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The Function of Money in Water–Energy–Food and Land Nexus

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Abstract: The water–energy–food (WEF) and land nexus is a basic element of prosperity. However, the elements of WEF are not equally distributed, and the dynamics of trading drives the distribution of goods. Money controls the trading, but money is just a convention and not a stable measure. Therefore, we have used the data of gross domestic product (GDP) and the price of electricity of each country in order to convert money to stable energy units. To evaluate the role of money in the WEF nexus, we also convert all the elements of the nexus, in energy units. In addition, we observe that land is the base of WEF and is positively correlated with all of its elements. However, we find that even the richest countries are facing critical deficits in WEF. Adding the money (GDP in energy units) to the WEF nexus, the balance becomes positive and we conclude that trading is necessary for both survival and prosperity. This may be obvious, but at present, global geopolitical conflicts which use economic sanctions as a tool transform the global balance of the WEF nexus, putting the global prosperity in jeopardy.

Keywords: water–energy–food nexus; land; economic sanctions; economy; resources

1. Introduction

An archetypical issue of prosperity is the ownership of land. Land is related to the hydrological cycle so it has fresh water, which is also needed for irrigation and for food production. As land has to be exploited, it demands proper infrastructure and energy in order to produce food. These necessary goods for survival are strongly connected to life and prosperity, composing the precious water–energy–food (WEF) nexus.

Humans began to survive in our hospitable planet as hunter–gatherers. Small amounts of energy were required, as hunter–gatherers worked less than 7 h per day to find their water and collect their food [1]. This was achieved as wide areas of land were needed to feed hunter–gatherers (one person needed about 2 ha to be fed [2]).

The agricultural revolution was based on the understanding of the Water–Energy–Food (WEF) nexus, as people realized that more water (irrigation) and more energy (use of animals) meant more food, and, therefore, less land could feed more people [3–13]. Sackett found that people in agricultural societies work more than 8 h a day [1]. In this way, people could live in stable clusters (societies) [14,15] with infrastructure (buildings, storages, irrigation, water supply) and create their civilizations.

It is important to note the interactions inside the WEF nexus: water can give energy (hydropower) and multiply the production of food (irrigation), energy inputs produce food but also could pump underground water, food can be assumed as an energy source (for livestock and humans) and contains water [16–19]. In addition, with the growth of infrastructure, the interactions and the availability of the sources of the WEF nexus have formed, diachronically, the social cohesion and the stratification of societies. Quoting the comment of N. Mamassis [20]:

> *"If a group of hunter-gatherers went to colonize an isolated island, first they had to act as primitive engineers and find water, after that they had to organize their production to*

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produce food as farmers and, if they could stabilize the prosperity of the new society, after thousands of years they would need an economist".

The management of the WEF nexus is a critical issue for prosperity [21–25]. The first use of the term WEF nexus was made by the World Economic Forum in 2011 [26], yet the concept and the interaction between its elements was also in wide use before then [27]. The systematic study [28] of the WEF nexus has emerged in literature in the last 10 years [29–37].

Archetypically, the economic system uses the abstract representation of money to trade real goods (products). In fact, prosperity is strongly connected with surplus, and money has been a proper mean to manage the complexity of tradable goods. In our era, the economy has the power to move the world within an extremely complex economic system. Tainter [38] considers that societies are complex systems, and complexity is a necessary element for their growth. However, the complexity of a system contains a structural weakness as the complexity can reach a limit where it cannot be managed [39]. In addition, a system that is designed to be complex has, also, several weaknesses. The monetary system is a typical complex system which hides its weaknesses [40], but money is considered as a stable value to assess goods or products, even if its value is changing in forex every second.

In order to evaluate the transactions of WEF with land and prosperity, and estimate the role of trading in it, we have to find a stable measure to express all these elements in the same value. Food is energy-dependent and can be expressed in energy units. In addition, water, which has various uses (drinking, hygiene, irrigation, hydropower), can be transformed to energy units. We have performed this by considering the energy used for the creation of desalinated water. In addition, we have expressed the gross domestic product (GDP) in energy units using the datasheet of electricity prices in different countries and global available data of GDP [41–44]. In this way, we have expressed all parts of the nexus in energy units.

This conversion in energy units is in accord with the archetypical definition of capital, which was energy based. In Homeric times, the herd size (oxen or cattle) signified the wealth of a person. The unit of wealth measurement in the Roman Empire was the head of an animal (Latin: capis), which bequeathed to us the term capital. In modern literature, there are a plethora of studies that link energy to money [45–47].

Elements of WEF, the principles of trading, the distribution of land and property, and the methods of land exploitation, were, diachronically, the base of social interactions, the stratification of societies, and the formation of political systems. In addition, as land is a fundamental base of prosperity [48], land ownership was the most common reason for military conflicts [49]. As the sources of the WEF nexus are not distributed equally in the world, to show the global inequalities of the available resources, we have employed two well-known measures of socio-economic inequality, the Lorenz curve [50–53] and the Gini coefficient [54–56], noting that inequalities of production are minimized by trading.

The objective of this paper is to describe the function of money within the WEF nexus, as preliminary investigation shows that, without it, there appear strong imbalances among countries in WEF elements. This could be considered as obvious; however, it is important to examine it, as, at present, economic sanctions and limitations in trading minimize the dynamic of money. As this balance must be positive for prosperity or, in marginal cases, survival; the function of money appears to be crucial in making the balance positive. In addition, by showing the inequality of the distribution of WEF resources among countries, we try to examine the dynamics of trading in adapting balance.

Section 2 of this paper presents the role of money and the conversion of money to energy units. Section 3 presents the incorporation of the social system into the water–energy–food and land nexus and Section 4 presents the availability of WEF and land, analyzing global data for 2019. Section 5 discusses the global balance and the inequalities of the resources, noting that even rich countries have critical deficits of WEF resources. However, by adding money in energy units (which can be considered as the dynamics of trading), the trend is to make the balance positive (surplus).

2. The Role of Money

Looking back in history, we understand that money is an ephemeral symbol. At present, one cannot buy goods with a Roman denarius or with a Greek drachma. However, as units of money are precious symbols, a highly complex mechanism has been created for its distribution, creation, and storage.

The concept of money does not have a universally accepted and scientifically tested definition. A useful description of the concept is provided by Pierce and Tysome [57]:

The word "money", as it is used in economics, has two very different meanings.

[. . .] a unit of measurement, denoting the value in exchange of all goods and services.

[. . .] a means of payment and, as such, money is also a medium of exchange.

As a unit of measurement and exchange, money has a social content, which is in contrast to the usual units of measurement of physical quantities. In particular, Marx [58] states that:

The particular commodity, with whose bodily form the equivalent form is thus socially identified, now becomes the money commodity, or serves as money. It becomes the special social function of that commodity, and consequently its social monopoly, to play within the world of commodities the part of the universal equivalent.

In addition, he notes:

Since all commodities are merely particular equivalents of money, the latter being their universal equivalent, they, with regard to the latter as the universal commodity, play the parts of particular commodities (ibid.).

The above descriptions are among the most understandable and acceptable for scientists who are used to logical rigor, as it is reflected in mathematical logic.

However, it seems that rigor is not a pursuit of the economic literature, where ambiguity is rife and the definitions often circular. For example, Spindt says that "money is what money does" [59]. An even more characteristic example is provided by Marx himself, who, in his famous book entitled Capital, characterizes capital (with an obvious cyclicality of definition) as follows [60]:

Capital is not the sum of the material and produced means of production. Capital is rather the means of production transformed into capital, which in themselves are no more capital than gold or silver in itself is money.

Commenting on the status of the modern world, Lietaer [61] notes:

The world has been living without an international standard of value for decades, a situation which should be considered as inefficient as operating without standard of length or weight.

In its fogged scientific definition, money has been formulated, diachronically, by its own rules that contain extreme variability (e.g., the value of denarius in the second century [62]). This can be also clarified by the variability of interest rates (IR), which are trying to protect price stability [63–65].

At present, the structure of money is based on its non-essential, tertiary functions, such as credit base and liquidity [66,67], which are the basis of operation of the modern world. Hence, money is most vulnerable, since these functions are based on various assumptions (e.g., forecasts and estimations for interest rates, creditworthiness, monetary stability, etc.), each of which depends on the dynamics of the rapidly changing socio-economic environment.

Nonetheless, the role of money is very important to the WEF nexus. As economies of scale should be applied in the construction of related infrastructures, or to land management [68–70], the availability of the necessary investments is crucial [71].

Using one precious element of the WEF nexus, food, instead of money, archeological research evaluates the wealth by the estimation of the wheat wages (i.e., the liters of wheat which can be purchased by a daily wage) [72–81]. In this way, the evaluation of wealth absorbs the variability and the subjectivity of money.

In our analysis, in order to exempt the effect of money's subjectivity, we chose to convert money into energy units instead of wheat wages. In this way, we introduce money inside the WEF nexus, as all the elements of the WEF nexus can be converted to energy. For our evaluations, we have chosen 2019, as it was the last year where the global balance seemed to be stable, i.e., before the COVID pandemic and the major geopolitical conflicts.

3. Incorporation of the Social System into Water–Energy–Food and Land Nexus

3.1. Water

The abundance of water on land depends on the geographic position, the climatic zone, and the meteorological characteristics of each area. However, water remains useless without hydraulic infrastructures to exploit it [82,83]. Wittfogel, [84] had a theory that, as hydraulic infrastructures need collective work, special knowledge, and bureaucratic management, the creation and management of the infrastructures were the key factors for achieving surplus from land. According to Wittfogel, these issues justified despotism and the existence of an elite.

3.2. Energy

The cultivation of land needs energy. Even if we have the perception that slavery was the energy base of antiquity, slaves were not a remunerative investment [85–87], as the owner had to be responsible for their survival. Therefore, an extreme stratification, with plenty of plebeians, was a more common system in ancient and medieval societies [88,89].

However, instead of using humans as an energy source (with the power of approximately 50–90 W) [7,90], a smarter way was the exploitation of animal energy (horse and ox, with power more than 300 W). Kohler et al. [91] note that the use of animal energy in the Old World was the reason why the societies were more stratified than in the New World.

3.3. Food

Diachronically, food was the issue in question for land management, as food supplies transform the dynamics of societal clustering. Therefore, land management by an elite [92] was a typical formula in ancient [93] and medieval societies [94,95], even if we could observe differences between political structures and stratification [96–98].

3.4. The Conflicts of WEF Nexus and Land in Modern Era

Marxist literature assumes that, in hunter–gatherer societies, social classes were equal with no property [99] (also supported by anthropological research [100,101]. However, recent research shows that, since prehistory, societies were stratified [102–104].

After the medieval period, colonization and the industrial revolution gave alternative priorities to the WEF nexus. In this period, the production and consumption of energy became also an issue in question [105–111]. In addition, the modern way of life and new hygienic standards demanded an increase in the supply of water on a per capita basis.

The creation of an energy surplus also demanded technological investments (ships, factories), which were controlled by a new elite of the industrial era. This process created new social dynamics, but the establishment of this status was overturned by emblematic social revolutions in modern societies [112–114]. These unrest periods disputed land ownership and, overall, formulated a new distribution of land and goods [115,116].

4. WEF Nexus and Land: The Key for Prosperity

As a key factor for prosperity is the proliferation of the elements of the WEF nexus, the nexus has to be functional and, in contrast to past eras, must have a cumulative surplus.

Within the WEF nexus, land can be used competitively, in addition to residence (housing in urban and rural areas):

- For the production of food.

- For water supply and/or hydropower.
- As a field for energy production by RE installations or for the cultivation of energy crops.

All of the above also have competitive interactions, as the production of food needs water and energy, the water supply often needs energy, and energy production by energy crops needs water and energy depriving food.

The FAO provides data for the global production of food supplies [117]. These include livestock feed, losses, seeds, and other uses. We choose to include all values, as these are the grand total of calories produced in the field. We express the data values, originally given in mass units, as kcal for each kind of food, according to conversion factors given in [118], and we further convert them to joules for each country's production. Assuming the cumulative calorie consumption for human survival (given also by the FAO, per capita for each country which depends on its specific needs, the availability, and the cultural heritage), we obtain the diagram in Figure 1, which shows food needs and the food balance, in energy units.

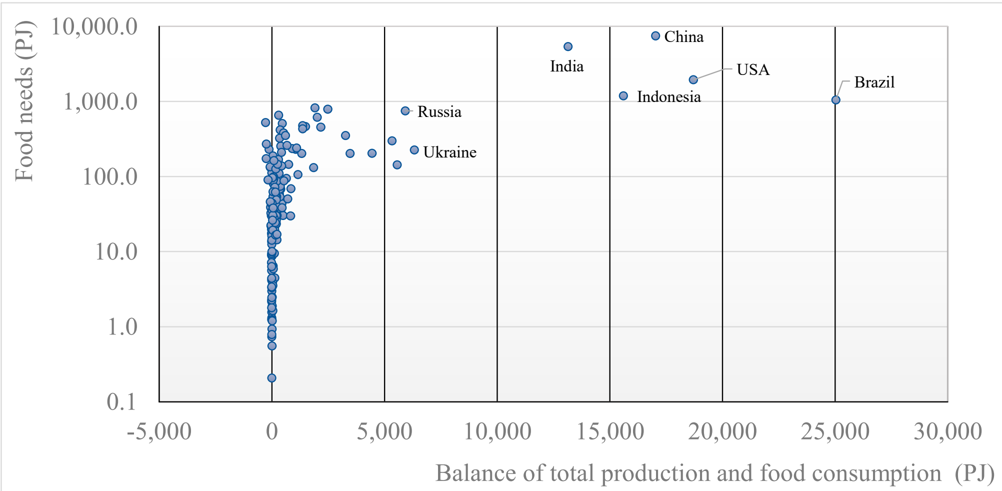


Figure 1. Balance of food vs. the food needs.

The big picture is that, in 2019, the food balance, expressed in energy units, indicates a global surplus of about 87%. We estimate this using the grand total production, which is 254,448 PJ for all uses. However, the estimates of food production that is edible by humans is significantly less [119]. As the digestive system of humans consumes food, not energy (Bahadur et al. note "when too much is not enough" [120]), and the body absorbs less than the total calories available in food [121,122], related data in Figure 2 shows that the real balance line (dash doted in Figure 2) is the trend of the available food consumption correlated with food needs, which is below the (doted) equality line [123]. We could assume that countries which are below the real balance line (Figure 2 dash doted) have a surplus of food production, and countries which are close to or above depend on imports.

The complete dataset from Our World in Data Energy [124] gives us the ability to evaluate the production of primary energy and the consumption in energy values, as shown in Figure 3. Specifically, it shows that countries which are close to or below the real balance line (dashed) have a surplus of energy, and countries which are above are dependent on imports.

The big picture of 2019 global energy balance is plotted in Figure 4, which also shows the inequalities of energy needs in the global balance of energy sources.

Evaluating the balance per capita, a minimum level is observed in food (Figure 5a), which indicates that the availability of food through autonomous production tends to be a priority of each country. On the contrary, the balance of energy per capita (Figure 5b) is more spread out, as energy needs depend on the industrial level, the climatic zone, or the habits of people. An interesting example is Mali, which has the maximum surplus per capita: the energy consumption per capita is less than 150 kWh [125] per year, while, in developed countries such as the USA, it is more than 10,000 kWh per year [126].

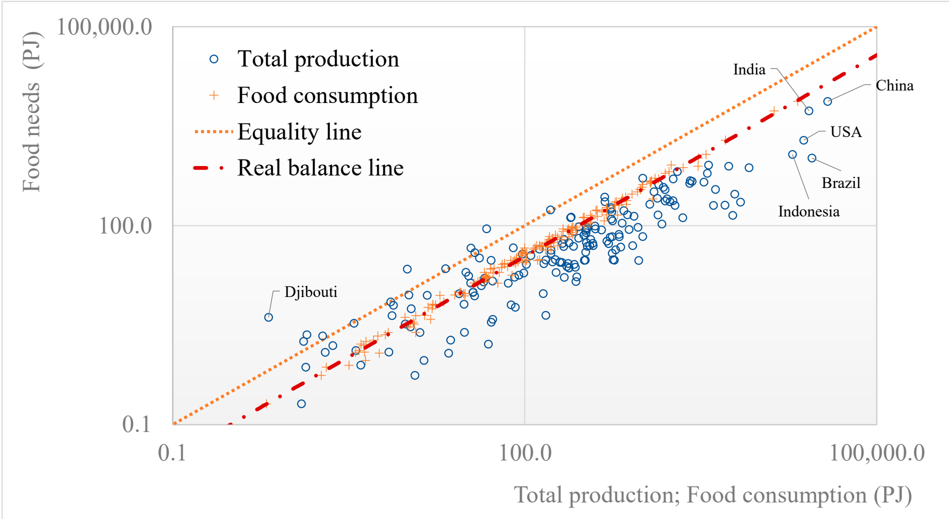


Figure 2. Food production and consumption vs. food needs, expressed in energy units (PJ) in different countries (2019).

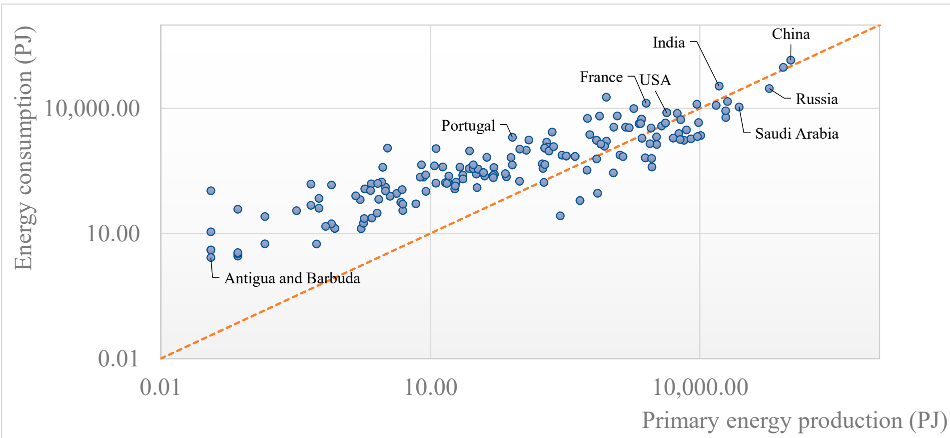


Figure 3. Production of primary energy vs. energy consumption in different countries (2019).

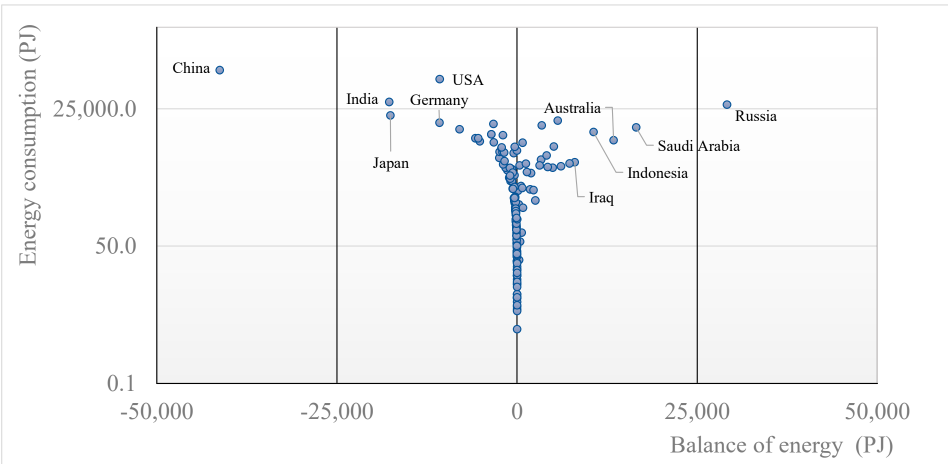
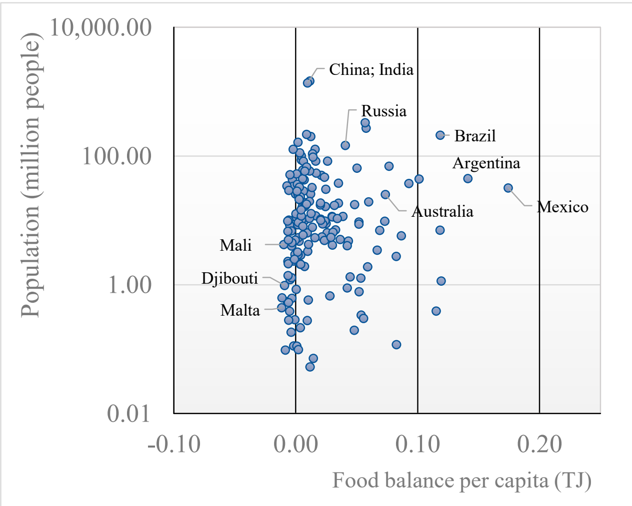
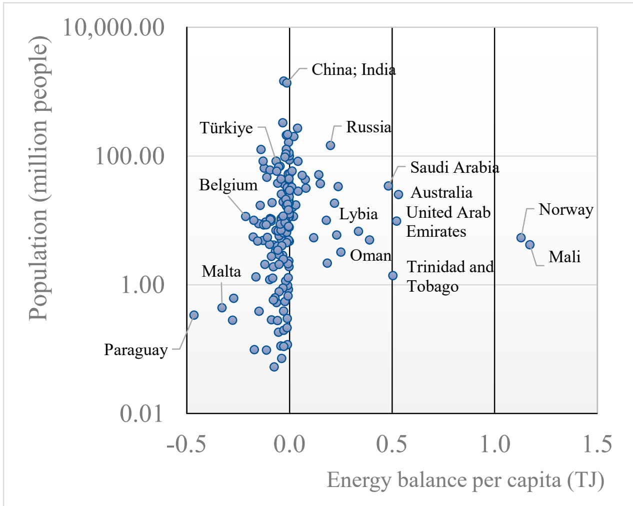


Figure 4. Balance of energy vs. energy consumption in different countries (2019).



(**a**)



(**b**)

Figure 5. (**a**) Food balance per capita vs. population; (**b**) Energy balance per capita vs. population (2019).

Highlighting the correlation between energy and food, we note that the production of food in energy units is about half of the primary energy production, while the FAO estimates that 30% of energy is consumed for agriculture [127]. It is also important to note that the literature has assumed a causal relationship between energy consumption with GDP and life expectancy [106,111,128].

Water participates in the WEF nexus with many uses (drinking, hygiene, irrigation, hydropower). Water availability varies globally, and, therefore, in order to standardize its value, we considered the total water withdrawals, which are available from the database of AQUASTAT [129], and we assumed the embodied energy of water to be that of desalinated sea water, which requires 5 kWh/m^3 [130–133] to be produced.

In Figure 6, we observe that water withdrawals are positively correlated with primary energy production, food production, and agricultural land.

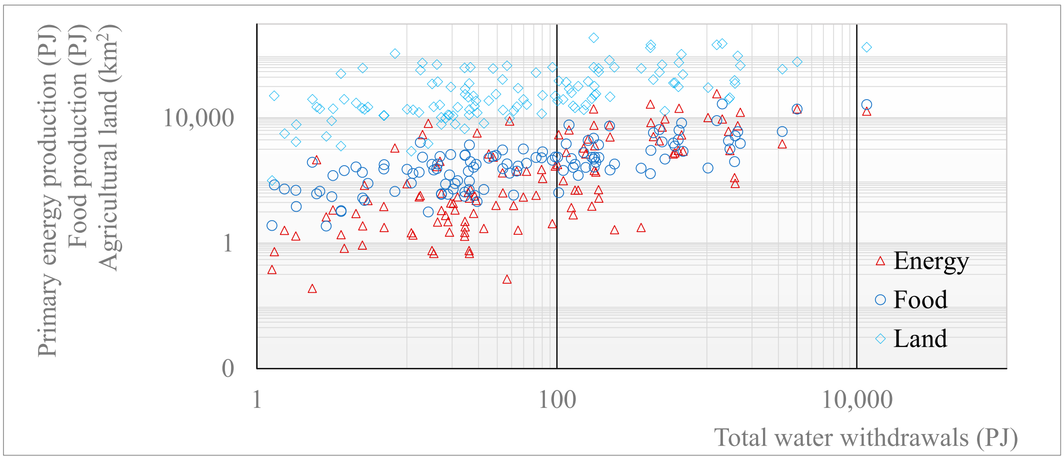


Figure 6. Primary energy production, food production, and agricultural land vs. total water withdrawals expressed in energy units as desalinated water (2019).

In order to convert GDP (USD) into energy units, we used each country's electricity prices (which is the higher price of energy) according to the World Bank's available datasheets [134,135].

The big picture indicates that the annual GDP is about 7.5 times higher than the annual energy consumption in energy values of electricity prices (Figure 7). Figure 8 shows that the ratio between GDP in energy units to GDP in monetary units is higher in countries with an energy surplus.

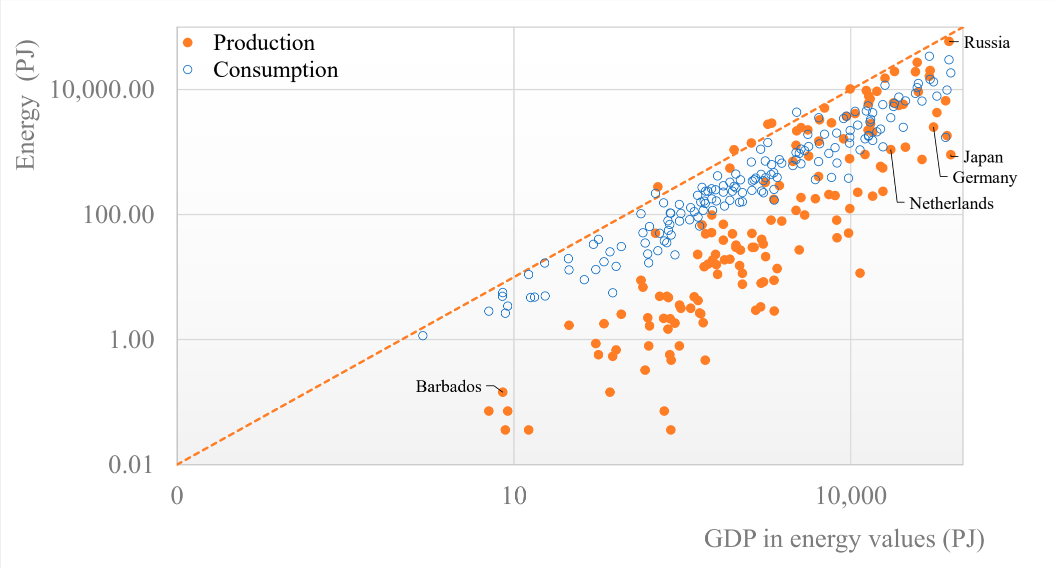


Figure 7. GDP expressed in energy units (PJ) correlated with primary energy production and energy consumption in different countries (2019).

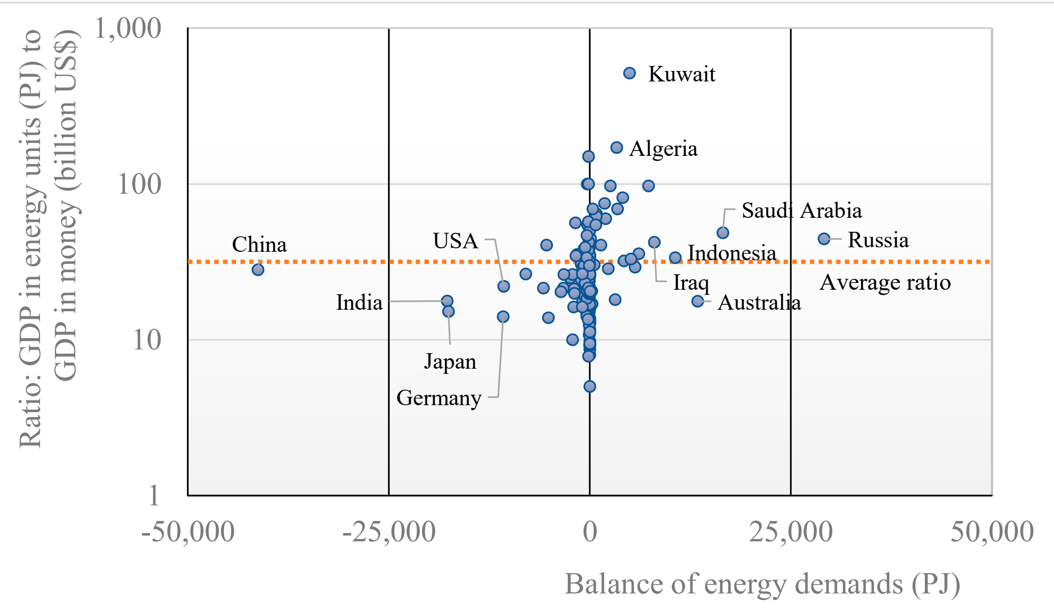


Figure 8. Ratio of GDP expressed in energy units to GDP in money (USD) vs. the balance of energy demand.

A closer examination of the relationship of countries' areas [136] (Figure 9) with the units of the WEF nexus and GDP shows a positive correlation. This can be justified by large-scale land acquisitions which aim at achieving economies of scale (minimization the unit cost) focusing on the optimization of one part of the nexus (e.g., renewable energy production [137–139]) or in one crop type [140].

However, even if land is a major driver of the economy, the inequality of the distribution of WEF sources produces impressive exceptions. One of these is Qatar, which is a small country with the highest income per capita as a result of its availability of energy sources.

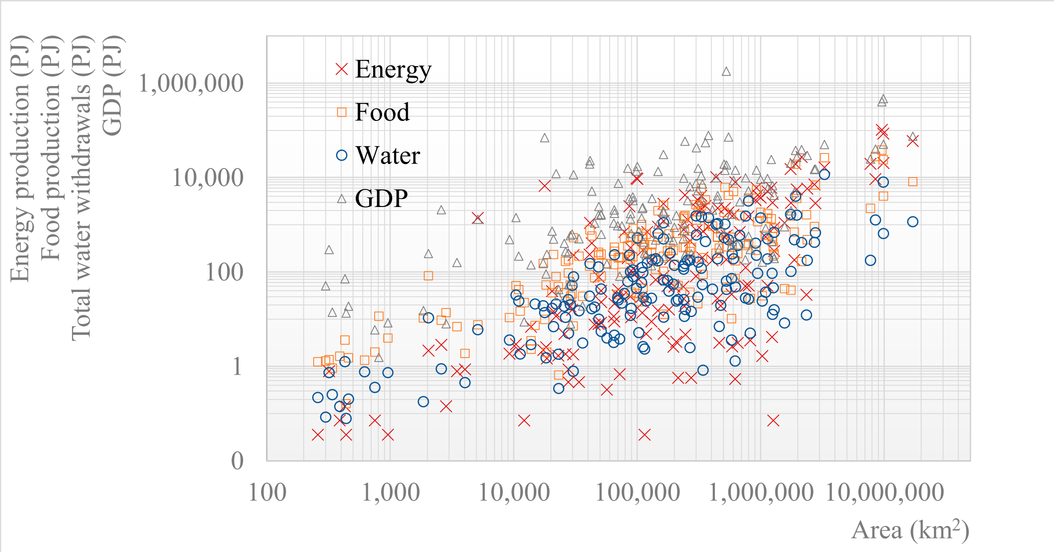


Figure 9. Primary energy production, food production, total water withdrawals, and GDP, vs. the area of each country (2019).

5. Discussion

Wealth expressed in money appears to be an indicator of well-being from its correlation with life expectancy [28]. This correlation arises from the population's access to health care and living standards in an environment with developed infrastructure. In addition, the standards for prosperity in the modern way of life are: the ownership of cars, mobile phones, domestic appliances, medicines, and high hygienic standards (abundance of water). These have two main characteristics:

- They are capital-intensive to achieve economies of scale in order to minimize the unit cost.
- They need energy, water, and other natural resources.

Therefore, a closer examination shows that the correlations with life expectancy arise due to access to the WEF nexus, since all the parts of the nexus are necessary for the existence and growth of society (hence the economy), and not vice versa, even if (in energy units) the composed nexus shares are: money 0.83; energy 0.11; food 0.05, and water 0.01.

WEF sources are not distributed equally in the world. The inequalities are quantified in Figure 10 in terms of average quantities among the different countries, even if, evidently, inequalities also exist among the people of each country. As usual with economic data, we follow the convention of expressing the income distribution in tenths of the share x (%) of people from the lowest to highest income vs. share y (%) of income earned. As income, we consider the availability of resources (food per capita, energy per capita, and water per capita). In Figure 10a, the double dashed grey line shows the case of all people having the same access to resources. Figure 10b shows the Lorenz curve, which is the plot of the cumulative share of income vs. the corresponding cumulative share of the population. In the case of a perfect equality, the curve is a straight line (plotted as a double dashed grey line). From the Lorenz curve, we can calculate the Gini coefficient, which is a measure of socio-economic inequality estimated as: $G = A/(A + B)$, where A is the area that lies between the line of equality and the Lorenz curve, and B is the area between the Lorenz curve and the horizontal axes. Values of G tending to 0 indicate equality, whereas values closer to 1 indicate extreme inequality. Figure 11 depicts the Gini coefficient and evaluates the inequalities of the distribution of different resources.

Major famines were not spotted in 2019. Therefore, as food needs per capita were almost stable and all humans had to have access to this resource, we note that trading decreased the inequalities in food production (Gini coefficient equal to 0.34). We also note that energy production (Gini coefficient equal to 0.63) was globally distributed as the consumption has a smaller Gini coefficient (equal to 0.45). Even if it is difficult to distinguish the interactions inside the nexus on a large scale, related data show that the interactions between the elements of the nexus are positively correlated, with a correlation coefficient equal to 0.1 for food–water, 0.1 for food–energy, and 0.2 for energy–water.

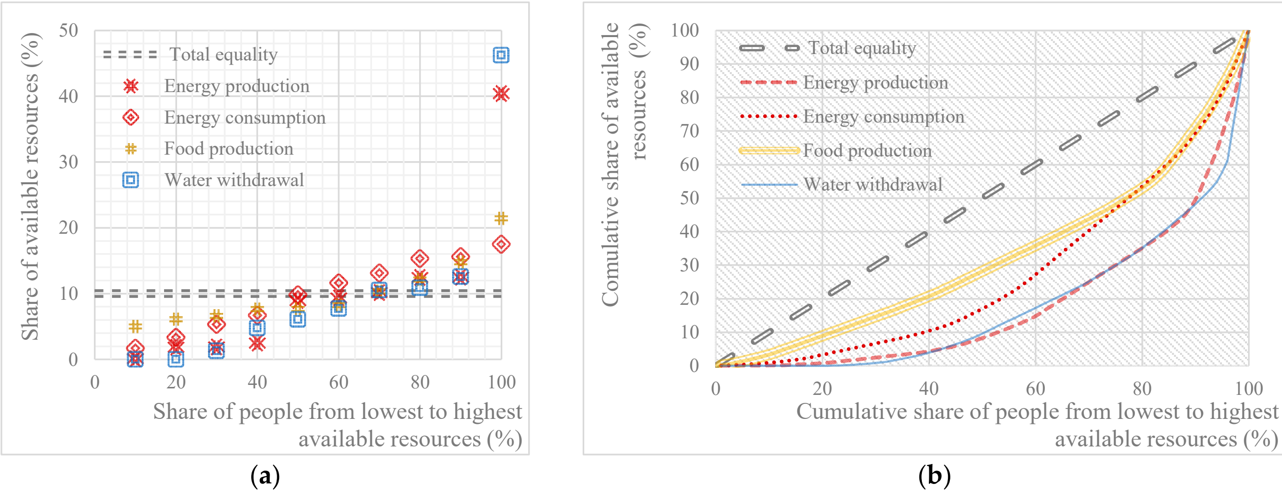


Figure 10. Inequalities of resource distribution per capita. Grey double dash line shows total equality with Gini coefficient equal to 0 (2019); (**a**) Share of resources; (**b**) Lorenz curve.

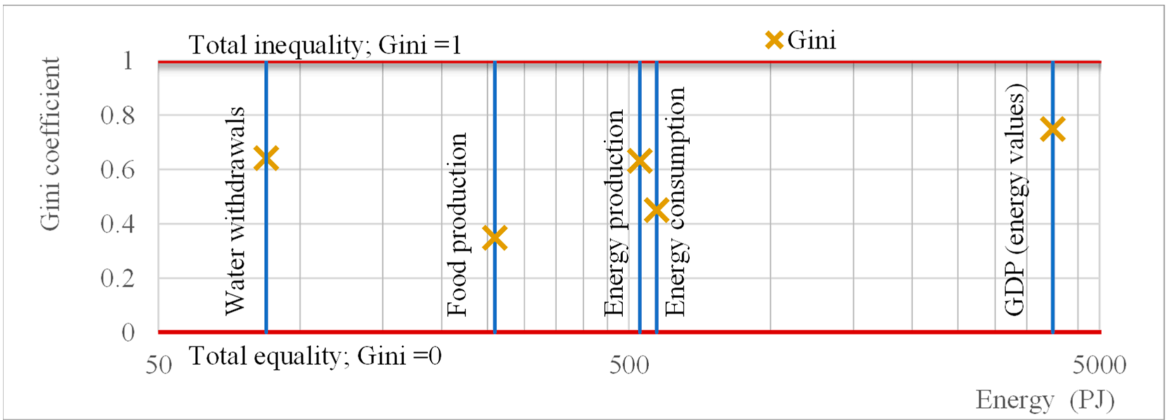


Figure 11. Gini coefficient vs. the total available resources and money in energy units.

From the above, it becomes clear that the base of prosperity, water, food, and energy, is not distributed equally in the world, yet the world finds a balance by means of trading.

As the needs vary for each country, countries must achieve a positive balance. Therefore, the trading of goods, especially energy and food, is a millennia-old survival tool to stabilize the balance of societies (e.g., in antiquity, Athens imported wheat from the area of Black Sea [141,142]).

Even countries with the wealthiest people have deficits of energy or food [143], e.g., Figure 12 highlights Kuwait (which has a deficit of food) and Luxembourg (which has a deficit of energy). Adding the dynamics of money in energy values, we see that these deficits are replenished by trading, which gives a surplus. However, this surplus may be marginal or negative for the least developed countries with low GDP per capita.

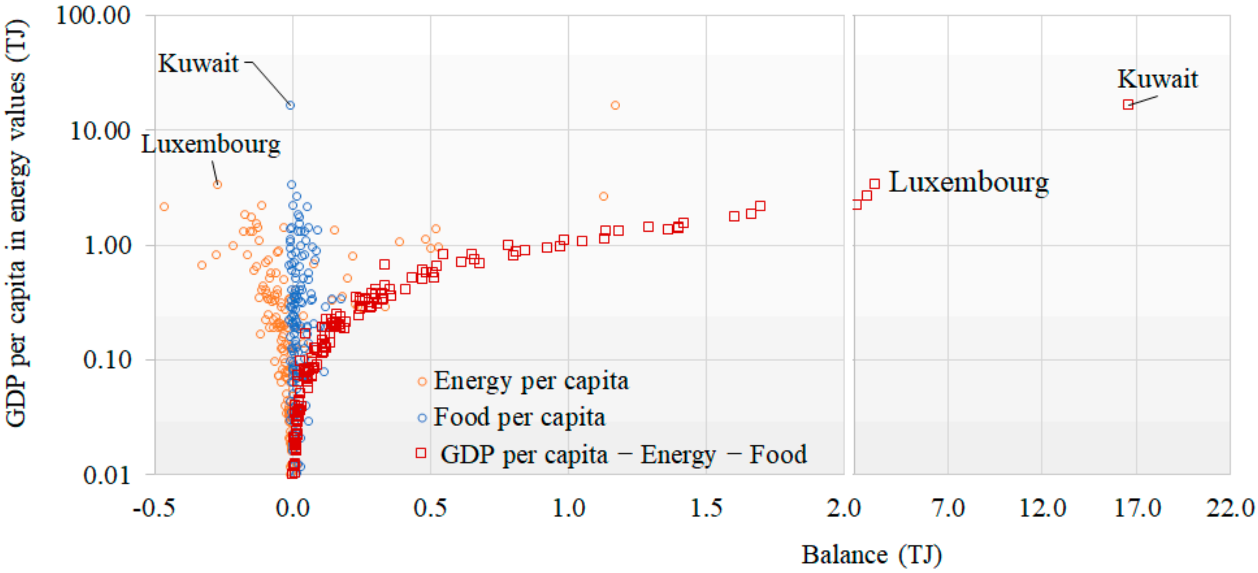


Figure 12. Balance of energy and food per capita, and GDP per capita in energy units minus the deficit (in absolute values) of energy and food per capita, vs. GDP per capita in energy units (2019).

6. Conclusions

Land is the basic element of the foundation of the society as it is the field for water, energy and food, which are the basic elements of prosperity. As the modern world is more focused on the economy than the WEF and land nexus, we studied the link of money with the nexus.

For each kind of evaluation, a necessary process is to standardize all the elements in the same unit. Therefore, in this paper, we chose energy units, as they give us a quantitatively stable measure diachronically, contrary to the subjectivity and high variability of the value of money. Using energy units, we investigate the links of money, land, and WEF.

Adding money (the dynamics of trading), we see that the world finds a positive balance [144]. However, the modern world gives more importance to economy [145], ignoring that, without the spread of the goods of the WEF nexus, the very existence of people (and society) will be in question immediately after a possible WEF nexus collapse. In addition, we highlight that money is not a stable value, and, therefore, a higher energy cost means less money. According to our approach, instead of using forex for the correlation of currencies, it is better to correlate currencies in a stable value, as energy units. Finding a rational evaluation of money's value is a way to manage the geopolitical conflicts followed by the ambiguity of the value of money [146–150].

Recent geopolitical events led BRICS to accelerate the connection of their currencies [151], creating a parallel monetary system using gold as its base [152]. In other words, the BRICS countries are trying to correct one blunder with another, as it is difficult to take lessons from the past [153,154] (cf., the Ancient Greek myth of Midas, which described the subjectivity of gold and how Midas was trapped and starved by his divine charisma transforming everything to gold, which is not eatable [155]).

A typical way to influence the power of money is the suspension of trading. A historical example is the suspension of trading caused by economic sanctions, as these were implemented in the economic war of Austria and Serbia (1906–1909) by closing the border to Serbian pork (widely known as the "pig war"). However, this proved a counterproductive measure, as Serbia quickly found other export markets [156]. At present, based on a related report from the UN [157], which highlights the global impact of the suspensions in trading caused by the economic sanctions on Russia, the Secretary-General of United Nations urged world leaders to "Act now to end food, energy and finance crisis" [158]. The same features for this conflict are highlighted by International Monetary Fund [159].

Discussing the suspensions of trading which arose recently between China and the U.S. due to geopolitical conflicts (cf. [160]), Brian Moynihan, CEO of Bank of America notes [161]: "It's interesting to watch the shadowboxing between these two countries. But the best thing in the world is to have free trade". Quoting Pepe Escobar [162], geopolitical conflicts which drive economic sanctions and cause suspensions in trading could be considered as "flirting with mushroom clouds".

Further research could examine, in a more analytical manner, the cost of energy and the energy mix by adopting the values of different energy sources. This evaluation could also study differences by climatic zones, geographical areas, or geopolitical zones (e.g., EU, West, BRICS). In addition, using 2022 updated data (not available yet) of the nexus, we could see the impact of present geopolitical conflicts. Additional evaluations could be focused on the use of fertilizers, population activity, and the dynamics of clustering (e.g., population density).

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