

Dynamics of Energy Sources: Development, Challenges, and Transitions

Mohamad Mokdad^{1,*}

¹Intelligentsia Center for Research and Studies, Zaragoza University, Zaragoza, Spain.
mhdmkd@gmail.com¹

Abstract: The evolution of energy sources reflects humanity's adaptation to growing demands and technological advancements. Initially reliant on traditional sources such as biomass, water, and wind, the energy landscape transformed with the Industrial Revolution and the widespread use of coal. Fossil fuels, including coal, oil, and natural gas, dominated the 20th century, driving industrial and economic progress but causing environmental concerns. Concurrently, the development of nuclear energy offered immense power potential but raised safety and environmental issues. In response to climate change and resource depletion, the 21st century has seen a significant shift toward renewable and alternative energy sources, such as solar, wind, hydropower, biofuels, and natural gas. Innovations in energy storage, infrastructure, and grid integration have made these new sources competitive and sustainable. Despite challenges like intermittency and investment requirements, renewable energy plays a pivotal role in reducing dependence on finite fossil fuels and achieving global energy security. The transition toward cleaner, more efficient energy systems marks a transformative period for energy production and consumption, shaping a sustainable future.

Keywords: Energy Evolution; Fossil Fuels; Renewable Energy; Hydropower and Biofuels; Sustainable Energy Transition; Technological Advancements; Energy Sources; Technological Innovation.

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1. Introduction

The evolution of energy sources is a fascinating journey through human history, reflecting the ingenuity and adaptability of civilizations as they harnessed various forms of energy to meet their needs. This historical outline spans millennia, from the earliest use of fire by our ancestors to the sophisticated energy systems of the modern era [12]; [5]; [11]; [17]; [13]. Ancient civilizations relied predominantly on biomass fuels such as wood, animal dung, and crop residues for cooking, heating, and lighting. The discovery of fire marked a pivotal moment in human history, enabling early humans to control their environment and expand their capabilities. Over time, societies developed more sophisticated techniques for utilizing biomass, including charcoal production and agricultural practices, to sustainably manage forests and fields. The transition from biomass to other forms of energy accelerated with the advent of agriculture and the rise of civilizations. Water became a crucial energy source for irrigation, transportation, and mechanical power, driving the development of early hydraulic civilizations such as those along the Nile and the Tigris-Euphrates rivers. The invention of the water wheel and the windmill further expanded humanity's ability to harness renewable energy sources, laying the foundation for future technological advancements [8].

*Corresponding author.

The discovery of fossil fuels, starting with coal in the 18th century, marked a revolutionary turning point in energy history. Coal powered the Industrial Revolution, fueling the rapid industrialization and urbanization of Western societies. The steam engine, powered by coal, transformed transportation, manufacturing, and agriculture, ushering in an era of unprecedented economic growth and societal change. The 20th century witnessed the rise of petroleum and natural gas as dominant energy sources, supplanting coal in many applications. The widespread adoption of internal combustion engines, fueled by petroleum, revolutionized transportation and enabled the mass production and distribution of goods. Meanwhile, natural gas emerged as a versatile fuel for heating, electricity generation, and industrial processes, reshaping energy systems around the world.

In parallel, the development of nuclear energy in the mid-20th century promised abundant and cheap power, albeit with significant environmental and safety concerns. Nuclear power plants became a major source of electricity in many countries, contributing to the diversification of energy sources and reducing dependence on fossil fuels. However, issues such as radioactive waste disposal and the risk of accidents tempered enthusiasm for nuclear energy. The latter half of the 20th century also witnessed growing awareness of the environmental impacts of fossil fuel combustion, particularly air pollution and climate change. This spurred renewed interest in renewable energy sources such as solar, wind, hydroelectric, and geothermal power. Technological advancements and policy incentives have accelerated the deployment of renewable energy technologies, leading to a global energy transition towards cleaner and more sustainable sources [12]; [5]; [11]; [17]; [13].

Looking ahead, the evolution of energy sources continues to unfold in response to technological innovation, economic trends, and environmental imperatives. The quest for energy security, affordability, and environmental sustainability drives ongoing research and development efforts in areas such as energy storage, grid integration, and efficiency improvements. As humanity confronts the challenges of the 21st century, the choices we make about energy sources will profoundly shape the future of our planet and society.

2. The Development of The Production of Traditional Sources of Energy

The development scenarios of traditional sources of energy, namely fossil fuels such as coal, oil, and natural gas, have undergone significant evolution over time, shaped by technological advancements, economic factors, and environmental considerations. These scenarios have varied across different regions and periods, reflecting the diverse energy landscapes and policy priorities of nations around the world. During the early stages of industrialization, the production of traditional energy sources followed a trajectory of expansion driven by growing demand for energy-intensive activities such as manufacturing, transportation, and electricity generation. This led to the establishment of large-scale extraction operations, often characterized by extensive mining or drilling activities in regions abundant in coal, oil, or gas reserves. These operations were typically vertically integrated, with companies controlling multiple stages of the production process, from extraction to distribution [14]; [4]; [1]; [6]; [18]; [7].

As industrialization progressed, particularly in the 20th century, traditional energy production underwent further transformation with the advent of technologies such as steam engines, internal combustion engines, and turbines. These innovations enabled more efficient extraction, processing, and utilization of fossil fuels, enhancing productivity and driving economic growth. The development of infrastructure such as pipelines, refineries, and power plants expanded the reach of traditional energy sources, facilitating their integration into global energy systems.

In the latter half of the 20th century, the production scenarios of traditional energy sources began to face growing scrutiny due to environmental concerns, particularly related to air and water pollution, as well as climate change. This led to increased regulation and oversight of extraction and production activities, with measures aimed at minimizing environmental impacts and ensuring public health and safety. Additionally, geopolitical considerations, including concerns over energy security and resource nationalism, influenced production scenarios, leading to strategic investments in domestic energy infrastructure and diversification of supply sources.

Despite these challenges, traditional energy sources have continued to play a dominant role in global energy production, accounting for the majority of electricity generation and transportation fuel consumption worldwide. However, the dynamics of traditional energy production are increasingly being influenced by shifting market trends and technological disruptions. The rise of renewable energy sources, advances in energy storage technologies, and the growing emphasis on sustainability are reshaping the energy landscape, prompting traditional energy producers to adapt their strategies and invest in cleaner and more efficient technologies [4]; [1]; [6]; [18]; [7].

Looking ahead, the future development scenarios of traditional energy sources are likely to be shaped by a combination of factors, including technological innovation, policy interventions, market dynamics, and societal preferences. While traditional energy sources will continue to play a significant role in meeting global energy demand in the near term, their long-term sustainability remains uncertain, necessitating a transition towards cleaner and more sustainable alternatives. Adaptation and

diversification will be key for traditional energy producers to navigate the evolving energy landscape and ensure their continued relevance in a rapidly changing world.

2.1. Traditional Sources of Energy

Since the advent of machinery, humans have sought energy sources to power them. Initially, this energy came from animals, wind, and water. The invention of the steam engine by the Scotsman James Watt in 1765 marked a pivotal change, as it allowed for the conversion of thermal energy into kinetic energy, laying the foundation for the Industrial Revolution [15]. However, Watt's steam engine was not solely responsible for the birth of modern industry; it was also a response to the significant accumulation of wealth, the need for market expansion, and the burgeoning demands of scientific, economic, and technical progress.

Energy sources can be categorized in several ways: as depletable or renewable, primary or secondary, polluting or environmentally friendly, and traditional or new. Fossil fuels fall into the category of traditional energy sources. Historical records suggest that oil sands were used by ancient Mesopotamians and the indigenous peoples of Canada, indicating an early recognition of their value [16]. In the 18th century, coal began to supplant wood as the primary fuel source. The discovery of oil in Pennsylvania in 1859 led to the use of kerosene and, subsequently, gasoline as a fuel for automobiles by the end of the 19th century.

Primary energy sources are those from which energy is directly obtained, such as solar, hydro, wind, or oil. Secondary energy sources, on the other hand, are derived from converting or processing a primary energy source. For example, electrical energy generated from solar or wind is considered a secondary source [2]. Initially, humans relied on muscular energy sourced directly from themselves or domesticated animals. This underscores the evolution from direct, manual labour to the sophisticated use of energy sources that define our modern industrial landscape. In parallel, he began to understand and invest in some natural factors, such as the thermal energy resulting from the sun's rays. Then, he discovered the mechanical energy resulting from water and wind.

After that, he began to domesticate fire and use it to produce energy, which he was able to tame. And when coal was discovered, and then oil, man moved to an advanced stage of development because of the huge amount that could be produced from energy. The discovery of nuclear energy was a cumulative result of all the progress factors, coupled with the endless new needs and human ambition that cannot be satisfied in any way.

2.1.1. Hydropower

Hydropower, commonly perceived as energy derived from the gravitational fall of water, involves transforming the mechanical energy from this fall into other forms of energy, including mechanical or electrical, using specialized transducers. However, water also produces energy through the motion of waves, tides, and the flow of rivers, which humans have harnessed since ancient times for transporting wood and supplies.

Hydropower stands as one of the most utilized renewable energy resources worldwide, mainly for generating electricity and commercial investment. The inception of water-powered electricity plants dates back to 1880, with global production increasing by approximately 5% annually since then. Hydropower accounts for about 16% of the world's electric energy production, serving as the primary electricity source in some countries, such as Brazil and Norway, where it contributes up to 90% of the national electricity supply International Energy Agency (IEA) in 2020.

The effectiveness of hydropower is contingent on rainfall patterns and the geographical characteristics of the landscape. It supplies half of the electricity in a third of the world's countries. By 1940, most of the suitable sites for hydropower plants had been developed in industrialized nations, slowing the establishment of new plants in these regions. Currently, new or ongoing hydropower projects are predominantly found in developing countries, notably India, China, and Brazil. It's important to note that the statistics mentioned do not account for small-scale plants, with outputs ranging from 10 kilowatts to one megawatt, even though their number significantly exceeds those of high-output facilities. This discrepancy is due to the smaller investment size required for these projects compared to the substantial investments needed for larger-scale operations.

A key advantage of hydropower plants is their longevity, with turbines having a minimum operational lifespan of fifty years, requiring minimal maintenance and repair. Once the initial investment and equipment costs are amortized over the lifespan of the facilities, the cost of producing electricity can be as low as 0.04 euros per kilowatt-hour, making it the most cost-effective means of energy production (International Renewable Energy Agency (IRENA) [10].

Besides turbine technology, two modifiable factors can influence energy generation: the height from which water falls onto the turbine and the volume of water passing through the system. The greater the height or volume, the more energy can be theoretically generated, depending on the turbine's capacity. Thus, controlling the amount of generated energy involves straightforward techniques long known in the field. For potential investors, securing the necessary funding for engineering works constitutes the bulk of the investment challenge [22].

Water-energy production plants excel in their rapid responsiveness to adjust output according to demand during peak and off-peak hours simply by regulating water flow through the generator. Moreover, these plants exhibit minimal technical energy loss, boasting an efficiency rate of up to 90%. Additionally, certain turbine models offer the capability to recirculate water used for power generation back into the system, conserving water while maintaining production efficiency at approximately 80% [22].

However, the social and environmental impacts of these projects cannot be overlooked. Such effects are project-specific and can vary significantly. When combined with the direct costs of infrastructure development, the side effects can be catastrophic, including environmental degradation affecting wildlife and fish, sedimentation from dams, corrosion of turbines, river pollution, and the loss of fertile land. Not to mention the social upheaval caused by displacing populations due to the inundation of homes and agricultural land [9].

These adverse effects have halted further investment in this sector in many developed countries, which have already exploited the most viable sites for dam construction decades ago. The United States, for instance, has ceased operations on several dams to promote "environmental flow." Nonetheless, some nations are enhancing production at existing sites by installing additional or more efficient turbines. Furthermore, the construction of small dams is encouraged as a means of positive local development (Table 1). Remarkably, in China, the output from such small dams exceeds the total hydropower production of many other countries [20].

Table 1: Existing and under-construction global projects to produce energy from water [25]

A	B	C	D	E	F	G
Country/Region	Technically Exploitable Potential/ TWh⁻¹	Economically Exploitable Potential/ TWh⁻¹	Actual Generation/ TWh, 1999	Installed Capacity/GW, 1999	Under Construction/ GW, 1999	Fraction Harnessed= D/B%
Africa	1890	n/a	73	20	2	4%
North America	1690	n/a	710	160	2	42%
Canada	951	523	340	67	2	36%
USA	530	376	320	80	0	60%
South America	2800	n/a	500	106	16	18%
Brazil	1490	810	285	57	11	19%
Asia	4900	n/a	567	174	71	12%
China	1920	1260	204	65	35	11%
India	660	n/a	82	22	15	12%
Japan	136	114	84	27	1	62%
Europe	2700	n/a	735	214	9	27%
Austria	60	56	41	11	0	68%
Norway	200	180	121	27	0	61%
Russia	1670	850	160	44	5	10%
UK	6	1	5	1	0	88%
Middle East	210	n/a	8	4	10	4%
Oceania	240	n/a	42	13	0	18%
Australia	35	30	17	9	0	49%
New Zealand	77	40	23	5	0	30%
World	14400	n/a	2630	692	110	18%

2.1.2. Coal

Coal is a type of sedimentary, organic, combustible rock primarily composed of carbon, hydrogen, and oxygen. It formed over millions of years through the accumulation of organic material under conditions of extreme heat and pressure. The combustion of coal generates substantial heat, and its globally discovered reserves are projected to exceed the world's demand for the next

century. Coal remains one of the earliest exploited fossil fuel sources and continues to be a pivotal energy resource. Found across various nations, coal can be extracted with relative ease in over seventy countries, with the largest reserves located in the United States, Russia, China, and India. It plays a crucial role globally in electricity generation, mining industries, the cement industry, and certain liquid fuel types. China, the United States, India, Russia, and Japan collectively account for approximately 76% of worldwide coal consumption.

Coal significantly contributes to the global electricity production landscape, with some statistics indicating that about 41% of electrical energy is derived from coal. This percentage soars to 98% in Mongolia, 94% in South Africa, 86% in Poland, and 81% in China. Coal-powered electricity is generated by converting large quantities of water into steam, which then drives the turbines in power plants, with the water being re-condensed for reuse in the system.

However, coal extraction and usage pose severe environmental and health risks, including increased mine waste, acid rain, water and air pollution, environmental poisoning, and a higher incidence of breast cancer among coal miners. Despite these drawbacks, coal is valued for several reasons, including its abundant global reserves, cost-effectiveness compared to other fuels, versatility in industrial and domestic applications, potential reuse in other industries, high reliability of coal-generated electricity independent of weather conditions, and the ease and safety of coal transportation and storage. Additionally, coal reserves are predominantly situated in regions distant from international and regional conflict zones, unlike oil.

Some countries issue legislation and place restrictions on greenhouse gas emissions that exacerbate the effects of global warming. Coal, despite its many advantages, is considered one of the most polluting energy sources for the ocean, both on land and in the air. Despite efforts to develop new technologies that allow the use of coal in a less polluting manner, this issue is expected to lead to a restriction on the use of coal, which will affect the energy market in general (Table 2). For example, the share of electric power production from coal in the United States of America decreased from 50% in 2007 to 37% in 2012. (International Energy Agency [IEA], 2020; [21].

Table 2: The first ten countries in the production of electricity from coal [23]

Mongolia	98%	Australia	68%	USA	43%
South Africa	94%	India	68%	Germany	43%
Poland	86%	Israel	59%	UK	29%
PR China	81%	Indonesia	44%	Japan	27%

2.1.3. Oil

The term “oil” is intrinsically linked to “energy,” underscoring oil or petroleum’s status as an indispensable primary energy source in today’s world. The affluence of oil-producing nations and the elevated incomes of their citizens have earned oil the moniker “black gold.” A key factor enhancing oil’s value is its finite availability and its non-renewable nature, necessitating its judicious use to build an infrastructure capable of mitigating future shortages or disruptions.

Oil has been known to humans for thousands of years, initially finding use in tool-making, medicinal applications, construction, moisture and smoke prevention, lighting, and later in paving roads. Its modern applications predominantly include fuel for machinery and vehicles. Historical records suggest that the Chinese drilled the first oil well in 347 AD, reaching a depth of approximately 240 meters. The extracted oil was utilized for lighting, heating, and salt extraction and drying.

The scientific advancement in oil refining techniques began between 1840 and 1850 AD. The era’s first noteworthy well was drilled near Baku, Azerbaijan, in 1848, followed by developments in Poland. Initially, oil production was concentrated around Azerbaijan, which saw the establishment of the first oil refinery in 1861.

A landmark event in the American oil industry was Edwin Drake’s discovery of oil in Pennsylvania in 1859, marking the onset of oil extraction and distillation to meet the limited market demands of the era, including kerosene and light bulbs. However, the real surge in oil production, transforming it into a matter of national importance, coincided with the advent of internal combustion engines at the start of the 20th century.

World Bank reports indicate a consistent decline in oil’s share in electricity production, from a peak of approximately 20% in the early 1970s down from about 2% in the mid-1960s to around 10% in 2010. This decline is attributed to the lessons learned from the 1973 oil crisis and the subsequent dramatic increase in oil prices. These factors compelled many countries to seek alternative energy sources offering economic benefits and greater political independence from oil, in addition to exploring fewer polluting options [19].

Electricity generation from oil varies significantly from one country to another. While some countries, such as Armenia, do not utilize oil for electricity production, others rely heavily on it. For instance, Malta, Eritrea, and Benin generate almost all their electricity from oil, with a staggering 99.4% of their electricity produced this way. Cyprus and Lebanon also have high dependency rates on oil for electricity, at 96.4% and 95.1%, respectively, placing Lebanon as the fifth highest in the world in terms of reliance on oil for electricity. According to the annual report by the Organization of Petroleum Exporting Countries (OPEC), member countries are among the largest consumers of oil in electricity production, generating approximately 30% of their electricity needs from oil.

The transportation sector, encompassing road transport, aviation, inland waterways, high seas, and railways, predominantly depends on oil as the most accessible and economically viable energy source. Worldwide, the transportation sector accounts for an estimated 57% of oil consumption. Figure 1 is expected to decline over time as countries gradually transition to alternative fuels or discover new energy sources.

In addition to its pivotal role in transportation, electricity generation, and heating, oil has numerous industrial applications. Its derivatives are integral to daily human life, with significant uses in road construction, military industries, chemical fertilizers, various petrochemical industries, plastics, paints, and solvents, among others (Table 3).

Table 3: The expected development of oil demand in the transport sector [19]

	Levels				Growth
	2009	2010	2020	2035	2009-2035
OECD America	12.1	12.5	11.9	10.1	-1.9
OECD Europe	6.2	6.0	5.1	4.2	-2.0
OECD Asia Oceania	2.6	2.7	2.8	2.1	-0.5
OECD	20.9	21.2	19.7	16.4	-4.4
Latin America	1.9	2.5	2.9	3.1	1.3
Middle East & Africa	1.3	1.3	1.8	2.2	0.9
India	0.9	0.9	1.9	4.8	4.0
China	2.5	2.5	4.6	5.8	3.4
Other Asia	2.2	2.4	3.3	3.9	1.8
OPEC	2.8	2.6	3.6	4.5	1.7
Developing Countries	11.4	12.2	18.1	24.5	13.1
Russia	0.8	1.0	1.2	1.1	0.3
Other Eurasia	0.7	0.6	0.8	1.0	0.3
Eurasia	1.5	1.6	2.0	2.1	0.6
World	33.9	35.0	39.8	43.0	9.1

2.1.4. Nuclear Energy

Scientific research with military underpinnings has often laid the groundwork for numerous inventions that possess the potential for both beneficial and harmful impacts on humanity. The realm of nuclear energy is a prime example of this. Contrary to the popular belief that military research was the genesis of nuclear energy, it is more accurate to say that military needs catalyzed the advancement of discoveries, which culminated in the first application of nuclear energy in creating the atomic bomb during World War II.

In 1789, uranium was discovered by German chemist Martin Klaproth, who named it after the planet Uranus. The process of ionization that generates radiation was uncovered in 1895 by Wilhelm Roentgen, who observed X-rays while passing an electric current through an evacuated glass tube. The following year, scientist Henri Becquerel discovered the phenomenon of alpha and beta radiations altering the colours of photographic films, and Paul Villard identified gamma radiations, noting their similarity to X-rays. Subsequently, Polish scientists Pierre and Marie Curie coined the term “radiation” and discovered polonium and radium in 1898.

Ernest Rutherford, in 1902, demonstrated that beta and gamma radiation could transform one element into another. By 1919, using radium to release alpha particles in nitrogen gas, he initiated a nuclear rearrangement process that led to a deeper understanding of the basic nuclear structure of elements. This understanding was further refined in 1940 by Niels Bohr, who elucidated the arrangement of electrons around an atom’s nucleus. James Chadwick’s discovery of the neutron in 1932 paved the way for John Cockcroft and Ernest Walton to achieve nuclear transformations by bombarding nuclei with fast-moving

protons. A year later, Enrico Fermi expanded this approach by employing neutrons instead of protons, enabling the production of a wider array of nuclear reactions.

The concept of atomic fission was validated in 1939, demonstrating experimentally, albeit in a non-practical manner, the immense amount of energy that could be harnessed. This experiment served as a testament to Albert Einstein’s theory formulated in 1905, which posited the equivalence of mass and energy. In that same year, Francis Perrin calculated the critical mass of uranium necessary to initiate a self-sustaining nuclear fission chain reaction, thereby laying the groundwork for the atomic bomb.

These advancements set off a wave of experimentation in laboratories worldwide, leading to the establishment of the principles underlying a continuous nuclear fission chain. This process amplifies fission alongside the generation of neutrons from each fission event, potentially leading to an explosion. Moreover, the development of materials that absorb excess neutrons enabled the regulation of the fission chain, allowing the reaction to be maintained without acceleration, thereby averting an explosion. This foundational work paved the way for the construction of nuclear reactors for energy production, in stark contrast to atomic bombs designed for explosion and destruction.

The United States built the first experimental nuclear reactor in 1951, following the wartime military application of nuclear energy. Subsequently, in December 1953, U.S. President Dwight Eisenhower officially introduced the concept of “peaceful nuclear energy” in a speech to the United Nations General Assembly. This initiative led to the global construction of nuclear reactors for electricity production and research purposes. Today, nuclear energy contributes to approximately 13% of the world’s electricity supply (Table 4).

Table 4: The first countries in the production of electric energy from the sun

Countries with the most installed solar energy in MW	MW
Germany	9,785
Spain	3,386
Japan	2,633
United States	1,650
Italy	1,167
Czech Republic	465
Belgium	363
China	305
France	272
India	120

3. The Development of New Sources of Energy

The development of new sources of energy represents a pivotal shift in humanity’s quest for sustainable and resilient energy systems, aiming to diversify away from traditional fossil fuels towards cleaner and more renewable alternatives. This transition is driven by a combination of technological innovation, environmental imperatives, and geopolitical considerations, shaping the dependency dynamics of energy production and consumption.

Renewable energy sources such as solar, wind, hydroelectric, geothermal, and biomass have emerged as key players in the global energy landscape, offering abundant, clean, and inexhaustible sources of power. Technological advancements have significantly reduced the costs of renewable energy generation, making it increasingly competitive with traditional fossil fuels. Additionally, concerns about air pollution, climate change, and energy security have spurred policies and investments to promote the deployment of renewable energy technologies, further accelerating their adoption worldwide [3].

The development of new energy sources has reshaped dependency dynamics by reducing reliance on finite and environmentally damaging fossil fuels. Renewable energy offers a decentralized and distributed model of energy production, empowering communities and individuals to generate their electricity and reduce their dependence on centralized utility grids. This shift towards distributed energy systems enhances resilience against disruptions and fosters energy independence, particularly in remote or underserved areas.

Moreover, the emergence of renewable energy sources has diversified the global energy mix, reduced the dominance of a few energy-rich regions, and promoted energy security. Unlike fossil fuels, which are often concentrated in specific geological

formations or controlled by a handful of countries, renewable energy resources are widely distributed across the globe, offering opportunities for countries to harness their indigenous energy potential and reduce reliance on imported fuels.

However, despite the promise of renewable energy, dependency dynamics remain complex and multifaceted. The intermittent nature of solar and wind power presents challenges for grid integration and energy storage, requiring innovative solutions to ensure reliability and stability. Additionally, the transition towards renewable energy sources necessitates significant investments in infrastructure, workforce training, and policy support, which may vary across regions and countries depending on their resources, capabilities, and political priorities [3]. While renewable energy offers environmental benefits compared to fossil fuels, it is not without its own environmental and social impacts. Large-scale deployment of renewable energy technologies such as hydropower and bioenergy can have ecological consequences, including habitat disruption, land use conflicts, and water resource management issues. Addressing these challenges requires holistic and sustainable approaches that balance energy needs with environmental conservation and social equity.

The development of new sources of energy represents a transformative shift towards a more sustainable, resilient, and diversified energy future. While renewable energy offers opportunities to reduce dependency on traditional fossil fuels and mitigate environmental risks, realizing its full potential requires overcoming technical, economic, and policy challenges. By fostering innovation, collaboration, and adaptive governance, societies can harness the power of renewable energy to build a more equitable, prosperous, and sustainable world for future generations.

3.1. What are the New Energy Sources?

Consensus among sources indicates that the global energy demand is continually rising. Experience has demonstrated that relying solely on the current flow of invested energy sources to meet future needs is unfeasible. The impact of global conflicts on energy source regions has largely been negative, driving prices up and adversely affecting economic performance and political stability. This situation has spurred efforts to identify new energy sources or to adopt novel approaches to underutilize existing sources.

Natural gas, although not a discovery, has been utilized since antiquity. Its usage began to expand on a limited scale at the start of the last century, initially confined to small projects and residential uses. However, the discovery of large reserves in the Arabian Peninsula, North Africa, Russia, and, more recently, the eastern Mediterranean has transformed perceptions of gas. It has evolved from being considered a secondary, marginal energy source to one of the primary sources. Furthermore, the growing discourse on global warming, greenhouse gas emissions, and their significant impact on Earth's climate has heightened the importance of natural gas, recognized as the cleanest fossil fuel with the least environmental impact on land, air, and sea.

The discovery of substantial shale oil reserves in Russia and the Americas, notably in the United States, has altered the conventional view of this energy source, which was previously deemed economically unviable due to its perception as being located in small, limited reservoirs. The increase in international oil prices also made shale oil extraction and refining financially viable despite its relatively high costs, making it profitable from both economic and geopolitical perspectives [19].

Biofuel has emerged as an alternative to fossil fuels, especially for countries lacking in oil reserves but rich in agricultural resources. This switch aims to reduce their economic and political dependence and save significant amounts of hard currency needed to purchase fuel. Biofuel, derived from living organisms, whether plant or animal, has seen regions like the United States focusing on crops such as corn and soybeans, Europe on rapeseed, Brazil on sugarcane, and Southeast Asia on palm oil, specifically for biofuel production.

3.1.1. Natural Gas

Certain historical accounts mention the worship of the "eternal fire" by groups who could not comprehend the nature of unquenchable flames ignited by gas seeping through rock fissures. Around 500 BC, the Chinese, while extracting salt from mines, discovered how to harness the heat generated by burning gas. Despite its ancient usage, natural gas is considered a relatively new energy source due to the growing preference for environmentally friendly energy sources and the increasing discovery of significant gas reserves globally.

Natural gas is distinguished by its rapid combustion, cleanliness, and minimal emission of environmental pollutants, making it the eco-friendliest fossil fuel, particularly for household use. The pollutants emitted from burning natural gas are less than 60% of those released by an equivalent amount of coal. Notably, natural gas is almost entirely free of sulfur compounds, which contaminate other fossil fuels. Furthermore, it requires no complex conversion before use, and its combustion byproducts readily mix with the air, minimizing the pollution associated with oil refining processes.

Natural gas is extracted from oil fields or distinct fields to satisfy demand and then transported through pipelines to major markets after processing. It can be stored to address peak demand, especially during winter, for heating purposes. Initially considered a by-product until the end of World War II, natural gas didn't attract independent exploration or reserve estimation efforts outside the United States until 1945.

The post-war years saw a surge in natural gas consumption in the U.S., driven by the expansion of pipeline manufacturing, which facilitated transport from fields to urban and industrial areas. By 1952, natural gas accounted for about a quarter of the energy consumed in the U.S. and represented approximately 90% of global consumption. Subsequently, the significance of gas consumption has grown worldwide, with natural gas increasingly replacing coal in many energy production and consumption sectors.

Following the United States, the former Soviet Union and European countries embarked on developing the natural gas industry. The Far East and South Asia later adopted this trend, and these regions have experienced significant increases in gas imports and consumption in recent years. An analysis of the annual growth rates of energy consumption versus gas consumption from 1965 to 1996 reveals that while the global energy demand increased at an annual rate of 2.5%, the demand for gas grew at a rate of 3.7% annually. Incorporating nuclear energy production into this comparison highlights a marked difference in the growth rate of gas demand compared to other fossil fuels.

The distribution of global natural gas reserves significantly differs from that of liquid oil reserves. Whereas liquid oil reserves are predominantly located in regions with relatively low consumption, most of the exploited gas reserves are found in industrial areas with high gas consumption. This distribution pattern has begun to shift in recent years, notably with the expansion of natural gas production in Qatar and Russia. A majority of these reserves are situated in fields lacking significant liquid content, allowing for the development of gas production policies that are independent of liquid oil production strategies.

Natural gas comprises several gaseous components utilized either as industrial chemicals or as fuel. Additionally, they can be blended in specific ratios for specialized applications, including:

- **Methane:** The lightest component, used both as a chemical in various industries and as a gaseous fuel.
- **Ethane:** The second component of natural gas, primarily employed as a chemical and occasionally as fuel.
- **Propane:** The third component is mainly used as a chemical. It can also be cooled and liquefied for export and utilization across multiple domains.
- **Butane:** The fourth component uses a technique similar to propane.
- A mixture of two or more of the gases, as mentioned earlier, in specific proportions, can form a blend tailored to the usage method and the distribution and transportation method via tanks, containers, networks, or retail cylinders.

Natural gas production supports several key industrial sectors, including petrochemicals, steel, cement, power generation, water desalination, and heating. Its production is on a continuous rise due to the growing demand for clean fuels. For instance, data from the World Bank indicates that the proportion of electricity generation from natural gas increased from 19.92% in 2004 to 21.88% in 2010.

In recent years, the adoption of natural gas in vehicles has followed the development of conversion kits that safely inject gas into combustion engines. This innovation has revolutionized gas consumption by establishing refuelling and maintenance stations catering to consumer needs. The gas and automotive industries are making strides to broaden their use in transportation, both in public transport and short-distance freight, aiming to decrease greenhouse gas emissions that contribute to global warming.

Natural gas is deemed one of the most crucial resources for rationalizing energy consumption, whether through fuel savings, extending the lifespan of oil reserves, or mitigating environmental pollution due to its clean combustion, which significantly reduces emissions. However, a point of contention has been the past practice by many companies of flaring gas associated with liquid oil wells due to insufficient utilization options and the failure of foreign firms operating in oil-producing countries to implement programs for re-injecting it into fields to maintain pressure. It was estimated that in 1977, OPEC countries flared approximately 140 billion cubic meters of gas daily, equivalent to 2.3 million barrels of oil. Despite such wastage, global proven gas reserves have seen a substantial increase, from nearly 20 trillion cubic meters in 1960 to over 200 trillion cubic meters by 2013, not including the vast potential in unexploited gas fields.

3.1.2. Shale Oil

Shale oil is emerging as a rapidly growing and economically viable energy source, with projections indicating a significant expansion in its global market share over the next two decades. Achieving this would revolutionize global markets by providing

a long-term, cost-effective source of energy for many countries and potentially lowering the average price per barrel of oil based on analyses that only consider liquid oil reserves.

Shale oil, distinct from oil sands or shale gas and conventional crude oil, has experienced a production boom in the United States, particularly in Texas. This surge led President Barack Obama in January 2012 to declare that the United States would surpass Saudi Arabia as the world's largest oil producer by 2017. The Organization of the Petroleum Exporting Countries (OPEC), in response, expressed concern in the same month about this development's threat to the future global demand for crude oil.

Considered an unconventional oil type, shale oil is extracted through hydro-treating or thermal processing of oil contained within specific rock types, aiming to produce liquid or gaseous oil comparable to conventional oil. The process starts with mining oil-bearing rocks, which are then crushed, ground, and processed using on-site or off-site facilities. The rocks are mixed with chemicals and subjected to high heat, with the final processing method varying by site and intended product.

However, investing in shale oil extraction is complex, with a critical factor being the energy return on investment, ensuring the energy derived from the oil outweighs the energy consumed in its extraction and processing. Shale oil recovery rates vary between 4.5% and 13% of the extracted rock weight, depending on the rock's nature and the processing technique employed. Shale oil, in its crude form, can be used for thermal energy production or further processed into various oil products and fuels. Initially utilized as a transportation fuel and wood preservative for railway construction, shale oil's distinct properties, including its melting temperature, preclude its transportation through conventional oil pipelines.

Moreover, shale oil contains high levels of polluting chemical compounds, such as sulfur and nitrogen, which contribute to air pollution. These elements, along with iron, may react with production and transportation solvents, increasing treatment costs and posing challenges to its wider adoption.

The rise in U.S. shale oil and gas production has significantly boosted its crude oil output to 7.7 million barrels per day by September 2013, up from 1.5 million barrels per day in previous years. This growth has also led to a decrease in oil imports to 7.6 million barrels per day. Projections by the U.S. Energy Information Administration suggest that shale oil production increased from 111,000 barrels per day in 2004 to 553,000 barrels per day in 2011, with anticipated growth to about 1.2 million barrels per day by 2035. Other estimates predict production could reach 3 or 4 million barrels per day.



Figure 1: Map of shale oil mines in the United States of America [24]

3.1.3. Biofuels

Traditional biomass, such as fuelwood, charcoal, and livestock dung, serves as a crucial energy source in many regions worldwide. For much of the global population living in extreme poverty, biofuels are the predominant source of fuel. Modern technology facilitates the extraction of biofuels in liquid, solid, or gaseous forms from a variety of materials, including wood, crops, animal waste, and other wastes, offering substantial savings and a cleaner energy source. Biofuel acts as an energy carrier, harnessing energy stored in biomass. A wide range of biomass sources can be utilized to produce bioenergy in different forms.

This includes food processing residues, industrial sector fibres and wood, agricultural sector crops and residues, forest logging residues, and organic waste, all of which can generate electricity, heat energy, kinetic power, and other forms of bioenergy.

Biofuels are considered a form of renewable energy, as they essentially convert solar energy captured by crops or residues. These naturally decompose if left untouched, releasing their stored energy into the atmosphere. Biofuels can take various forms: solid (like wood), liquid (like ethanol), or gaseous (like biogas). Biofuels are categorized into primary biofuels, used in their natural state, and secondary biofuels, which undergo a transformation process before use:

- Primary biofuels, such as fuelwood and wood pellets, utilize organic matter in their collected, natural form. This fuel is directly burned to meet the needs for cooking fuel, heating, or electricity for residential or industrial applications.
- Secondary biofuels encompass three fuel types: solid (like charcoal), liquid (like ethanol and biodiesel), or gaseous (like biogas, syngas, and hydrogen).

Estimates suggest that biofuel consumption is split between domestic use (80%), industrial use (18%), and the transportation sector (2%). However, advancements in production and technology, along with the appeal of biofuels as a clean material that reduces greenhouse gas emissions, are accelerating the uptake of biofuels in major consumer sectors, particularly transportation. According to the Colorado Oakhaven Center for Agricultural Studies, one acre of corn can yield 57 litres of oil, soybeans 182 litres, safflower 315 litres, sunflower 391 litres, flax 483 litres, palm trees 413 litres, and algae an impressive 7,030 litres. Since 1970, Brazil has been utilizing sugarcane to produce ethanol, a form of biofuel. In 2010, the US Environmental Protection Agency recognized fuel derived from Brazilian sugarcane as an advanced biofuel, noting that this fuel reduces greenhouse gas emissions by 61% over its lifecycle. This reduction accounts for both the direct and indirect impacts of land use in biofuel production.

Beyond sugarcane in Brazil, other plants are also used for biofuel production, such as *Jatropha* in India and Mexico, a tree indigenous to Mexico and Central America; *Pongamia* in Australia, a leguminous plant native to the tropics; and algae in the United States. However, the adoption of agricultural products for fuel production is under scrutiny by numerous international bodies and governments due to concerns about its potential effect on global food security if agricultural lands are diverted from food to biofuel crop production.

Utilizing waste for energy production addresses two primary issues: waste management and the reduction of environmental and public health impacts. Secondly, it leverages the potential energy in waste, recycling it into the global energy distribution networks, thus decreasing reliance on fossil fuels and extending their availability. Most waste contains combustible materials with considerable thermal energy. Moreover, the decomposition of organic waste generates methane gas, a natural gas classified as a fossil fuel. The increase in waste quantities, a byproduct of modern lifestyles, presents both challenges and opportunities for energy recovery.

The thermal energy harvested from waste can provide each individual with 5% to 15% of their total needs for heating, hot water, and electricity. Burning one ton of waste in specialized furnaces can produce 2 to 2.5 tons of steam, which is then converted into 300-500 kilowatt-hours of electricity using a condensing turbine or 150-200 kilowatt-hours using a reciprocating turbine, in addition to providing steam for heating and water heating needs. Incineration also significantly reduces waste volume to about a tenth of its original size. Materials such as glass, sand, and pottery are melted down, transforming incinerator waste into valuable material for construction and road paving, thus preventing environmental pollution.

4. Conclusion

The evolution of energy sources reflects humanity's continuous ingenuity and adaptability to meet its growing needs. From the early use of fire and biomass fuels to the dominance of fossil fuels during the Industrial Revolution, each phase of energy development has driven societal, economic, and technological transformations. Coal, oil, and natural gas emerged as traditional energy sources that shaped industrialization and modern progress, but their environmental impacts, resource limitations, and geopolitical complexities have posed significant challenges. The development of hydropower, nuclear energy, and, more recently, renewable energy sources marks a significant shift toward sustainable and clean energy alternatives. Today, technological innovation and policy incentives are accelerating the transition to renewable energy sources such as solar, wind, and biofuels. These developments reflect humanity's effort to address critical issues like climate change, energy security, and the need for resource diversification. While traditional energy sources remain vital, their long-term sustainability is uncertain, emphasizing the importance of cleaner energy systems and efficient energy management. Looking ahead, the evolution of energy sources will be shaped by environmental imperatives, economic trends, and technological breakthroughs. A global commitment to renewable energy adoption, energy efficiency, and sustainability will be crucial for building resilient and equitable energy systems that meet future demands while protecting the planet.

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