

Future of Energy: Science, Economics, and the Path to a Low-Carbon World

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<https://doi.org/10.5281/zenodo.18255122>

ABSTRACT

This article explores the evolving landscape of global energy by examining the scientific principles of energy, its economic importance, and the transition toward a low-carbon future. It begins by highlighting how energy drives economic development and shapes geopolitical relationships, especially in nations dependent on fossil fuels. The piece explains key energy concepts and distinguishes between renewable and non-renewable sources, emphasizing the environmental impacts of carbon-intensive fuels such as coal, petroleum, and natural gas. It also discusses the rapid growth of renewable technologies (like solar, wind, and hydropower), increased investments in clean energy, and the resulting rise in global energy production capacities. Despite this progress, the article notes that carbon emissions continue to reach record highs, underscoring the ongoing challenge of balancing growing energy demands with environmental sustainability. The narrative points toward a future where sustainable energy systems, including electric vehicles and hydrogen fuels, play a central role in reducing emissions and shaping a carbon-neutral world.

Keywords: Energy Security, Low Carbon, Renewable Energy, Energy Economics

ARTICLE

In recent times, we have all heard about countries like Sri Lanka and Pakistan going through an economic crisis, with their people facing numerous problems. However, one issue that received the most attention was the scarcity of oil and electricity. The importance of energy can be understood through this example: in a country like Sri Lanka, the lack of energy was one of the biggest challenges when it was economically struggling.

Today, energy is one of the most precious resources for a country. When it comes to development, a country with abundant energy resources has an advantage over those that rely on others for their energy needs. Looking at the facts, one can easily see how quickly some Middle Eastern countries developed due to their energy resources.

For an oil-dependent country like India, Russia became the biggest supplier of oil because of the cheap oil it offered, despite geopolitical pressure on India.

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In physics, power comes with energy, and the same applies to global affairs. This fact is evident when examining various historical events and wars, many of which were driven by the greed for oil.

The use of fossil fuels has significantly accelerated global development, and it would not be wrong to say that the world would be far behind if these fuels had not been discovered. Therefore, fossil fuels have played a crucial role in the advancement of human civilization.

Energy

Energy is the ability to perform work. In our day-to-day life, we say that a person with more energy can do more work, and the same applies to the concept of energy in physics.

We are all surrounded by matter, and matter is made up of atoms. The electrons in an atom revolve around the nucleus because of energy, and the nucleus itself is bound by a force known as binding energy. Therefore, nothing in this world can exist without energy, so it would not be wrong to say that mass also comes with energy.

Basically, there are four fundamental forces present in nature:

1. Gravitational Force
2. Electromagnetic Force
3. Weak Van der Waals Forces
4. Nuclear Force

These fundamental forces are responsible for the creation of different types of energy, depending on how these forces interact. For example:

- When the electromagnetic force acts on a spring, compressing or elongating it, it produces potential energy.
- When the gravitational force acts on a falling ball, it generates both kinetic energy (K.E.) and potential energy (P.E.).
- A charged ball, when accelerated by an electromagnetic force, gains kinetic energy.
- A closed coil, when passed through a changing magnetic field, generates electricity.

Kinetic energy is associated with the movement of a body, while potential energy is related to the configuration of a body. Other forms of energy include thermal energy, nuclear energy, electrical energy, chemical energy, etc.

To do anything in nature, we need energy, and energy can exist in different forms. Each form of energy can be converted into another. For example, when a ball is dropped from a height, it has both potential and kinetic energy. As it moves toward the ground, its kinetic energy increases while its potential energy decreases, keeping their sum constant. This demonstrates the law of conservation of energy.

Sources of Energy

Today, we have two main sources of energy: renewable and non-renewable sources.

Non-renewable sources are those that exist in limited quantities on our planet and can be exhausted with excessive use. Common examples include

coal, petroleum, and natural gas. These fuels are formed from the remains of plants and animals that were buried inside the Earth millions of years ago. Under extreme pressure and heat over a long period, they transformed into the fossil fuels we use today.

The primary component of these fuels is carbon, which, when burned in air, produces carbon dioxide (CO₂) a greenhouse gas responsible for global warming. From ancient times to the present, we have relied on fossil fuels for our energy needs, and they have played a crucial role in transforming the world. In India, most of the electricity is generated from coal, and most vehicles run on fuels like petrol and diesel, which are derived from petroleum.

Nuclear energy is another non-renewable source, where energy is produced through the fission or fusion of atomic nuclei. A very small amount of mass can release enormous energy through these processes. As of 2023, nuclear power contributed approximately 4% to global primary energy consumption and about 9% to global electricity generation. As of 2022, coal accounted for approximately 25.1% of global primary energy consumption and was responsible for about 35.6% of global electricity production.

On the other hand, renewable sources of energy include solar energy, wind energy, and hydropower plants. These sources are abundant and will never be depleted, no matter how much we use them. The sun's heat energy makes life possible on Earth, while windmills and dams are designed to harness wind and water energy for electricity generation. As of 2022, hydroelectric power contributed approximately 6.32% to global primary energy consumption and accounted for about 15% of global electricity production.

In 2023, global energy production grew by 1.4%, which was below the average growth rate of 1.7% per year observed from 2010 to 2019. Renewable energy sources added 24.1 gigawatts (GW) of capacity in 2023, leading the way in new power generation installations. Investments in clean energy technologies have reached record levels, reflecting a global shift toward sustainable energy solutions.

Despite this growth in renewables, global carbon emissions from energy reached a record high in 2023, highlighting ongoing environmental challenges.

In 2023:

- Global primary energy consumption reached a record 620 exajoules, marking a 2% increase from the previous year.
- Fossil fuels accounted for 81.5% of global primary energy consumption, slightly decreasing from 81.9% in 2022.
- Coal production increased by 2%, while natural gas production remained nearly the same. Global oil production surpassed 100 million barrels per day for the first time, reflecting a 2% increase from the previous year.

This rising demand for energy requires us to find ways to fulfill our energy needs with minimal environmental damage. Transitioning towards cleaner and more sustainable energy sources is crucial for the future of our planet.

Energy Carriers

The discovery of electricity has transformed the way we used energy before its invention. It is the most widely used form of energy storage because it can be transmitted over long distances in a very short time through wires. Additionally, it is highly feasible to develop devices that can efficiently utilize this energy. Electricity can be easily stored in batteries, and it enables the generation of very high power, making it one of the most suitable forms for energy transfer.

Other energy carriers, such as LPG (Liquefied Petroleum Gas) and CNG (Compressed Natural Gas), are also efficient for specific applications, like cooking cylinders and vehicle fuel tanks. However, electricity acts as an all-rounder and is often the most efficient form of energy transfer due to its ease of transportation and use. Unlike other energy carriers that require containers and transportation infrastructure, electricity can be transmitted instantly through power lines without the need for physical storage or movement.

Another advantage of electricity is its ability to be easily converted into different forms of energy using specific devices. For example:

- A bulb converts electricity into light.
- A heater converts electricity into heat.
- A speaker converts electricity into sound.

Other energy sources like coal, petrol, diesel, and hydrogen carry chemical energy, but transporting them requires significant effort and infrastructure compared to electricity. Thus, in most cases, electricity proves to be the superior energy carrier due to its convenience, efficiency, and versatility.

Why do we need to save energy?

There is a fundamental law associated with energy, well known as the law of conservation of energy. According to this law, in a closed isolated system, energy can neither be created nor destroyed, but it can be transformed from one form to another. This law is incomplete without realizing the fact that the universe is also an isolated system. We often hear advice to save energy, but why do we even need to think about saving it if it cannot be destroyed? This is since while using energy to perform any work, we change the useful form of energy into a non-useful form. The useful form of energy is limited and requires significant effort to create. For example, electricity is a usable form of energy, but it requires a lot of effort, such as building dams, using boilers to generate electricity, or burning coal for electricity generation. Therefore, we need to use energy carefully.

We cannot create energy, but we can transform it from a non-usable form to a usable form, and when we do so, we call it the production of energy. While converting energy into a usable form, we face several challenges. In nature, we have renewable and non-renewable sources of energy, and we use their energy to convert it into a usable form like electricity. We encounter several challenges in this conversion, such as the need for significant capital to build power plants and a large amount of labor. Extracting energy sources like coal and transporting them also require substantial capital and labor. This increases the overall cost of producing that usable form (electricity), and thus, we need to pay for its use.

Beyond economic challenges, there are environmental challenges as well. The heat energy produced by burning coal is not very usable for general households, so an arrangement called a thermal power plant is used to convert the heat obtained from burning coal into electrical energy, which is far more usable than heat energy. However, burning fossil fuels like coal in thermal power plants releases gases such as carbon dioxide, which contribute to global warming. Global warming is a significant global concern today and is highly destructive to humanity. Additionally, gases like nitrogen oxides and sulfur oxides are responsible for acid rain. Moreover, these energy sources are limited in nature, and their excessive consumption could exhaust them one day. Therefore, we should use these fossil fuels carefully and ensure their availability for future generations. This is known as sustainable development. The term sustainable development holds great importance due to economic and environmental considerations. Thus, development should not come at the expense of environmental health. Environmental challenges faced in using fossil fuels for energy

Using fossil fuels is easy because, over the years, we have become experts in their extraction and utilization for energy production. However, this method of generating energy from fossil fuels comes with numerous environmental challenges. We often hear that air pollution in some Indian cities is extremely high, largely due to the use of petrol and diesel in vehicles, which, when burned, produce harmful gases. Sometimes, this pollution reaches levels beyond what is considered safe. Long-term exposure to such pollution can lead to serious health problems. For instance, when the Air Quality Index (AQI) exceeds 400, the situation becomes highly hazardous. To put it into perspective, a person walking in an AQI greater than 400 feels like walking in a fog with visibility reduced to just a few meters. The acidic nature of the pollutants can cause irritation to the eyes and throat. A study suggests that Delhi's 30 million residents could lose nearly 12 years of life expectancy due to sustained exposure to such high levels of pollution.

In addition to air pollution, the carbon dioxide released from burning fossil fuels is a major contributor to global warming. The rise in global temperatures can lead to the melting of glaciers, which ultimately results in rising sea levels. Furthermore, pollution from fossil fuels can cause acid rain, which damages monuments and harms plant life. The oxides of nitrogen and sulfur released during the combustion of fossil fuels are primarily responsible for acid rain. Mining fossil fuels also presents significant challenges. The biodiversity of areas where mining occurs is greatly impacted, leading to severe environmental consequences for flora and fauna. People working in coal mines often suffer from lung and heart-related health issues, highlighting the numerous environmental and health challenges associated with fossil fuel use.

Despite these problems, fossil fuels remain one of the most convenient sources of energy. Much of the development we see today has been powered by fossil fuels. However, their use has a profoundly negative impact on the environment. Therefore, rather than hating fossil fuels, we need to focus on gradually replacing them with renewable energy sources.

Recently, the Electric Vehicle (EV) market has grown significantly, and

terms like the "hydrogen economy" have gained attention in discussions about cleaner fuels. Hydrogen, often referred to as the "fuel of the future," has the potential to play a key role in the future of energy due to its zero carbon emissions during combustion. Hydrogen can be used in internal combustion engines, making it a versatile energy source. However, it is crucial to consider the source of hydrogen whether it is green, blue, or grey hydrogen. Our efforts should prioritize the use of green hydrogen in the future to minimize emissions and maximize environmental benefits.

Electric Vehicles: A Step Toward Sustainability, But Challenges Remain

The use of electricity for energy appears to have zero carbon emissions when viewed superficially, but a deeper analysis reveals a different story. Today, the transportation industry is increasingly shifting toward Electric Vehicles (EVs). However, do EVs cause damage to the environment? The answer is yes, but with important nuances. While EVs themselves do not directly produce pollution since they run on electricity, the critical question is: How was the electricity generated to charge the EV? Since a significant portion of electricity is still produced from fossil fuels, the electricity used to power EVs has already contributed to emissions during its production.

Additionally, the manufacturing process of lithium-ion batteries is highly energy-intensive, resulting in higher carbon dioxide (CO₂) emissions compared to the production of conventional gasoline-powered vehicles. However, despite these initial environmental costs, EVs generally produce fewer greenhouse gas emissions over their operational lifetime than traditional internal combustion engine vehicles. This is largely due to the absence of tailpipe emissions and their greater energy efficiency.

Adopting EVs is still beneficial, as they have the potential to adapt to both renewable and non-renewable energy sources. To maximize their environmental benefits, our efforts should focus on using electricity generated from renewable sources for charging EVs. This approach ensures that the overall carbon footprint of EVs is minimized, making them a more sustainable option for the future.

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