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RESEARCH ARTICLE

Energy Sources in Natural and Anthropogenic Ecosystems

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ABSTRACT

This study makes an inventory, a classification and a SWOT analysis of all energy sources that support the functionality of natural and man-made systems. The analysis is carried out at the planetary level, taking into account the entire ecosphere. It is an interdisciplinary study based on literature, integrating information from the field of ecology with that of physics, chemistry, biology, meteorology, and geography. The study carries out an inventory of all types of energy sources; makes a classification of these sources according to their origin and determines which is the most advantageous source through a SWOT analysis. The entire activity of the earth is supported by two large categories of energy sources, namely solar energy and telluric energy. Currently, ten types of energy sources are used or are in the experimental stage, five sources with solar origin and five sources with telluric origin. The most advantageous energy source in terms of regeneration capacity, production costs and ecological footprint is the biofuels. The conclusions of this study are very useful in the realization of energy production strategies and the selection of the most advantageous sources in terms of cost and benefit.

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1. Introduction

The entire activity of the ecosphere, which is evident through many processes and phenomena, is sustained by numerous sources of energy. Without an input of energy, the activity of the ecosphere would be impossible. From the point of view of their origin, the energy sources that support the functioning of the ecosphere are of two categories: sources of solar origin and sources of telluric origin. The sources of solar origin are the following: fossil fuels, biomass, solar energy fixed by photovoltaic panels (the visible and ultraviolet spectrum radiations) and thermic solar energy (infrared spectrum radiations), wind and wave energy. The sources of telluric origin are the following: nuclear, geothermal, hydropower tidal and energy.

1.1. Sources with Solar Energy Origin

Fossil fuels represent radiant solar energy that was fixed through photosynthesis processes in the Cambrian period. This energy was stored as biomass and fossilized in the very slow geological processes that were involved in the formation of fossil fuels such as oil, coal and methane gas. We can say that the fossil fuels represent biomass from the Cambrian Era that fossilized over time (Karatzos et al., 2014). The most important sources of energy production were based on fossil fuels (mostly oil and gas but coal also – exhaustible energy resources), which caused consequences in the form of excess emission of greenhouse gasses (Ziemiński & Frąc, 2012).

Biofuels (biomass, biodiesel, wood, etc.) represent radiant solar energy fixed through current photosynthesis processes

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and stored as biomass. Any organic materials, living or that have been dead for a short period derived from plants or animals are classified as biomass. In plants, biomass is formed through the conversion of carbon dioxide in the atmosphere into carbohydrates in the presence of the sun's energy (Basu, 2018). Bioenergy derived from biomass is a renewable source of energy that can be utilized as an alternative to non-renewable sources of energy like coal for energy generation (and electricity production). However, biomass as provided by nature has less energy density, more moisture and the volatiles when compared to coal (Wen et al., 2014). Biofuel is a fuel that is produced by contemporary biomass processes, rather than by the very slow geological processes involved in the formation of fossil fuels, such as oil. Biofuel can be produced from plants (i.e., energy crops), or by agricultural, commercial, domestic, and/or industrial waste (if the waste has a biological origin). Biofuel generally involves contemporary carbon fixation, such as those that occur in plants or microalgae through the process of photosynthesis (Karatzos et al., 2014).

The most important biofuels are bioethanol, biodiesel, herbaceous biomass, wood and methane (gas obtained by anaerobic fermentation of plant residues). These biofuels have biomass as a precursor. Hydrothermal liquefaction (HTL) is a thermo-chemical process that converts wet biomass or organic waste into a liquid bio-oil under high temperature and pressure conditions in the presence of water (Halil, 2023). Biomass is one of the most promising alternative energy sources, because similar to carbon neutrality and availability from multiple sources (Mamvura & Danha, 2020). Biomass is an inexhaustible source of energy that regenerates at a rapid rate compared to the regeneration rate of other inexhaustible resources. It is produced naturally without the need for infrastructure and equipment; through the process of photosynthesis, it fixes, stores, and recycles the CO_2 from combustions. Hence, biomass is the most cost-effective source of energy for the future, having zero risk compared to nuclear energy and the lowest ecological footprint (Gheorghe & Strat, 2023).

Solar energy is represented by radiant light and heat from the Sun. This energy can be harnessed using a range of technologies to generate electricity and thermal energy which can be used for heating the water or the air in one's house (Gheorghe & Strat, 2023; IEA, 2012). It is an essential source of renewable energy, and its technologies are broadly characterized as either passive solar or active solar, depending on how they capture and distribute solar energy or convert it into other energy sources. Active solar techniques include the use of photovoltaic systems, concentrated solar power, and solar water heating to harness the energy. Passive solar techniques, on the other hand, include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces in which the air circulates naturally. In 2021, the Carbon Tracker Initiative estimated the land area needed to generate all energy from solar alone was 450,000 km^2 or about the same as the area of Sweden, Morocco, or California (0.3% of the Earth's total land area) (Gheorghe & Strat, 2023; Walther, 2021). Photovoltaic panels predominantly absorb radiation from the visible and ultraviolet spectrum, and radiation from the infrared spectrum enhances the fixing capacity of the semiconductors in them. Energy enjoys a high level of socio-political acceptance and is preferred to other renewables, although it is unclear whether this acceptance persists if the technology is deployed on a large scale (Cousse, 2021). Radiant solar energy from the infrared spectrum can be used directly by heating water or air in different buildings, or indirectly by using wind and wave energy.

Wind and wave energy is due to the non-uniform heating of air and vapors in the atmosphere through the inhomogeneous absorption of infrared radiation from solar radiation. Air masses, charged or not with water vapor, have different densities, those at high temperatures being lighter, and those at lower temperatures being heavier. These different densities determine a certain air circulation either vertically or horizontally and are the basis of wind formation. In coastal areas, or on the surface of bodies of water, the wind transmits some of its energy, causing standing waves. In conclusion, winds and waves are also generated by sunlight, the radiation from the infrared spectrum being responsible. Wind power is the result of using wind turbines to generate electricity. Wind power is a popular, sustainable, and renewable energy source that has a much smaller impact on the environment than burning fossil fuels. Wind farms consist of many individual wind turbines, which are connected to the electric power transmission network. Offshore wind is more constant and stronger than the one on land and, it has a lower visual impact. Although there are fewer offshore wind farms at the present moment, and construction and maintenance costs are higher, it is expected to expand in the future (Gheorghe & Strat, 2023; Haluzan, 2011; Millborrow, 2010).

1.2. Sources with Telluric Energy Origin

Nuclear energy represents the process through which electricity is obtained from nuclear reactions. This process consists of splitting atoms in a reactor to heat water into steam, which further turns a turbine and generates electricity. There are several ways in which it can be obtained, such as nuclear fission, nuclear decay and nuclear fusion reactions (Gheorghe & Strat, 2023).The chemical elements that have radioactive isotopes used as nuclear fuels in fusion power plants to sustain a nuclear chain reaction are Thorium, Uranium and Plutonium.

These chemical elements with Z greater than or equal to 90 have large nuclear masses and present a varied number of isotopes, as follows: $^{207\text{-}238}$Th $^{214\text{-}242}$U and $^{228\text{-}247}$Pu.The large number of isotopes indicates a large number of neutrons in the nucleus, which induces a state of instability in the nucleus of

some of these isotopes. These unstable isotopes represent the radioactive forms of the respective chemical elements. In the case of thorium, except for the radioisotope ^{232}Th which is relatively stable, all others are unstable. Thorium boasts several advantages over the conventional nuclear fuel, ^{235}U. Thorium can generate more fissile material (^{233}U) than it consumes while fueling water-cooled or molten salt reactor, and it generates fewer long-lived minor actinides than plutonium fuels. It is estimated that the Earth's upper crust contains an average of 10.5 parts per million (ppm) of thorium, compared with about 3 ppm of uranium (Vlasov, 2023).These fuels are fissile, and the most common nuclear fuels are the radioactive metals ^{235}U and^{239}Pu .^{235}U is used as a fuel in different concentrations. For example the CANDU reactor can use natural uranium with ^{235}U concentrations of only 0.7%, while other reactors require the uranium to be slightly enriched to levels of 3% to 5%. ^{239}Pu is produced and used in reactors (specifically fast breeder reactors) that contain significant amounts of ^{238}U. It can also be recycled and used as a fuel in thermal reactors. Current research is being done to investigate how ^{232}Th can be used as a fuel (Murray, 2008). At the present moment, the vast majority of electricity obtained from nuclear power is produced by the nuclear fission of uranium and plutonium in nuclear power plants. This type of energy is considered clean concerning greenhouse gas emissions. However, it has two major disadvantages. On one hand, the fission and fusion reactions cannot be completely controlled; hence a risk of nuclear incidents/accidents is always present. On the other hand, the nuclear waste resulting from the use of nuclear fuel cannot be neutralized, and its storage requires special conditions. Such conditions are mandatory, as the physical and radioactive cooling generates radiation with harmful effects on human health, flora and fauna. Therefore, waste storage requires special enclosures and caves in areas with low seismic risk (Galindo, 2021; Gheorghe & Strat, 2023). Ninety-three nuclear reactors in 28 states generate nearly 20 percent of the nation's electricity, all without carbon emissions because reactors use uranium and not fossil fuels. These power plants function constantly/are constantly in use: well-operated to avoid interruptions and built to withstand extreme weather (Gheorghe & Strat, 2023; Ritchie et al., 2021).

Geothermal energy is made up of two components, namely the thermal energy in the Earth's crust which results from the cooling of the magma and the energy which follows from the disintegration of radioactive materials. The ratio between the two components is currently uncertain but there is a possibility of roughly equal proportions in some cases (Dye, 2012). The earth's crust, the solid and cold form of the earth, has high temperatures in the deep layers. The high temperature and pressure in the Earth's core cause some rock to melt and solid mantle to behave plastically. This results in parts of the mantle converting upwards since it is lighter than the surrounding rock. Temperatures at the core-mantle boundary can reach over 4000 °C. The agent that takes the thermal energy of the deep and hot layers of the earth's crust is water from the depths. This, in the form of steam or hot liquid, reaches the surface of the earth through the various cracks or penetrations of the crust.

Hydropower is the energy produced by the water flow through the gravitational fall. Mountain, hill, and plain relief forms have different altitudes, and the classification of an area from a geographical point of view is closely related to the altitude. Water from watercourses located at high altitudes has a high potential energy compared to low relief areas. In free fall, the potential energy of water is transformed into kinetic energy, energy that sets the turbines of hydropower plants in motion and produces electricity. I considered the hydro energy to be of telluric origin because the oscillations of the height of the Earth's crust lead to different forms of relief, of different altitudes between which there are potential differences. Hydropower also known as water power, is the use of falling or fast-running water to produce electricity or to power machines. This is achieved through the gravitational potential or kinetic energy of a water source to produce power. Hydropower is a method of sustainable energy production. Since ancient times, hydropower from watermills has been used as a renewable energy source for irrigation and the operation of mechanical devices, such as gristmills, sawmills textile mills, trip hammers, dock cranes, domestic lifts, and ore mills (Egré & Milewski, 2002). Water energy is mainly used for hydroelectric power generation. Half of this is produced by the free gravitational fall of water and half by the pumped water in dams. Hydropower is an attractive alternative to fossil fuels as it does not directly produce carbon dioxide or other atmospheric pollutants and also provides a relatively consistent source of power. Nonetheless, it has economic, sociological, and environmental downsides and requires a sufficient power source of water, such as a river or an elevated lake (Donald, 1996).

Tidal is another form of hydro-energy that uses twice-daily tidal currents and waves to drive the turbines of generators. Although tidal flow is not constant (unlike some other hydro-energy sources), it is highly predictable and therefore, it can compensate for the periods when the tide is currently low (Griffin, 1992; Gheorghe & Strat, 2023).

Hydrogen combustion: Hydrogen is an attractive alternative fuel. However, unlike coal, gas or oil, hydrogen is not a primary energy source. Rather, its role mirrors more closely that of electricity as a secondary 'energy carrier', which must first be produced using energy from another source and then transported for future use where its latent chemical energy can be fully realized. Hydrogen can be obtained from diverse resources, both renewable (hydro, wind, wave, solar, biomass and geothermal) and non-renewable (coal, natural gas and nuclear). It can be stored as a fuel and used in transportation and distributed heat and power generation systems using fuel cells, internal combustion engines or turbines, with the only by-

product at the point of use being water. The ability of hydrogen to replace fossil fuels in the transportation sector could address one of the world's major environmental problems (Johnston et al., 2005).

Hydrogen can also be used as a storage medium for electricity generated from intermittent, renewable resources, such as solar, wind, wave and tidal power; it thereby provides the solution to one of the major issues of sustainable energy, namely the vexing problem of intermittency of supply. As long as the hydrogen is produced from non-fossil fuel feedstock, it is a genuinely 'green' fuel. Moreover, locally produced hydrogen allows for the introduction of renewable energy to the transport sector, provides potentially large economic and energy security advantages and the benefits of a new infrastructure based on distributed generation. It is this key element of the energy storage capacity of hydrogen that provides the potent link between sustainable energy technologies and a sustainable energy economy, generally placed under the umbrella of 'hydrogen economy' (Muradov & Veziroglu, 2005).

Hydrogen has an outstanding potential for becoming a major factor in catalyzing the transition of our carbon-based global energy economy ultimately to a clean, renewable and sustainable economy. The development of hydrogen production, storage and utilization technologies is set to play a central role in addressing growing concerns over carbon emissions and climate change, as well as the future availability and security of energy supply. Hydrogen and fuel cells are considered in many countries as an important alternative energy vector and key technologies for future sustainable energy systems in the stationary power, transportation, industrial and residential sectors (Edwards et al., 2007)

2. Materials and Methods

It is an interdisciplinary study based on literature, integrating information from the field of ecology with that of physics, chemistry, biology, meteorology, and geography. The specialized literature was consulted; all the energy sources that are used by both humans and natural ecosystems were identified. Based on the origin of the respective source, two classes were created. For the production mode of each energy source, the strengths and weaknesses were determined by performing a SWOT analysis. Based on this analysis, the energy source that is the most advantageous for the product was identified.

3. Results and Discussion

The production of energy using certain sources has the same or different limitations. To conclude which is the most advantageous energy source, a SWOT-type matrix must be made, taking into account at the same time the weak points and the strong points, a multivariate analysis. The table below specifies the advantages and disadvantages that appear in the energy production process (Table 1).

Table 1. The advantages and disadvantages that appear in the energy production process.

No.	Source	Advantages	Disadvantages
		Sources with Solar Energy Origin	
1	***Fossil fuels***	- the industry that processes them is already developed - the industry that uses the finished products obtained through processing is already developed - there is a lot of know-how regarding the extraction, processing and use of the finished products	- it is an exhaustible source - more than 90% of the energy consumed by the world's population (electricity, home heating, transport, etc.) is provided by fossil fuels; economies of states being dependent on an exhaustible energy resource - it requires equipment for extraction and processing and the ecological footprint for the production of this equipment is large - during exploitation, transport and processing there is a risk of accidental and historical pollution. - in the processing process, polluting secondary products appear - burning them and the products obtained through processing is polluting - uneven distribution at the level of the globe, which generates inequities in exploitation and use for different states. - it does not regenerate in a reasonable time (accumulation of peat as a type of lower coal requires hundreds of years) - used equipment requires large amounts of energy for recycling - extraction and processing pose a risk to the health of those working in coal mines. - suspended powders and gaseous noxes resulting from combustion present an increased risk to human health

			- surface mining of coal produces the total destruction of the ecosystems that covered the deposit - accidental or historical oil pollutions have a destructive effect on both the marine and/or terrestrial fauna and flora where the ecological disaster occurred. - the transport of methane gas involves the risk of explosions and fires - high costs for making the constructions and equipment
2	***Biofuels***	- the industry that processes them is already developed - the industry that uses the finished products obtained through processing is already developed - by processing, products are obtained in all three states of aggregation: solid (charcoal); gaseous (methane which is produced by the anoxic fermentation of vegetable waste and liquid products (biodiesel obtained by processing oilseeds such as rape, for example) - there is a lot of know-how regarding the extraction, processing and use of the finished products - it is a source of renewable energy - it is an inexhaustible source of energy - it does NOT require equipment for fixing and storing solar energy - in the production process of biofuels, the CO_2 content in the atmosphere decreases; it is fixed in the photosynthesis process - in the production process, the ecological footprint is negative - fix and store their own atmospheric CO_2 produced by burning and processing them - captures and stores atmospheric CO_2 produced by burning and processing other fuels - it does NOT require special space for production and storage - DO NOT modify the natural ecosystems where they are produced (for example wood from the forest)	- research interest concerning exploitation and processing into finished products has slowed down, attention is directed towards other alternative sources of energy - liquid products (biodiesel) are not adapted to the internal combustion engines of motor vehicles (cars, diesel locomotives), the motor vehicle industry must adapt its engines to the new fuel. - burning in internal combustion engines of biodiesel produces a significant amount of noxes and CO_2
3	***Solar energy***	- it is a source of renewable energy - it is an inexhaustible source of energy - it is a clean energy source	- requires special equipment (photovoltaic panels, energy storage batteries) - they generate energy only during the day, they are not functional at night - in the production of photovoltaic panels, rare metals such as silver are used, the resource that can be limiting for production - copper and pure silicon are present in the photovoltaic panels, their extraction and processing are energy-consuming and polluting - battery production requires lithium or lead, metals that can be limiting in the case of production, and their extraction and processing is carried out by an energy-consuming and polluting industry - the production of equipment has a large ecological footprint - recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting - photovoltaic parks change the way land is used, reducing agricultural areas, or other types of natural ecosystems - high costs for making the constructions and equipment
4	***Wind energy***	- it is a source of renewable energy - it is an inexhaustible source of energy - it is a clean energy source	- requires special equipment (wind turbines - blades, rotor and metal tower -, energy storage batteries) - battery production requires lithium or lead, metals that can be limiting in the case of production, and their extraction and processing is carried out by an energy-consuming and polluting industry - in the production of wind turbines, light metals such as aluminum are used, the resource that can be limiting for production

			- aluminum and iron are present in the wind turbines, their extraction and processing is energy-consuming and polluting - the production of equipment has a large ecological footprint - recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting - the wind blows irregularly, the production of wind energy being unpredictable - the winds whose regularity is greater overlap the migration routes of the birds, leading to their killing by the turbines blades - inside wind turbines parks change the way land is used, reducing agricultural areas, or other types of natural ecosystems - wind turbine parks outside, located in the coastal area, have negative effects on navigation - high costs for making the constructions and equipment
5	***Wave energy***	- it is a source of renewable energy - it is an inexhaustible source of energy - it is a clean energy source	- the waves are produced irregularly, the production of wave energy being unpredictable - requires special equipment (floating platforms with wave turbines, energy storage batteries) - floating platforms with wave turbines located in the coastal area, have negative effects on navigation - the production of equipment has a large ecological footprint - high costs for making the constructions and equipment
		Sources with Telluric Energy Origin	
6	***Nuclear energy***	- it is a source with increased efficiency of converting nuclear fuel energy into electrical energy - the production of electrical energy from radionuclides is also accompanied by thermal energy that can be used to heat homes - the production of nuclear energy can be done in compacted spaces	- requires special constructions (nuclear power plants with reactors) - nuclear fuels (Th, U and Pu) are unevenly distributed globally, they are a limiting factor in energy production - extraction and processing pose a risk to the health of those working in radionuclide mining - exploitation in U and Pu mines have destructive effects on the ecosystems where the mining is done and on the neighboring ones - the waste resulting from the burning of nuclear fuels cannot be neutralized by chemical methods, and the neutralization by physical methods is at an experimental stage and with high energy consumption - the storage of nuclear waste requires special conditions because nuclear reactions continue in this waste, and the emission of radiation α, β, and γ, predicts a risk to human health - fission and fusion reactions are insufficiently controllable reactions and there is a risk of incident and nuclear accident - the production of equipment has a large ecological footprint - recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting - the bars in which the nuclear fuel pellets are arranged are made of cadmium, a relatively rare metal, and the storage containers are made of lead, metals that are extracted and processed by a polluting and energy-consuming industry. - the use of lead, as in the case of the production of solar panels, makes the two industries competitive in terms of lead consumption - the production of heavy water (^3H_2O) used to reduce fission product emissions from the reactor requires special equipment - high costs for making the constructions and equipment
7	***Geothermal energy***	- it is a source of renewable energy - it is an inexhaustible source of energy	- there are very few areas on the surface of the globe with cracks where water and vapors come to the surface

		- it is a clean energy source	- requires special equipment for capture and transport - the hot water has solubilized a large amount of salts and the transport pipes are corroded and obturated by the precipitation of carbonates and other salts - the production of equipment has a low ecological footprint - high costs for making the constructions and equipment
8	***Hydropower***	- it is a source of renewable energy - it is an inexhaustible source of energy - it is a clean energy source	- requires special constructions (storage lake, escape tunnels, dam with turbines, power generation network) - the construction of the dam and the reservoir (storage lakes) have a destructive effect on the rivers and neighboring ecosystems - the production of equipment (turbines, cables, etc.) has a large ecological footprint - recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting - the oscillations of the water level in the river downstream of the hydropower plant induced by the various turbines have a harmful effect on the aquatic flora and fauna and the shore areas. - retention of water in accumulation lakes during dry periods has harmful effects on the flora and fauna of the river downstream of the dam - the functioning of the dam bypasses, in the case of torrential precipitations, produce abnormal increases in downstream flows with harmful effects on aquatic flora and fauna - high costs for making the constructions and equipment
9	***Tidal***	- it is a source of renewable energy - it is an inexhaustible source of energy - it is a clean energy source	- there are very few areas where the effect of tidal is evident - requires special equipment (floating platforms with wave turbines, energy storage batteries) - the production of equipment has a large ecological footprint - recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting - high costs for making the constructions and equipment
10	***Hydrogen combustion***	- it is a source of renewable energy - it is an inexhaustible source of energy - it is a clean energy source - the combustion of hydrogen is equivalent to “0” emissions	- it is still in the experimental stage - requires expensive equipment - the storage tanks in which it is compressed must withstand high pressures - during transportation and handling there is a risk of explosion - internal combustion engines are not adapted to this new fuel - the production of equipment has a large ecological footprint - recycling waste from equipment production and end-of-use equipment requires large amounts of energy and is polluting - high costs for making the constructions and equipment

Following the inventory of energy sources currently used, 10 types of sources were identified (Table 2). The number of sources identified for each of the two categories was perfectly balanced (five sources with solar origin and five sources with telluric origin).

Table 2. Number of the advantages and disadvantages that appear in the energy production process.

No.	Source	Number of Advantages	Number of Disadvantages
1	Fossil fuels	3	15
2	Biofuels	13	3
3	Solar energy	3	9
4	Wind energy	3	11
5	Wave energy	3	5
6	Nuclear energy	3	13
7	Geothermal energy	3	5
8	Hydropower	3	8
9	Tidal	3	5
10	Hydrogen combustion	4	8

The largest number of disadvantages in energy production is the use of fossil fuels (15), followed by nuclear fuels (13). Except for the use of biofuels, as an energy source, which presents a net higher number of advantages (13) compared to disadvantages (3), the rest of the sources have a higher number of disadvantages compared to advantages (Table 1 and 2). Biofuels represent the most advantageous energy source in terms of regeneration capacity, production costs and ecological footprint. Therefore, it would be advisable for future energy research to consider this source as a priority. It is recommended that studies focus on how to transform these fuels into products that can be used in current internal combustion engines and other energy-generating systems.

4. Conclusion

Although there are a relatively large number of energy sources, most of them have more disadvantages than advantages. The greatest number of inconveniences in the production of energy they have industries based on fossil fuels and nuclear ones. The energy industry with the most advantages in production is the one based on biofuels. Energy strategies designed for the future must focus research on biofuel processing technologies adapted to internal combustion engines and energy generating systems; identifying new advantageous energy sources; and equipment, internal combustion engines and systems as efficient as possible in the use of energy, leading to a saving in its consumption.

Conflict of Interest

The author has no conflict of interest to declare.

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