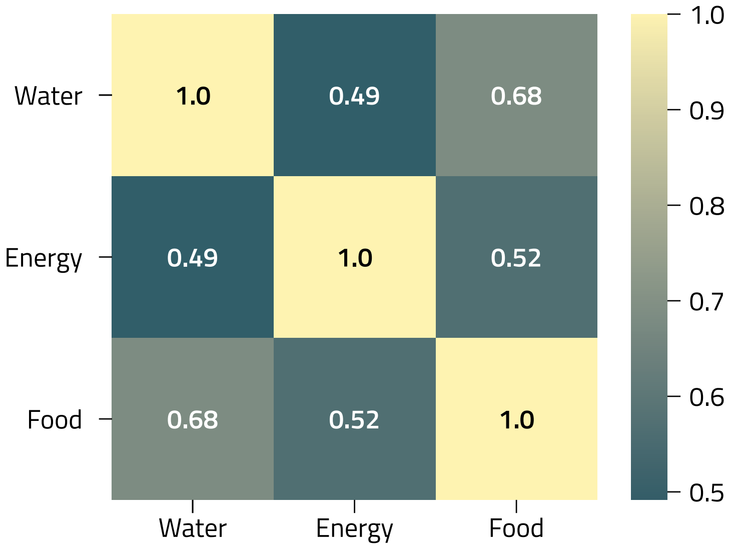
Source: Authors' own elaboration.

4.2. The weighted sum model

The weighted sum model (WSM), also known as the weighted linear combination, or simple additive weighting, is the simplest MCA. Water, energy, and food can be combined into one overall value by multiplying the value score of each indicator by its weight and then adding all those weighted scores together. When assigning weights to indicators, it is important to recognize that water and food reserve/deficit are linearly dependent. Water resources are often extracted to use in agriculture, thus, water shortfalls can inform a food deficit.

Figure 35 shows a strong correlation between food and water (r = 0.72), and a much weaker one between energy and water (r = 0.48), energy and food (r = 0.58). Several scenarios of water, energy, and food weights were considered. Figure 36 presents the results of a model in which food and energy are each twice as expensive as water, abbreviated as 1w2e2f.

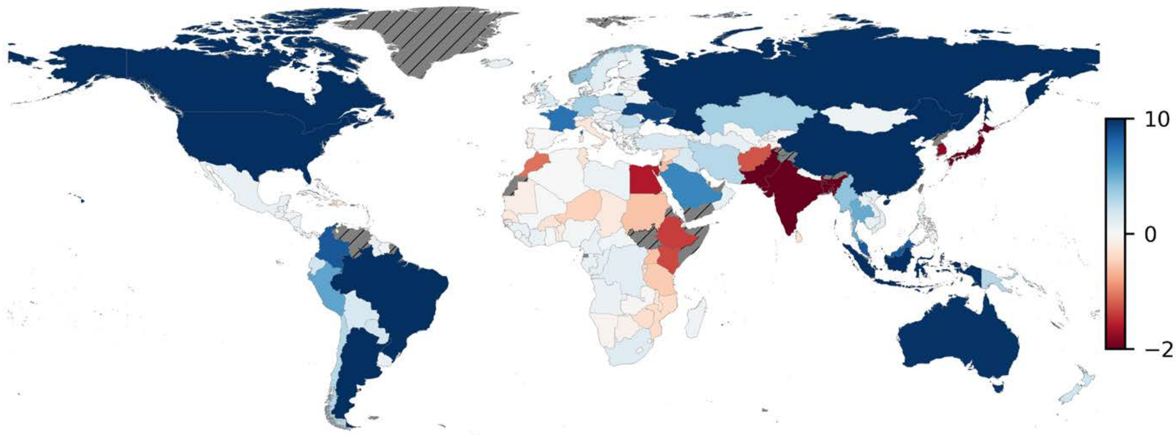
Figure 35. Correlation matrix of water, energy, and food reserve/deficit indicators



Source: Authors' own elaboration.

The WEF nexus map (Figure 36) shows that densely populated Bangladesh, India, and Pakistan, along with Japan and the Republic of Korea, have the highest total deficit of essential water, food, and energy resources. Afghanistan, Burundi, Egypt, Ethiopia, Haiti, Jordan, Kenya, Lebanon, Morocco, Mozambique, Niger, Rwanda, Sri Lanka, the Sudan, Syria, Uganda, the United Republic of Tanzania and Zimbabwe are in the top 25 resource-driven fragile states.

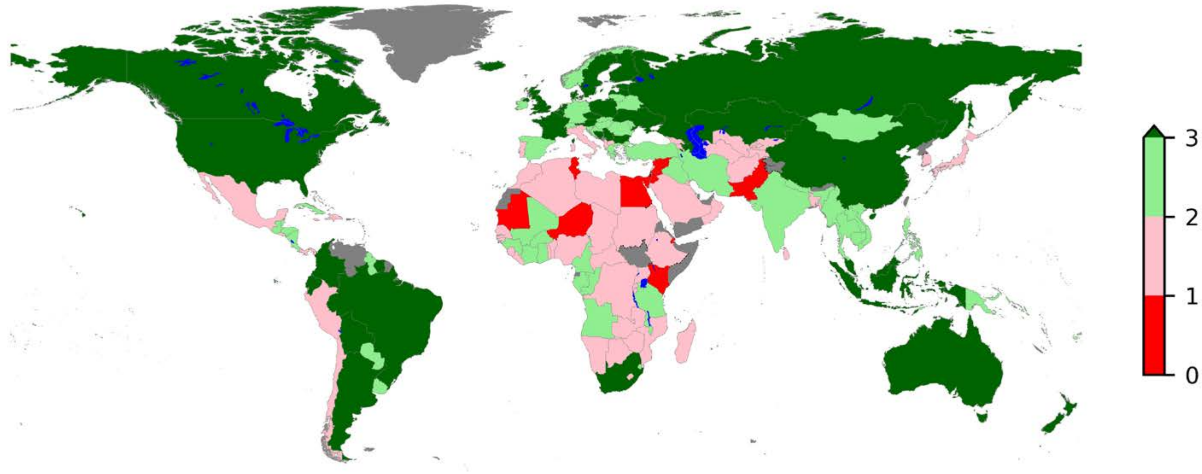
Figure 36. WEF nexus weighted sum model score



Source: Authors' own elaboration, based on data from FAOSTAT (2022b) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Comparing MCA results with the map of water, energy, and food global spare capacities shows that most of the WEF nexus fragile countries (Afghanistan, Arabian Peninsula, Bangladesh, Central Asia, India, Mexico, Pakistan, Peru, as well as Italy, Japan, the Republic of Korea, and most African countries) undersupply more than one resource. That aside, India and the United Republic of Tanzania have the capacity to provide a plethora of water and food to their population (Figure 37).

Figure 37. Water, energy and food resources surplus



Source: Authors' own elaboration, based on data from FAOSTAT (2022b) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

4.3. The pairwise comparison

The pairwise comparison (PC) compares individual countries. It consists of three main steps. The first step requires constructing an indicator comparison matrix, in which each cell represents a numeric difference between two compared countries (Table 4). The second step calculates the average of these differences per country. The third step multiplies indicator averages by indicator weights and combines all indicators into one final score. The final score, therefore, represents the weighted sum of the average relative distances of each country from the rest of the world.

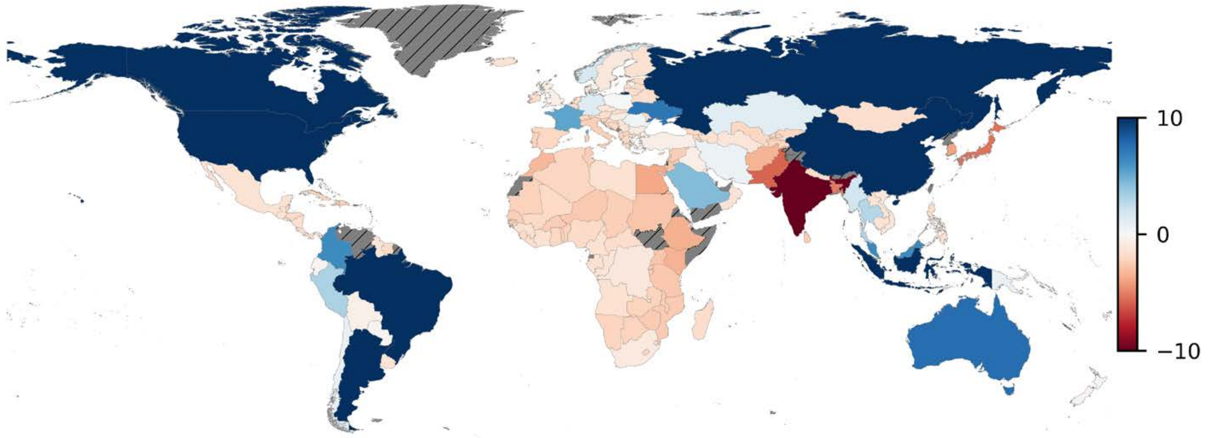
Table 4. Example of the pairwise comparison matrix

Country	C1	C2	C3	C4
C1	1	c1-c2	c1-c3	c1-c4
C2	c2-c1	1	c2-c3	c2-c4
C3	c3-c1	c3-c2	1	c3-c4
C4	c4-c1	c4-c2	c4-c3	1

Source: Authors' own elaboration.

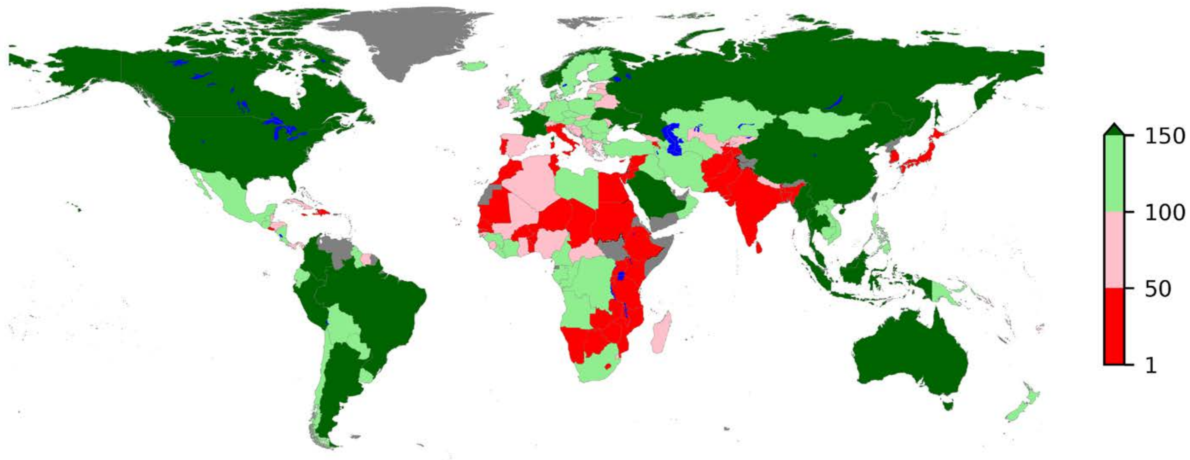
The PC highlights the gaps between countries with a plethora of water, energy, and food resources, and those with undersupply, as well as small spare capacities. As a result, some countries without estimated resource shortfalls (i.e. Finland, Sweden, and Uruguay) result in negative relative scores, while those with at least one resource shortage are in red (Figure 38). The final ranking order, however, is identical between models (Figure 39).

Figure 38. WEF nexus pairwise comparison model



Source: Authors' own elaboration, based on data from FAOSTAT (2022b) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Figure 39. WEF nexus fragility ranking

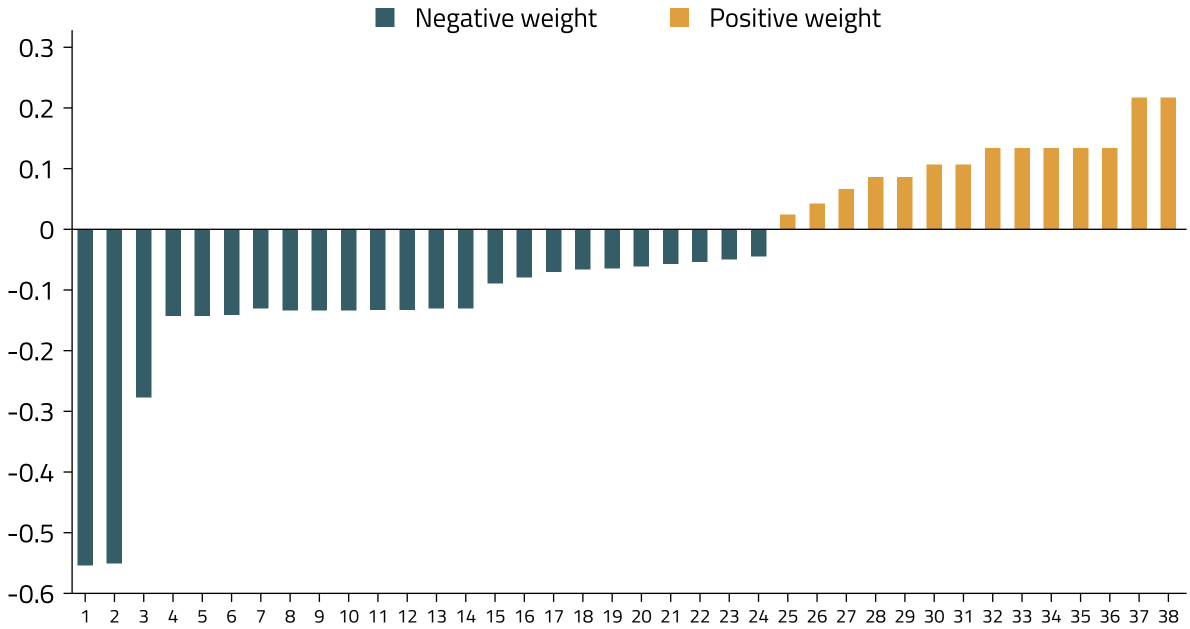


Source: Authors' own elaboration, based on data from FAOSTAT (2022b) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

4.4. Results of MCA of confounding factors

The variables in Table 2 were normalized between the different nations taking into account the maximum and minimum value across all countries. This was done in order to combine indicators within the categories and to guarantee that variables have an identical range between 0 and 1. For variables with a negative correlation to the overall resilience (positive correlation with fragility), the normalized value is then multiplied by -1.

Figure 40. Confounding factors' relative weights



List of confounding factors

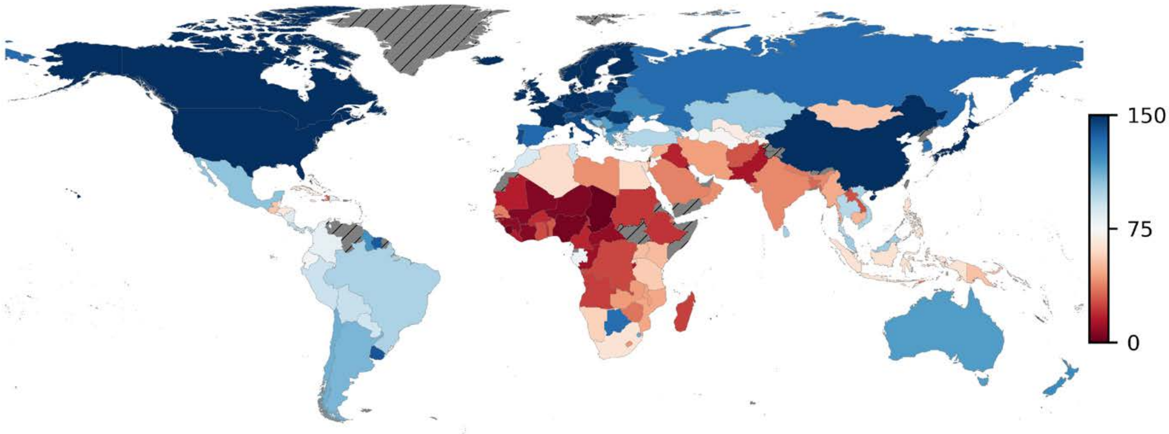
1 - Water pollution
2 - Air pollution
3 - Total natural resources rents
4 - Number of countries required
5 - Nitrogen leaching
6 - Peak flows risk index
7 - Habitat degradation
8 - Agricultural water stress index
9 - Drought intensity change
10 - Crop yield change
11 - Number of hot days
12 - Dryland arid areas ratio
13 - Number of Earths required
14 - Threatened species
15 - Agriculture, forestry and fishing, value
16 - CO_2 emissions 2018
17 - Projection of future IWR change
18 - Water stress index
19 - SPEI
20 - Days with precipitation > 50 mm
21 - Employment agriculture
22 - Ores and metals exports
23 - Fuel exports
24 - Food exports
25 - Insurance and financial services
26 - ICT goods exports
27 - Growing season length
28 - Manufactures exports
29 - Merchandise exports
30 - GDP per capita
31 - ICT service exports
32 - Agricultural land
33 - Forest land
34 - Artificial surfaces
35 - Inland water
36 - Coastal water
37 - Exports of goods and services
38 - High-technology exports

Source: Authors' own elaboration.

The confounding factors are related with each component of the resilience viewed as a dimension. In this way, the confounding factors can be used as a direct guide to policy, as the final score can be decomposed to measure the individual impact of each component and to extend the analysis of country performance. Sub-component indicators were combined within each category by using a weighted mean with weights proportional to the impact level.

The relative weights used in this exercise (Figure 40) were determined from the stakeholder forum questionnaire and workshop (see Section 2.6). Figure 41 shows the aggregated confounding factor score across the world. Most countries in Africa, parts of the Near East, and South Asia are significantly less resilient to the challenges of natural resource-driven fragility than those in North and South America, Europe, and Central and East Asia.

Figure 41. Confounding factors (sum of the economy, technology, environmental management, and climate risk dimensions)



Source: Authors' own elaboration, based on references included in Table 2, and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

5. Fragility map

5.1. Ranking

WEF Nexus model was combined with the confounding factors to create the natural resource-driven fragility ranking (Figure 42). Defining the natural resources and food security conditions enable not only the visualization of global maps of vulnerable areas, particularly those exposed to fragility, but also allows the identification of root causes and, consequently, guides decisions over geographical and thematic areas of intervention.

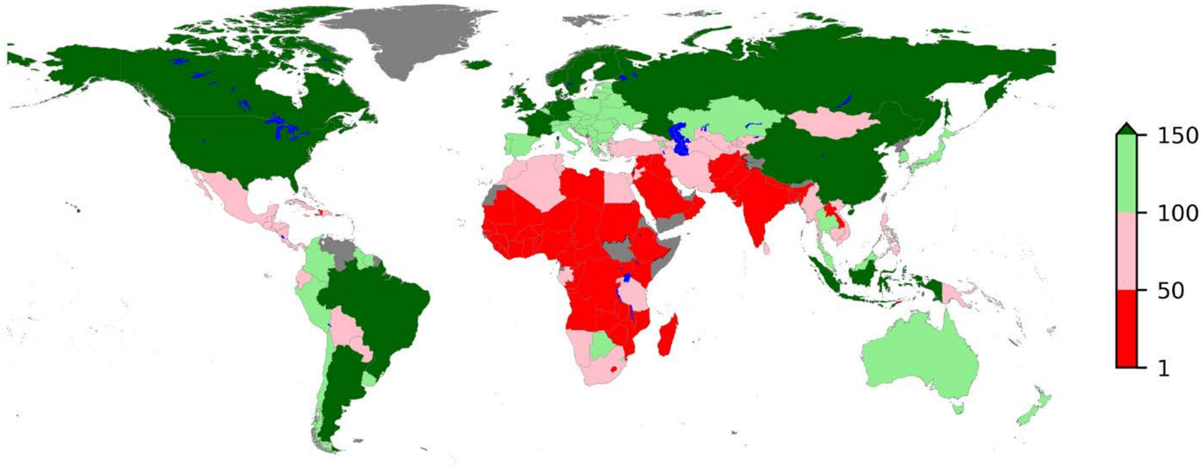
Ultimately, the fragility mapping not only fosters healthier and integrated human/environmental ecosystems but also depicts clear investment opportunities based on scientifically elaborated needs, in support of development efforts. The tool also allows areas and modalities of interventions to be classified, in support of decision-making, from both financial and technical standpoints. Looking at the root causes of fragility, a list of interventions could be identified and their potential to reduce fragility could be evaluated as to changes in fragility scores using the method developed.

This further supports policymakers, aid programmes and financial investment decisions to understand both the current state of fragility due to natural resources (diagnose risk areas and opportunities) and to track the progress of their policies, programmes, and decisions over time.

5.2. WEF Nexus ranking vs WEF Nexus Index

Various conceptions of fragility have emerged in recent years, each with its own methodological approaches (Desai and Forsberg, 2020; Simpson *et al.*, 2020; Taft, Blyth and Wilson, 2019). A notable, recent example is the new WEF Nexus Index (Simpson *et al.*, 2020).

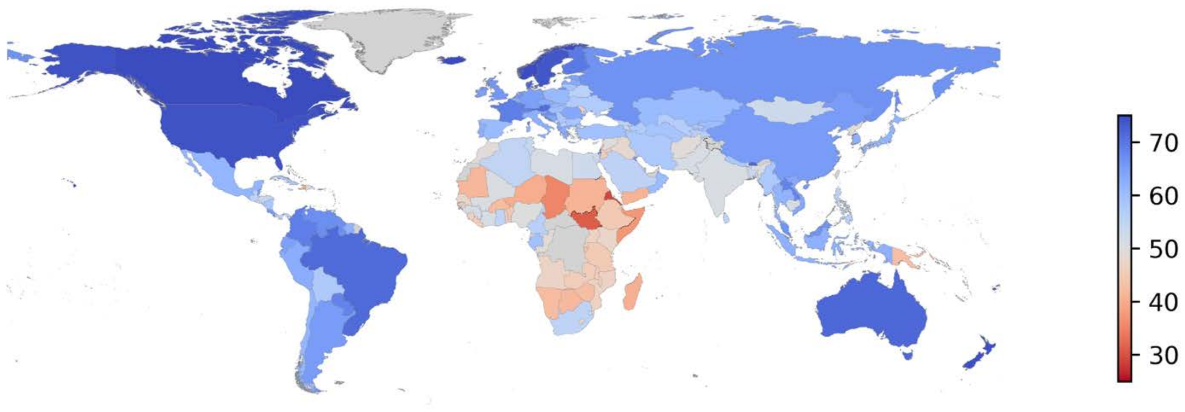
Figure 42. WEF nexus model combined with the confounding factors



Source: Authors' own elaboration, based on data from FAOSTAT (2022b), references included in Table 2 and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

WEF Nexus Index builds on multidisciplinary literature and advances the discourse on water, energy, and food resources fragility through theoretical integration of resources availability and access. The application of this framework is shown in Figure 43.

Figure 43. WEF nexus index scores



Source: Authors' own elaboration, based on data from Simpson et al. (2020) and maps from United Nations Geospatial (2020). Note: The final boundary between the Sudan and South Sudan has not yet been determined. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.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6. Monetary value equivalents cases studies

The presentation of case studies aims to convert water, energy, and food metrics into a comparable monetary value dimension (USD) to further inform the multicriteria analysis model. Therefore, the values could be characterized as country-specific rough approximations of water, energy, and food reserves/deficits. These high-level estimates aid in validating relative weights of the water, food, and energy surplus/deficit, as well as providing some comparative examples from the WEF relationships on a national scale. It is important to note that this methodology allows for large inherited uncertainties in the USD estimates (Figure 44). The illustrated methodology and findings may, however, be tailored for the analysis of different case studies.

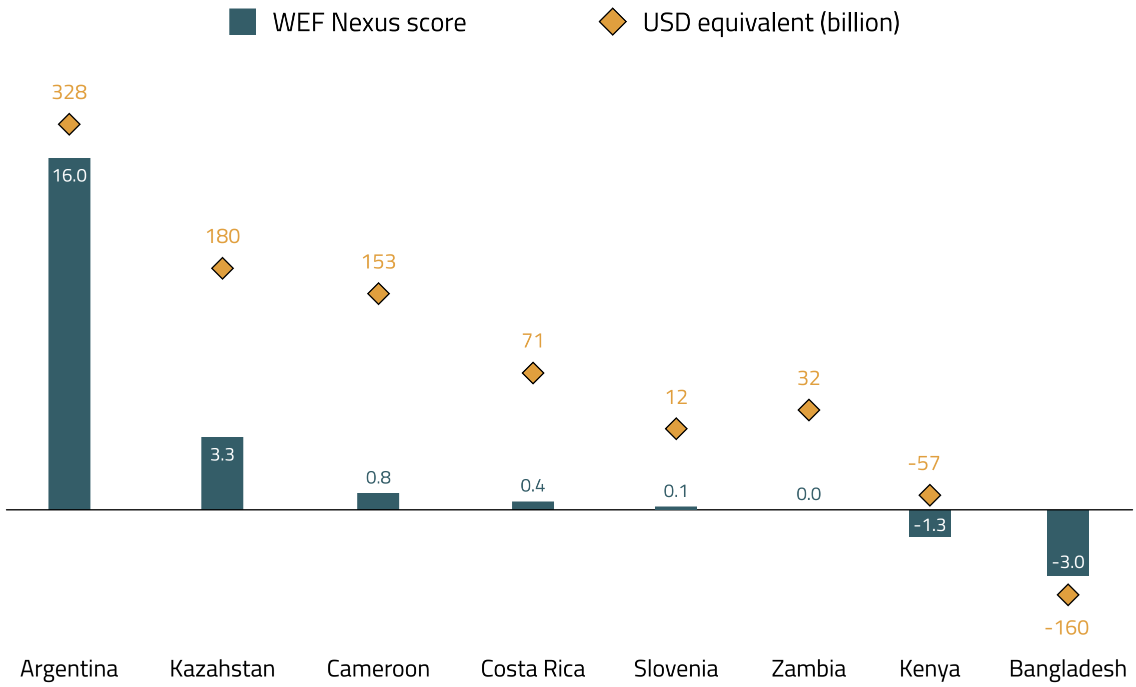
6.1. Methodology

The respective difference in water, energy, and food for selected case study countries was monetized following the approaches outlined below.

Water

Country-specific water tariffs were derived from the International Benchmarking Network (IBNET) tariff database, which is a joint product of Global Water Intelligence (GWI) and the World Bank's IBNET. IBNET tariff benchmarking data provides the water, wastewater, and stormwater tariff profiles for 567 cities across 186 countries. The median estimate of all global tariffs was used to convert counties surplus/deficit values into USD equivalents.

Figure 44. WEF Nexus score vs USD equivalent



Source: Authors' own elaboration.

Food

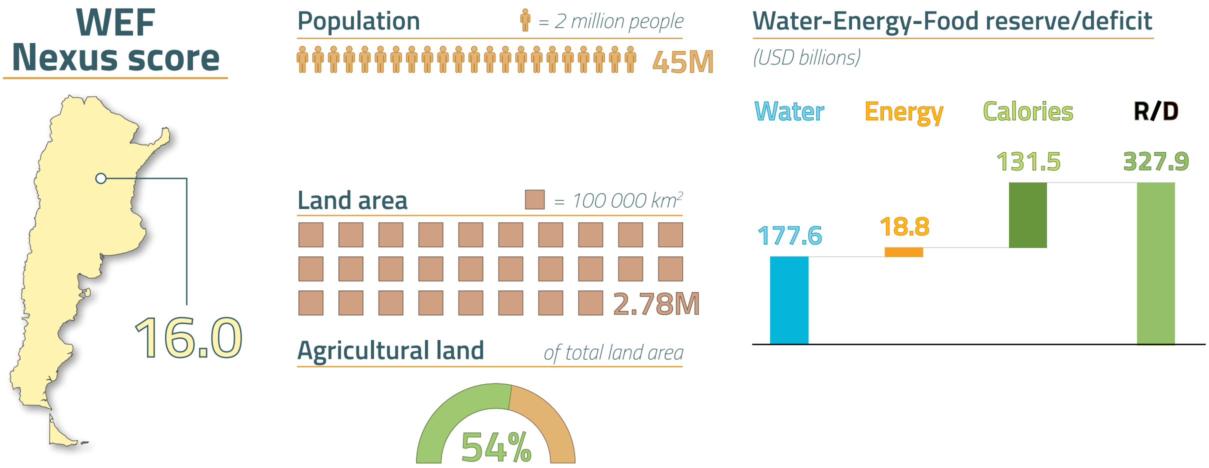
The cost of an energy-sufficient diet (CoCA) was used to convert food resources/deficits into USD equivalents. It is defined as the minimum cost to meet energy requirements using the least-cost available starchy staple food in each country. These values were sourced from a background paper for FAO's report on the State of Food Security and Nutrition in the World (FAO, IFAD, UNICEF, WFP and WHO, 2020). It is based on prices for locally available food items from the World Bank's International Comparison Program. The energy/nutritional requirements correspond with the World Health Organization (WHO) recommendations for the median woman of reproductive age. The least-cost diets used to measure affordability are based on food prices and availability in local markets, omitting information on the time cost of acquiring and preparing meals at home.

Energy

Energy reserves/deficits were monetized using the Levelized Cost of Energy or Levelized Cost of Electricity (LCOE), which measures the average net present cost of electricity generation for a generating plant over its lifetime. The median estimates of LCOE for 2020, with a 7 percent discount rate, for the following energy sources, were sourced from The Projected Costs of Generating Electricity – 2020 Edition, produced by the International Energy (IEA) and the OECD Nuclear Energy Agency (NEA) under the oversight of the Expert Group on Electricity Generating Costs (EGC Expert Group). Overall, the report provides total data for 243 plants in 24 countries. This report includes cost data on power generation from natural gas, coal, nuclear, and a wide range of renewable technologies. Oil LCOE was taken from The International Renewable Energy Agency (IRENA). USD/MWh figures were multiplied by the country's energy mix source and energy gap.

6.2. Argentina

Figure 45. Country summary - Argentina



Source: Authors' own elaboration.

Water

Argentina is a water-rich country, but the distribution of water resources is uneven. Total renewable resources are approximately 19 792 m^3 per capita – well above the water stress threshold defined by the United Nations Development Programme (UNDP) (1 700 m^3 per capita). The Plate River Basin concentrates more than 85 percent of national water resources and is the largest centre for human settlements, urban development, and economic activity. Outside the Sistema of La Plata, the most important rivers in Argentina drain into the Atlantic Ocean. The total contribution of the Atlantic slope, which includes the Cuenca del Plata, adds almost 95 percent of the total surface water supply of the country. The difference between Total Renewable Water Resources of 876 billion m^3/year and Total Internal Renewable Water Resources of 292 billion m^3/year results in 67 percent water dependency from outside the country. 74 percent of total water withdrawals are used in agriculture, and only 15 percent – municipal waters leaving 387 679 with no access to drinking water and 20 million – to sanitation. Most water utilities do not cover their operational costs.

Food

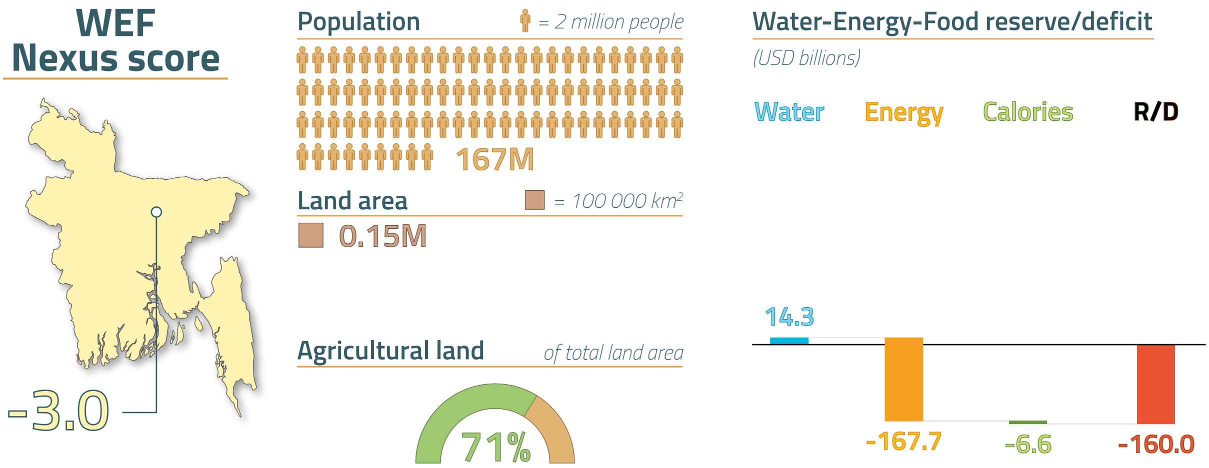
Argentina is the world's 10th largest exporter of agricultural products. The agricultural sector is the country's main source of income, employs over a third of the labour force and contributes about 8.3 percent to GDP and up to 20 percent (including the entire value chain). Agricultural exports account for a quarter of the country's total exports. The main agricultural products of Argentina are soybeans, corn, wheat, meat, wool and wine, but the country is also a major producer of fruits and vegetables. Soy occupies nearly half of the cultivated land whilst being the country's number one export product (36 percent of exports). Argentina produces nearly 20 percent of the world's soybeans, behind the United States of America and Brazil. In 2016, Argentina exported USD 36 billion worth of agricultural products, which is higher than Imports (estimated USD 3.2 billion) and the local price Gross Production Value (USD 23 billion) combined. Argentina can meet its food demand and export up to 90 percent of its total production. But a healthy diet in Argentina is expensive costing around USD 3.5 per person, meaning that 8.6 percent of the population cannot afford it.

Energy

Argentina's primary energy is a fossil fuel, with the following share in 2019: 2 percent coal, 33 percent oil, and 54 percent gas. Hydro- and bioenergy contribute 4 and 5 percent respectively. In addition, there is a merging demand for solar and wind energy. Argentina may have the potential to fully cover its population demand and export up to USD 19 billion of energy.

6.3. Bangladesh

Figure 46. Country summary - Bangladesh



Source: Authors' own elaboration.

Water

Bangladesh has plenty of surface and groundwater resources, with two main rivers, the Brahmaputra and the Ganges, accounting for more than 80 percent of stream flows and alluvial aquifer systems representing productive groundwater reservoirs. However, the notable difference between Total Renewable Water Resources (1 227 billion m^3/year) and Total Internal Renewable Water Resources (105 billion m^3/year) indicates a strong (91 percent) water dependency from outside the country. Bangladesh receives plenty of rainfall in the monsoon, extending from June to October. During the seven-month dry season between November and May, evaporation is greater than average rainfall, except in the northeast region. Water resources are distributed unevenly. An overabundance of monsoon often causes catastrophic floods. In contrast, the scarcity of the dry season causes severe drought conditions, leading to the loss of crops and livestock, public health problems and environmental degradation. Only 10 percent of total water withdrawal is used for municipal purposes, with 13.1 percent of the population of Bangladesh (2015) not having access to safe drinking water. Instead, a large part of total withdrawals (88 percent) is used in agriculture.

Food

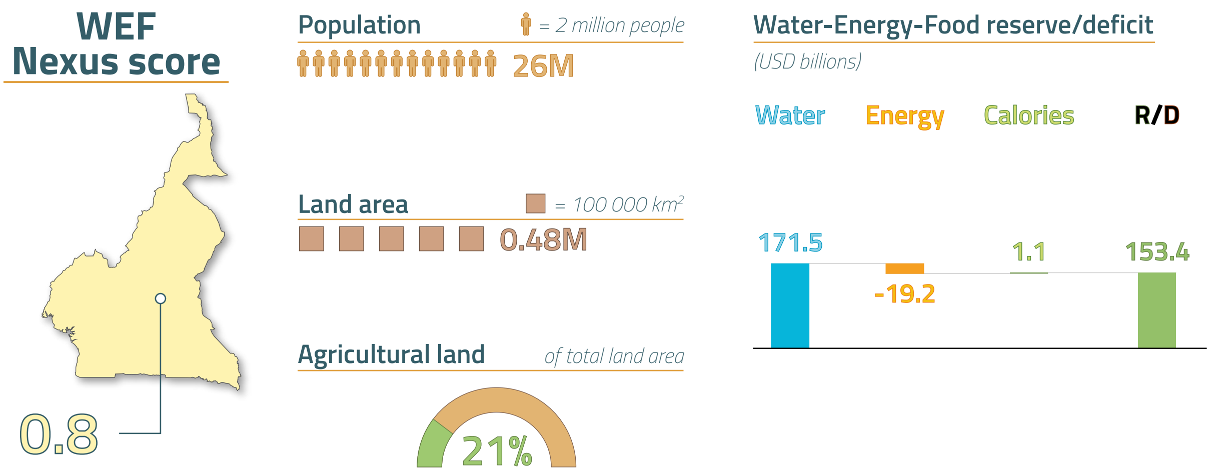
In Bangladesh, 70.1 percent of the land area is devoted to agriculture, with a 17.5 percent share of agriculture in GDP. The main crops cultivated include rice, jute, wheat, tea, pulses, oilseeds, vegetables, and fruits. But despite agriculture contributing to such a large proportion of Bangladesh's economy, it has remained largely subsistence, with uncertain crop yields and inefficient infrastructure limiting farmers' ability to commercialize their products. As a result, a large part of the population lacks access to sufficient, safe, and nutritious food. In 2017, 77 percent of the population couldn't afford a healthy diet. If everyone in Bangladesh is fed a calorie-rich diet, the current food deficit will rise even further, suggesting that the agricultural sector cannot meet true demand.

Energy

Power generation in Bangladesh relies heavily on fossil fuels, as natural gas and coal are the main sources of electricity. Of the total electricity generated, about 50 percent comes from natural gas, 10 percent from diesel, 6 percent from coal, 5 percent from heavy oil, and 3.3 percent from hydropower. The supply of population and industry with modern energy is low compared to countries with similar economies. Commercial energy production per capita has increased to 371 kWh since 2010 but is still one of the lowest in the world. The country is considered to be a net importer of crude oil and other liquid fuels. Since the country's oil consumption has increased since 2010, as a replacement for natural gas shortages, imports of crude oil and oil products are also rising. If Bangladesh supplies the global average demand per capita, the energy deficit will rise to USD 168 billion (7 million TJ).

6.4. Cameroon

Figure 47. Country summary - Cameroon



Source: Authors' own elaboration.

Water

Cameroon's dense network of perennial rivers, coupled with high rainfall throughout the year, results in fairly secure water resources. The dry season brings with it water insecurity, particularly in rural areas where most of the population is forced to rely on groundwater. Changing weather patterns due to climate change affects the water security of the country and can be a significant barrier to progress towards Sustainable Development Goals (SDG) targets, specifically SDG 6. Despite the water stress due to drought, Cameroon shows a reserve of water resources, with a positive estimated gap worth up to USD 171 billion.

Food

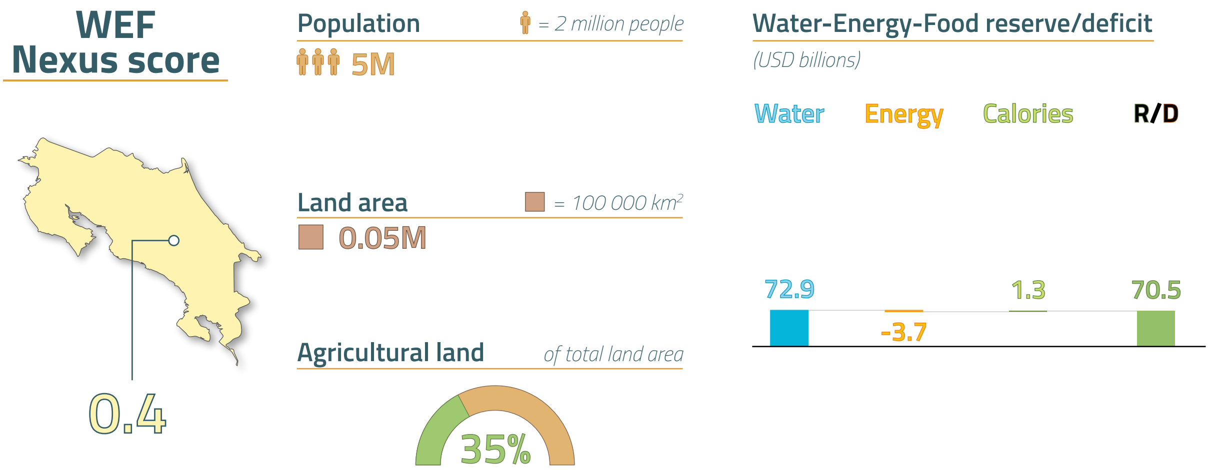
Cameroon is among the world's largest cocoa beans, cassava, and plantain producers. Agriculture is key to the economy of Cameroon, with the sector employing over half the workforce. Despite a growing population and crop yields adversely affected by climate change and other environmental pressures, the country's food production has been maintained, and Cameroon is generally self-sufficient. The export of food to Belgium, France, Indonesia, Malaysia and the Netherlands accounts for more than 17 percent of Cameroon's merchandise exports. This is evident when we consider the calorific difference between food production and supply, where Cameroon has an estimated surplus of USD 1.1 billion.

Energy

Renewables account for 74 percent of Cameroon's primary energy supply, with 94 percent of its renewable energy supply from bioenergy and 6 percent from hydro. Oil (19 percent) and natural gas (7 percent) make up the remainder of the country's energy mix. Despite showing an energy surplus when considering the current consumption of 12 GJ/capita, if people in Cameroon consumed the global average of 54 GJ/capita, the country would not support their demand, with a deficit of 903 198 TJ (more than USD 19 billion). The deficit value provides further perspective on the investment required for Cameroon to progress towards achieving the SDGs, specifically in this case, SDG 7.

6.5. Costa Rica

Figure 48. Country summary - Costa Rica



Source: Authors' own elaboration.

Water

Costa Rica's primary water source is groundwater, which accounts for nearly 90 percent of agricultural, industrial, and domestic water demands. Costa Rica has the highest water demand, both in total and per capita measures, in Central America.

Food

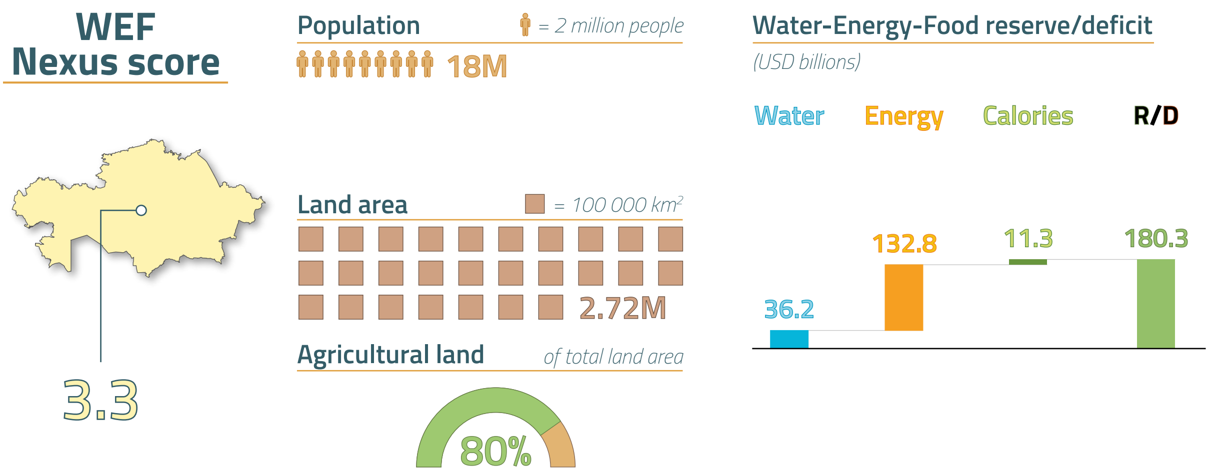
Costa Rica has historically been a predominantly agricultural country, dedicated to traditional export crops such as coffee, sugar and bananas. Today, the agricultural sector employs 14 percent of the Costa Rican workforce and accounts for 6 percent of the country's GDP. Coffee, bananas, beans, oil palm and oranges use approximately 82 percent of Costa Rica's agricultural land. Beef is still the most extensive land use activity but has declined in productivity being overtaken by dairy production (OECD, 2022b). Recently, export opportunities for non-traditional products such as pineapple, melon, foliage and ornamental crops changed the agricultural sector, so that the orientation towards export markets required the growing use of imported seeds, fertilizers and agrochemicals. Notable food imports are maize, soybeans and wheat. Between 76 and 96 percent of the food energy consumed in Costa Rica comes from crops that are not native to the region. Most of these plants' diversity is found elsewhere on the planet. Daily food consumption in Costa Rica is equal to the global average. The local diet relies heavily on fruit and vegetables, with rice and black beans as a staple for most meals. When considering the calorific difference between food production and supply, Costa Rica has a surplus of USD 1.3 billion. However, with these statistics in mind, Costa Rica faces challenges with widespread poverty and hunger throughout the country.

Energy

Costa Rica's energy mix is almost equally split between fossil fuels and renewables. Oil imports make up 100 percent of the 49 percent share of fossil fuel contribution to the country's energy mix, while renewables contribute the remaining 51 percent. The main renewable energy source is geothermal (24 percent), followed by hydro (13 percent), bioenergy (11 percent) and wind (3 percent). Costa Rica shows an energy deficit of up to USD 3.7 billion. This value provides further perspective on the investment and/or technological development required for Costa Rica to progress towards achieving the SDGs, specifically SDG 7.

6.6. Kazakhstan

Figure 49. Country summary - Kazakhstan



Source: Authors' own elaboration.

Water

Agriculture is the primary consumer of water, accounting for about 67 percent of the total withdrawal. Industry and public supply account for around 29 percent and 4 percent, respectively. The availability of water resources in Kazakhstan relies on transboundary inflows, with 41 percent of the stored water resources in the country formed outside of its boundaries flowing into the Irtysh, Ili, Chu, Talas, Ural and Syr Darya rivers. 7.1 percent of the population of Kazakhstan has no access to drinking water.

Food

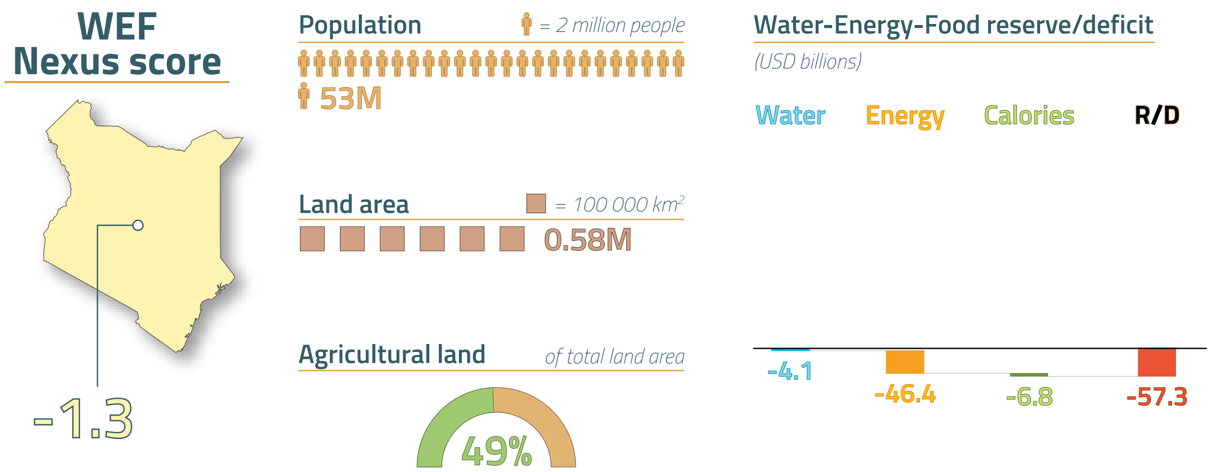
Agriculture contributes about 4 percent of GDP and employs 15 percent of the country's working-age population. Kazakhstan has the ninth-largest land area in the world and is one of the least densely populated countries. It has the second highest per capita availability of arable land in the world. Kazakhstan has been a net agrofood importer since the mid-2000s, yet is one of the world's largest wheat exporters. More than 60 percent of food exports are primary commodities. More than 60 percent of food imports are processed commodities, the bulk of which are for final consumption. In 2019, Gross Production Value was estimated at around USD 8.8 billion, imports – USD 3.7 billion, exports – USD 3.32 billion. The country is a large producer of wheat, milk products, linseed, meat, tomatoes, potatoes, cucumbers, apples, etc. Kazakhstan has the potential to export up to 75 percent of its production. Only one per cent of the population cannot afford a healthy diet.

Energy

Kazakhstan owns about 0.5 percent of the world's mineral energy resources – 90 billion tonnes of oil equivalent. Primary energy in Kazakhstan is fossil fuel resources, with the following share in 2019: 50 percent coal, 23 percent oil, and 25 percent gas. Fossil sources cover 99 percent of its energy needs. The fuel energy sector contributes about 17 percent of GDP. Kazakhstan can export around USD 130 billion of energy (2019). However, the share of renewable energy, mainly hydropower, is about 1 percent.

6.7. Kenya

Figure 50. Country summary - Kenya



Source: Authors' own elaboration.

Water

As most of Kenya is semi-arid, the majority of its surface water originates in the central highlands, coming from Lake Victoria and the Tana River, with only 33 percent of its water coming from outside the country. Water resources are stressed and often scarce, which is compounded by climate change and high inter-seasonal rainfall variability. Kenya's current freshwater withdrawals (0.2 m^3/person/day) are among the lowest in the world. For this reason, the county's internal resources – withdrawals' statistics show the availability of freshwater reserves of 16.7 billion m^3. However, if Kenya's water demand is recalculated based on the global mean per capita consumption, then the country faces a deficit of 14 million m^3 (estimated USD 4 billion equivalent).

Food

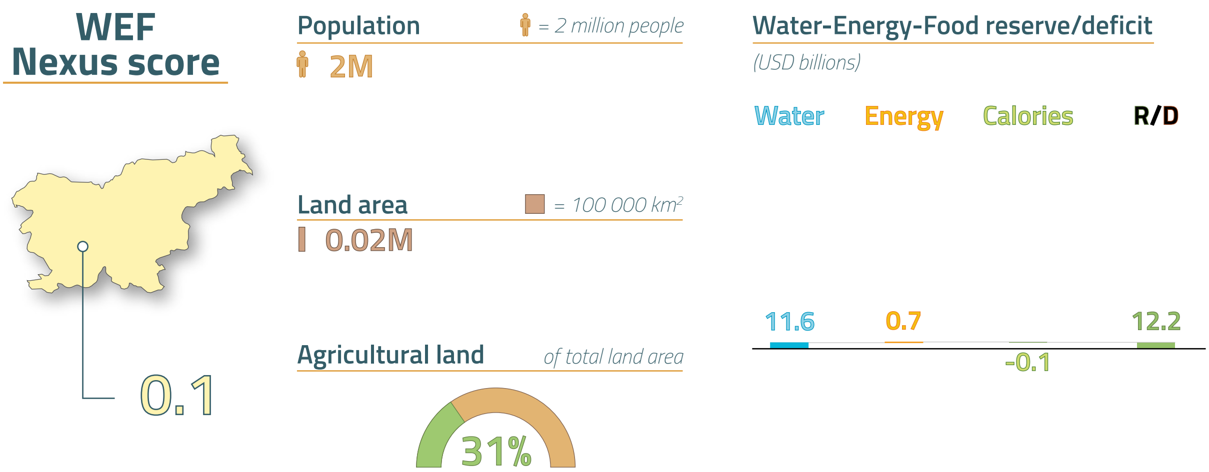
Agricultural land makes up approximately 49 percent of Kenya's total land area. Maize is the main staple food, with other sources including rice, beans, potatoes, and traditional foods such as sorghum, millet, cassava, arrowroots and yams. Agriculture dominates the Kenyan economy, accounting for 40 percent of the workforce (70 percent of the rural workforce) and about 25 percent of the annual workforce. The country's major agricultural exports are tea, coffee, cut flowers, and vegetables, and is the world's leading exporter of black tea and cut flowers. Yet, the country can't meet its population's basic food demand. When we consider the calorific difference between food production and supply, monetized using the cost of energy–sufficient diet (CoCA) estimate for Kenya, the deficit reaches USD 6.8 billion.

Energy

Renewables account for 78 percent of Kenya's primary energy supply, with 73 percent of its renewable energy supply from bioenergy, 25 percent from geothermal, and 2 percent from hydro. Oil (20 percent) and coal (2 percent) imports make up the remainder of the country's energy mix. From our estimates, Kenya shows an energy surplus of 235 024 TJ. However, the country's low per capita consumption of 10 GJ/capita indicates that if people consume the global average of 54 GJ/capita, Kenya would not support the demand, with a significant deficit of 2 158 368 TJ (more than USD 46 billion). However, it must be noted that Kenya still heavily relies on traditional biomass for cooking and heating at domestic and institutional levels, which is often unregulated and therefore difficult to reflect in our analysis.

6.8. Slovenia

Figure 51. Country summary - Slovenia



Source: Authors' own elaboration.

Water

Although unevenly distributed, Slovenia has abundant water resources, with approximately 41 percent of water originating from outside the country. Total renewable resources per capita are approximately 15 322 m^3. Slovenia shows a positive gap of 17.7 billion m^3 between IRWR and TFWW, which remains significant even after aligning current per capita consumption (1.2 m^3/person/year) with the global mean (1.4 m^3/person/year).

Food

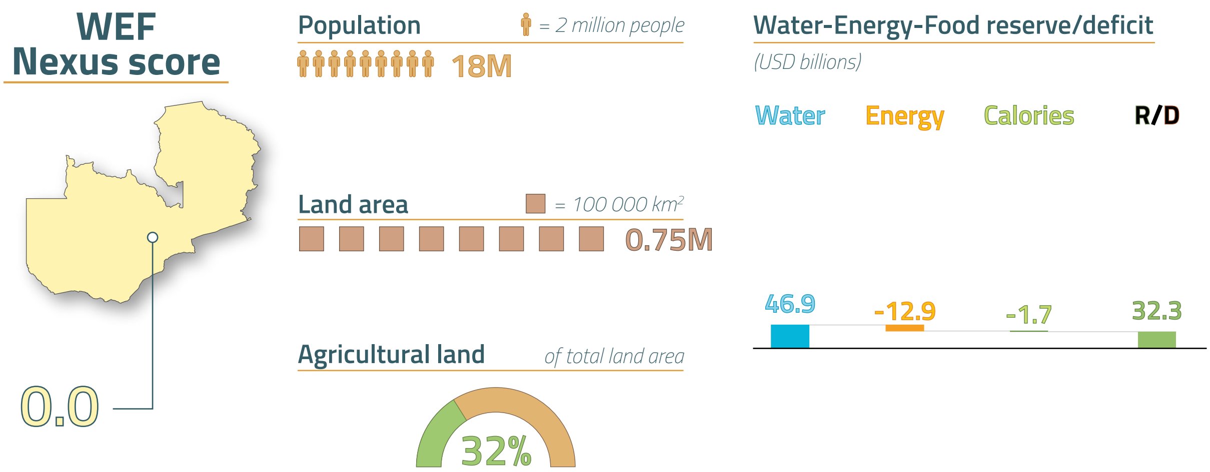
Slovenia is a net food importer, producing less than 60 percent of its cereals, sugar, and pork. Agriculture accounts for approximately 2 percent of the country's GDP, employing approximately 8 percent of the workforce. The daily food supply in Slovenia (3 149 kcal/person/day, in 2019) is higher than the global average. When considering the calorific difference between food production and supply, Slovenia has a deficit of approximately USD 0.1 billion.

Energy

Fossil fuels account for 64 percent of Slovenia's primary energy supply, with coal, oil, and natural gas contributing 17 percent, 36 percent, and 11 percent, respectively. The remaining share comes from nuclear (22 percent) and renewables (15 percent). Slovenia shows an energy deficit of 58 651 TJ. Despite showing an energy deficit when considering Primary Production minus Total Final Consumption, the country's high per capita consumption of 97 GJ/capita and a small population indicate that if it consumed the global average of 54 GJ/capita, it would shift its energy profile to positive, with a surplus of 30 189 TJ (USD 0.7 billion).

6.9. Zambia

Figure 52. Country summary - Zambia



Source: Authors' own elaboration.

Water

Zambia is a country rich in water resources, with a number of large perennial rivers, in particular the Kafue River, which supports agriculture, energy generation and industry in the Kafue River Basin, where most of the population lives. Total renewable resources per capita are approximately 6 131 m³. Zambia shows a water surplus of 70 billion m³ converted to USD 46.9 billion. Despite well-distributed water resources, the region is severely affected by climate change and the associated droughts and extreme weather events, affecting water security.

Food

Maize is grown by approximately 80 percent of Zambia's households. Despite the fertile soil and consistent rainfall, productivity remains low, resulting in the agricultural sector contributing only 20 percent to the country's GDP. With current food consumption of 2 267 kcal/person/day, which is below the global average, Zambia exports around 8 percent of its food to the Democratic Republic of the Congo, Malawi, Kenya, South Africa and Switzerland. However, if everyone in Zambia consumed the same calorific diet as people in China in 2019 (the closest to the global average), Zambia would have to import USD 1.7 billion worth of food.

Energy

Renewables account for 84 percent of Zambia's primary energy supply, with 90 percent of its renewable energy supply from bioenergy and 10 percent from hydro. Oil (10 percent) imports and coal (6 percent) produced in the country make up the remainder of the country's energy mix. A low per capita consumption of 18 GJ/capita and a high reliance on inefficient, traditional biomass by the majority of its rural and urban population result in an energy deficit of 610 939 TJ if all Zambians consumed the global average of 54 GJ/capita. Closing this gap and meeting the new theoretical energy demand would require an additional USD 12.9 billion.

7. Conclusions

Water, energy, and food are critical for human well-being, poverty reduction, and long-term development, and they are also major contributors to natural resource-driven fragility. Global projections show that demand for freshwater, energy, and food will rise significantly over the next few decades as a result of population growth and mobility, economic development, international trade, urbanization, diversifying diets, cultural and technological changes, and climate change, putting the most vulnerable communities and states at risk.

The need to understand the interactions between food, energy, and water at various scales globally has stimulated research in the Water–Energy–Food nexus. Nexus approaches assess synergies and tradeoffs that occur in interactions between the food, energy, and water sectors. They are a meaningful tool to improve the understanding of resource utilization and management (Fernandes, Hellen and Lima, 2019). Latest nexus frameworks depict the geopolitical underpinnings that influence and result from interactions such as national strategies to achieve SDGs. They also investigate policy options that can be obtained by comprehending the WEF nexus. As a result, they are remarkably useful for informing policies and strategies that best address resource management and utilization at various levels.

This report, therefore, presents a framework for estimating natural resource-driven fragility based on the water, energy, and food nexus calculated as resources surplus or spare capacity/deficit per country. This dimension of countries' fragility was framed in the context of their ability to meet their demand (consumption) based on their own resources' availability. Thus, water, energy and food surplus/deficits were calculated as numerical differences between resources availability and consumption. Availability and consumption values for water, energy and food were drawn from indicators provided by UN databases. Water data were sourced from the FAO AQUASTAT; energy – the UNSD Energy Balances, and food – FAOSTAT Food Balances. For the availability, most recent values were used, for the demand, however, two different scenarios were considered. In the first scenario, the demand was equivalent to the most recent values of water, energy, and food consumption.

Since these values factor in various geographic, climatic, and socioeconomic conditions, they may not represent the required, desired, or sustainable consumption figures. The second scenario, therefore, evaluated worldwide national demands based on fixed equal consumption values of water, energy, and food resources per person per day multiplied by the population sizes. These globally fixed consumptions were derived from dividing current resources consumption of all studied countries by their joint population in a given year, thereby levelling the effect of all confounding factors on the resources demand. Both scenarios were first examined for water, energy and food resources separately and then the second scenario was used to produce the integrated WEF nexus scores with no confounding factors.

On average, more than two-thirds of water withdrawn by most worlds countries is used in agriculture, approximately 17 percent – in industry with remaining eleven/twelve percent known as the municipal/domestic water. In light of this, approximately a third of the world's nations withdraw volumes of renewable water almost equalled or much greater than their internal renewable freshwater resources. The indicated points to high reliance on external renewable resources (e.g. transboundary rivers) that are vulnerable to upstream hydrological interventions; and/or water extraction from non-rechargeable aquifers (fossil water). Moreover, if consumption per person is levelled with the global averages even higher number of countries result in water deficit. The indicated is particular important in arid and semiarid African regions where in hot and dry climate, an average daily water consumption is below the global average of 1.4 m^3/person/day (a moderate estimate).

Several countries across the Near East, North Africa, and South Asia are shown to be in deficit when comparing availability to demand, facing extremely high levels of water stress: Egypt, Iraq, Mauritania, Oman, Pakistan, Qatar, Saudi Arabia, the Sudan, the Syrian Arab Republic, Tunisia, the United Arab Emirates, Turkmenistan, Uzbekistan, and Yemen have withdrawal volumes largely exceeding 100 percent of internal renewable resources. The extent of this deficit can be even greater, as there are inherited uncertainties in the indicators of water withdrawals and internal freshwater resources. Furthermore, neither value represents the spatial or seasonal variation in water resources and their demand. This lack of consideration in global resource evaluation contributes to the lack of guidance on how these resources can be used to reduce national and international water-driven fragility.

To meet their water needs, and minimize vulnerability to seasonal and spatial weather patterns, some countries, e.g. Algeria, Australia, Israel, Kuwait, and Saudi Arabia utilize desalination technology. However, desalination methods entail high-cost energy intensive infrastructure (and, in some cases, carbon emissions) as well as potential environmental risks.

Given that food production strongly correlates with water availability, food deficits greatly overlap water deficits, but they also expand further across South Asia and Africa. Since average human diet consists of mostly vegetables (plus derived products), followed by cereals and animal products, vast arable land and abundant water resources are required to satisfy global population demand. Nevertheless, if a country has a negative food resource gap but its water gap is positive, this potentially indicates an opportunity to improve primary food production through better water supply/reuse infrastructure and sustainable management practices for both water and food resources. Unlike water and food resources, energy gaps are relatively independent of either. Since about 80 percent of primary energy comes from fossil fuels, the production of energy is driven by the earth's geology and mineral resources. Given that renewable energy currently accounts for less than 20 percent of global primary energy, if reliance on fossil fuels falls sharply, countries with large fossil energy surpluses can face knock-on effects on other economic sectors. As a result, the world's top five energy producers (China, India, the Russian Federation, Saudi Arabia, and the United States of America) may benefit from diversifying their energy resources.

Comparing water, energy, and food global spare capacities shows that Mexico, Peru, most African countries, the Arabian Peninsula, Central Asia, Afghanistan, Pakistan, India, Bangladesh, as well as Italy, Japan, and the Republic of Korea undersupply more than one resource. It is also notable that although India and the United Republic of Tanzania are known to experience water supply challenges, both countries have the capacities to meet their population demand for water as well as food resources. When water, energy and food gaps were integrated, densely populated India, Bangladesh, and Pakistan, along with Japan and the Republic of Korea, resulted the high total deficit resources. Afghanistan, Burundi, Egypt, Ethiopia, Jordan, Haiti, Kenya, Lebanon, Morocco, Mozambique, Niger, Rwanda, Sri Lanka, the Sudan, the Syrian Arab Republic, Uganda, the United Republic of Tanzania and Zimbabwe were in the top 25 resource-driven fragile states. These integrated scores aimed to represent fragility based solely on differences between resource availability, and population–driven demand.

Converting water, energy and food gaps to USD–cost equivalent approximations of fixed daily portions of water, food and energy in USD, allowed to compare prices of resources gaps as the means of validating the indicators developed. These USD–equivalents were derived from global resource cost statistics, and aimed to help determine the weights for water, energy, and food criteria, and to compare countries' integrated scores on a dollar–equivalent scale. Here, energy proved to be the most expensive resource, followed by food and only then water, which means, for example, that the high surplus of water does not weigh as much as the high surplus of energy, or a small surplus of water does not financially compensate for a food deficit. Eight countries were randomly selected to compare side by side, the WEF nexus and the dollar–equivalent orders, which showed an agreement between the two.

However, the WEF integrated scores are only a facet of natural resource-driven fragility. Thus, a set of confounding factors was created by integrating indicators of countries' socioeconomic and technological development, natural resources management, and climate risks, to further inform the complexity of the WEF nexus fragility concept. The stakeholder survey was used to evaluate these components. Climate change received the highest scores from most respondents, followed by resource management and the dimensions of economy and technology. The majority of participants also agreed that socioeconomic growth and the availability of technology play a critical role in compensating for the natural–resources fragility.

As a result, all indicators were ordered from negative (water and air pollution, resources rents and climate riks) to positive (infrastructure, land area, coastal and inland waters, exports of goods and services and high-technological exports) when determining the final fragility ranking. Most countries in Africa, parts of the Near East, and South Asia showed to be significantly less resilient to the challenges of natural resource-driven fragility than those in North and South America, Europe, and Central and East Asia.

There are several broad knowledge gaps that need to be filled in order to better understand natural resource-driven fragility and inform pathways for resilience. Particularly, we have identified three broad key areas where more research is urgently needed: 1) the robust and transparent global data on renewable water resources, food production and primary energy, with both interannual / seasonal variations in a country, 2) the indicators of resources cost per country, and 3) the global sustainable resource consumption metrics. Addressing all three pillars are necessary to understand the growing challenges associated with natural–resources driven fragility and implement effective strategies for building global resilience. We therefore encourage researchers, funding organizations, policy makers and other relevant stakeholders to take the steps needed to fill these knowledge gaps. There is a pressing need to breakdown the silos and open new collaborations to ensure that sufficient data and tools are available to those who need them most. Bringing together ideas from large international companies and public organisations as well as small utility companies, supermarkets and farms could be a step urgently needed to enable us to work together to protect fragile communities by meeting basic water, food and energy needs. Additionally, the concept of the natural capital supplementing the more traditional economic accounts could assist in better management of national resources availability and demand.

For example, the concept of a natural capital account, in addition to the more traditional economic national accounts, is designed to encourage countries to track their wealth rather than just their income. Natural capital is typically embedded in complex dynamic systems and real options, the value of which rises with volatility, causing the capital stock to fluctuate over time. The long-term management of this natural capital including all natural resources necessitates rethinking its governance and dealing with increasingly complex interdependencies and volatility. Moreover, opportunities for reducing demand should be focused on improving Resource efficiency and decoupling of economic growth from resources use and pollution. New processes and ecosystems are required to create more sustainable designs and innovations. Growth could be redefined from a resource–intensive, linear process to a resource–productive, circular process.

In line with the UN 2030 Agenda for Sustainable Development, which envisions a future of inclusive equity, justice and prosperity within planetary boundaries, there is a need to improve global resource efficiency in consumption and production, and decoupling economic growth from environmental degradation. Countries should be investing in a range of technological, institutional and behavioural changes which accelerate decoupling reducing fragility to natural resources. Switching the base of economic transaction and growth toward access and performance has the potential to restructure the economics of consumption, encouraging more sustainable use of resources and delivering wider benefits to human health and well-being.

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In an increasingly interconnected world, we are confronted with formidable global challenges stemming from resource depletion, unsustainable production and consumption patterns, and the alarming consequences of climate change. The scientific consensus is clear: the current models of production and consumption are pushing our planet towards unsustainable limits.

While there is growing awareness of the political processes that transform environmental concerns into social issues and policy development, the absence of reliable indicators on access to natural resources hampers the integration of water, energy, and food security into the sustainable development agenda.

This report endeavours to define and map natural resource-driven fragility, aiming to lay the foundation for the development of a visualization tool - a global map highlighting vulnerable areas acutely exposed to natural resources-driven fragility.

By providing empirical evidence, this tool will serve as a compass, guiding decisions regarding geographical and thematic areas of intervention, thereby alleviating the burden of natural resources-driven fragility faced by the most vulnerable nations.

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