

Transitioning to Sustainability: Evaluating the Costs and Benefits of Renewable Resources

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Abstract: *This article examines the shift to sustainable energy sources and assesses the related costs and opportunities. It highlights the environmental, economic, and social advantages of adopting renewable energies like solar, wind, and geothermal, while also addressing their inherent obstacles. Through systematic analysis and real-world examples, the study examines whether the long-term benefits of sustainability exceed the initial investment costs. The results underscore the urgent need for innovation, policy support, and international cooperation to build a sustainable future. The move to sustainable systems is now driven by economic logic as much as moral duty. The examples in the report show that economies of scale and technological advancements are lowering costs, as innovation accelerates, the cost of "doing the right thing" (renewables, digital inclusion, transparent governance) declines.*

Keywords: renewable energy, sustainability, cost analysis, environmental impact, green energy

1. Background

Sustainability involves practices that meet current requirements without compromising the ability of future generations to fulfil theirs. The transition offers opportunities, including economic savings, improved health, and job creation in green industries (International Energy Agency 2021), while also being environmentally friendly. The transition to sustainable systems enhances national savings by reducing dependency on costly energy imports and protecting the economy from negative supply-side shocks caused by volatile prices.

Carbon Border Adjustment Mechanism (CBAM): A landmark EU policy (fully operational as of Jan 2026) that imposes a carbon price on imports (steel, cement, aluminium) to prevent "carbon leakage" and ensure fair competition for domestic green industries.

2. Global Issue

The global issue highlighted in the report is environmental degradation and climate change, underscoring the need for nations to adopt renewable energy sources and reduce greenhouse gas emissions to achieve long-term sustainability. As the change, the process, and any solution impact all living beings across borders and require local, national, and international collaborations, the issue is global in nature.

Renewables on the rise

For the **760 million people in the world who lack access to electricity**, the introduction of modern clean energy solutions can enable vital services such as improved healthcare, better education, and internet access, thus creating new jobs, improving livelihoods, and reducing poverty.

However, there is tension between the Global North and the Global South. Developing nations often argue that the high upfront costs of renewable infrastructure (like Green Hydrogen or Geothermal) pose a threat to immediate poverty alleviation and industrial growth. Conversely, developed nations push for aggressive emission targets. This "Climate Justice" debate centres on who should bear the financial burden of a crisis caused primarily by historical emissions. This composition highlights various dimensions of resource conservation and sustainability, mainly focusing on questions, perspectives, costs, and opportunities for adopting sustainable methods. The aim is to assess whether the long-term benefits of sustainability outweigh the short-term costs and challenges.

3. Mapping the Causes and Consequences

As we navigate this change, it is crucial to understand the associated costs and opportunities to make informed, environmentally friendly decisions. The following table maps some of the causes, consequences, costs, and opportunities:

Sources	Cost		Opportunities	
	Factor	Effect	Factor	Effect
Solar Energy	Energy-intensive Manufacturing Process, Initial Cost	Emission during Production and Transportation	Renewable, Abundant, Natural Source	Low Emission, Accessible, Environmentally Friendly, Subsidy Available
Ethanol	Partial Transition	Limited Impact	Production from Crops like Sugar Cane	Offsets Carbon Emission, Greener Alternative
Wind Energy	Turbine Blades, Not Recyclable	Challenges in Waste Management	Wind, Renewable and Abundant	Clean and Green Generation Process
Geothermal Energy	High-upfront Infrastructure Cost, Solid Waste	Need for Waste Management	Use of Natural Source	Low Carbon/ Greenhouse Gas Emission

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Green Hydrogen	Production Cost	Limited Adoption	Production from Renewable Energy	Less Carbon Emission, Decarbonization of Industrial Processes
Hydro Power	Use of Flowing Water, Dependence on Waterflow	Impact on Aquatic Ecosystem	Natural Water, Return Water	Reliable, Environmental Friendly
Compressed Natural Gas	Methane Emission during Extraction and Transportation	Global Warming	Less Maintenance of the Engine, Cleaner Fuel	Less Waste in Landfills
Budget, Balance between Environmental and Socio-Economic Sustainability	Planning, Cost, Regulations	Potential Resistance from Industries for the initial upfront capital investment	Capital Investment, Innovation, Decentralised Solution	Reduced Grid Load, Long-Term Sustainability, Waste-to-Energy

4. Methodology

The methodology follows a mixed-method approach, from brainstorming and conceptualisation to research, an observatory visit to vehicle (Electric/Hybrid/Fuel) dealerships, a focused interview with a person working at a solar panel manufacturing company, analysis, reflection, and examples. The references and sources for this research paper are based on credibility, relevance, and evidence from organisations such as the United Nations, the International Energy Agency, the U.S. Environmental Protection Agency, and the MIT Energy Initiative. These sources provide relevant information and examples on the transition to greener energy. Videos like "How Green Is Solar?" from DW Planet and the attached UN website provide critical analysis. The budget 2024-25 focuses on transitioning to greener energy sources and enhancing resource efficiency, emphasizing the critical role of energy security in India's sustainable development. These references support the paper's perspectives and contribute to the global conversation on green energy.

5. Environmental and Socio-Economic Imperative

The government's strategy focuses on energy **availability, accessibility, and affordability** while promoting resource-efficient economic growth. A policy document is proposed to balance employment, growth, and environmental sustainability. This shows an acknowledgement that energy transition is not just an environmental necessity but also a socio-economic imperative.

The Sun, A Source of Energy

Solar power is a sustainable energy source because it depends on the Sun. It's widely known for its ability to generate electricity without emitting greenhouse gases, significantly reducing environmental impacts compared to fossil fuels. This can be implemented in small spaces, such as rooftops, as well as on large-scale farms.



The launch of 'PM Surya Ghar Muft Bigli Yojna' (Budget 2024-25) highlights the government's commitment to expanding access to renewable energy at the grassroots level by providing electricity through rooftop solar installations to over one crore households. The scheme promotes clean energy and eases the financial burden on citizens, making it a more accessible, economically and environmentally viable resource. The scheme serves as a model for decentralised energy solutions by reducing the grid load at the national level. However, solar power generation faces challenges that must be addressed to fully realize its potential. The production, transportation, and assembly use substantial energy, often derived from non-renewable sources. Solar panels, made from chemicals like silicon, silver, aluminium,

and plastic (EVA Sheets and Junction Box), and glass, which can contribute to environmental pollution if not properly managed. Many of these components, like the aluminium frame, copper wire, plastic components, and glass, can be recycled, which is a significant benefit. However, processing materials like silicon requires energy consumption. According to DW Planet, most solar panels are technically recyclable. Yet in practice, they are not recycled at scale, raising sustainability concerns for the industry's future. Further, solar panel waste is expected to increase by 2050, necessitating proper management. This directs one to evaluate emissions through a life-cycle assessment. Greenhouse gas emissions are attributed to kilowatt-hours, and a comparison between emissions and production is drawn. This can be

reduced through snowballing collaborative efforts to address the environmental footprint of solar power and maximise its long-term sustainability. effect. Additionally, as discussed in the interview, solar technology is becoming much more efficient. This means we can now meet the same energy needs using fewer panels. These improvements are also making panels last longer and reducing their overall life cycle emission, which further lowers their impact on the environment.

Wind, As a Source of Energy

Wind turbines harness wind energy using mechanical power to spin a generator and generate electricity. Wind is an abundant resource, and infrastructure can be installed on existing farms, making them both environmentally and economically sustainable. However, sources like wind and solar are inherently variable. Here, the proposal of a pumped storage policy serves as a strategic move to stabilize the energy supply. This policy proposes storing surplus electricity and releasing it when demand peaks or generation is low. This enhances the reliability of renewable energy, making the transition to greener energy more feasible. The fact that wind energy in the U.S. alone avoids 336 million metric tons of carbon dioxide emissions annually (Office of Energy Efficiency and Renewable Energy) underscores its far-reaching impact in the fight against climate change.

It is important to consider the material used to produce turbine components. Although most of the materials used to make wind turbines can be recycled, turbine blades cannot. Researchers at the National Renewable Energy Laboratory (NREL) developed an approach to manufacturing wind turbine blades that employs a thermoplastic resin system, reducing the energy required to manufacture blades and enabling recycling. The development of new technologies is directed towards innovation and employment in the field. Moreover, the use of recyclable materials in wind turbine manufacturing is of global significance. This global outlook underscores the importance of international collaboration in advancing environmental and economic sustainability.

Example of Corporate Investment: Capital Reallocation & The "Gold Mine" of Kutch

The video explains why Kutch, Gujarat, is the epicentre of this "most significant capital reallocation." It identifies three reasons why Ambani and Adani are investing in this specific geography:

- 1) The Torrid Zone Advantage: Kutch receives 50-60% more solar energy than temperate zones
- 2) Wind-Solar Hybridisation: Wind speeds in Kutch hit the "excellent" industry standard (8 m/s). Crucially, wind

speed is highest at night when solar production is zero, allowing for 24/7 power generation

- 3) Land Availability: Kutch has low population density (under 50 people per sq. km), minimising the "controversial" land acquisition delays that plague other Indian mega-projects [04:36].

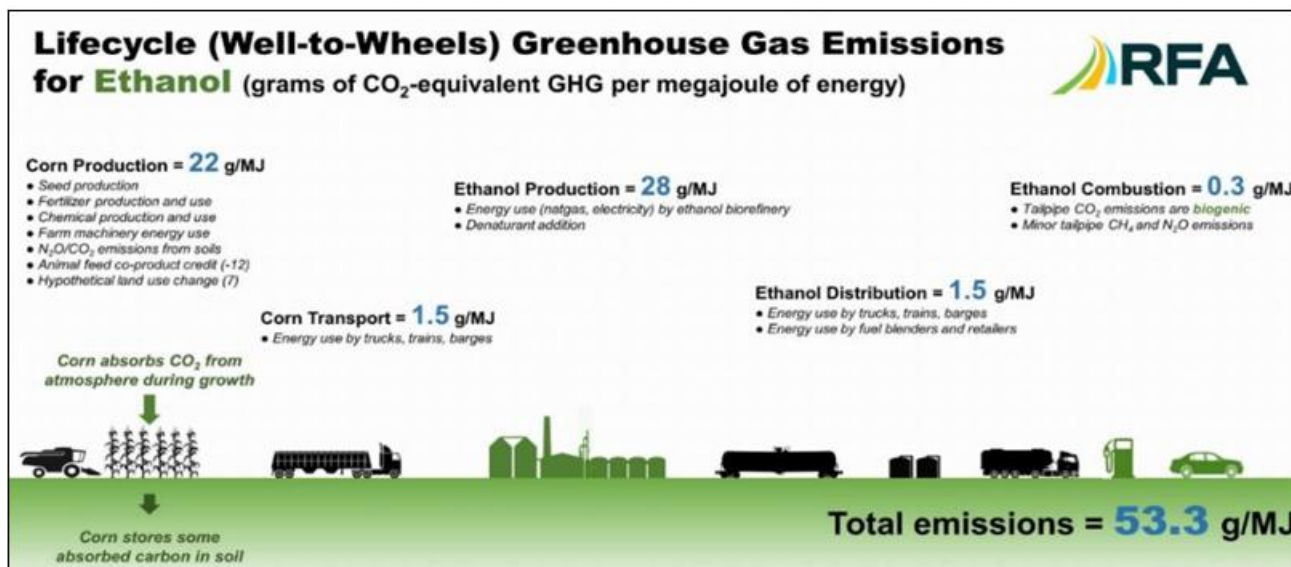
Compressed Natural Gas

Given the benefits of Compressed Natural Gas (CNG) or green fuel compared to regular fuel, its popularity is increasing every day. Regular fuel and diesel are heavily loaded with substances like formaldehyde and benzene, and when used, they release damaging byproducts into the air. Compressed Natural Gas is non-corrosive, and engines that run on CNG have been found to require less maintenance and ultimately last longer. Fewer broken parts mean less waste in landfills. Furthermore, CNG contains fewer hazardous chemicals and is lead-free, so discarded engine parts are less harmful to landfill leachate. According to information shared by the UN Environment Program on its website, Natural Gas has long been billed as a good stepping stone for a world looking to replace coal with renewable energy, especially as solar and wind grow farms. However, methane emissions during extraction and transportation are less climate-friendly. Therefore, considering CNG as an alternative to dirtier fuels like diesel might be a good option; however, it must be used alongside sustainable energy sources.

Advanced Ultra Supercritical Thermal Power Plants (AUSTP) mark a significant technological advancement in India's energy sector. These plants with higher efficiency and lower emissions are a bridge technology that helps transition from traditional coal-based energy to more sustainable alternatives. The partnership between NTPC and BHEL, with government support, will use local technology, leading to economic benefits and advancing high-quality steel production and metallurgy, thereby improving industrial and environmental sustainability. (Budget 2024-25)

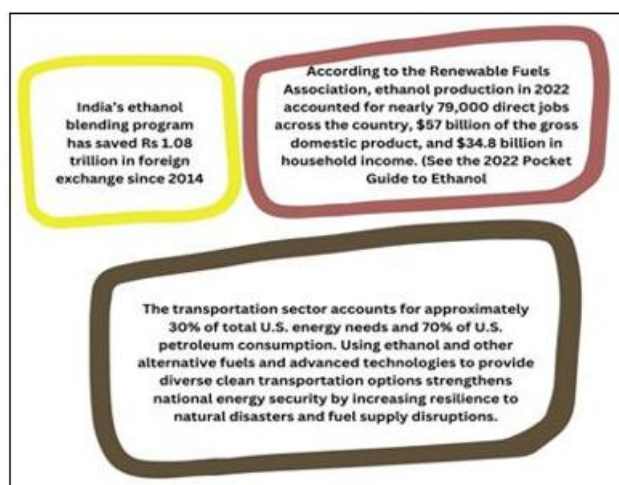
Geothermal Energy

Geothermal Energy is drawn to the surface from naturally occurring steam and hot water to generate heat and electricity. Geothermal energy generates less nitrous oxide and sulphur dioxide, and produces only about one-sixth as much carbon dioxide as a natural gas power plant. Binary-cycle run in a closed cycle and therefore has negligible or no emissions. With a high-capacity factor of 90% or more, geothermal power plants can run almost continuously at full capacity. They are an essential component, balancing intermittent energy sources like solar and wind while contributing to the country's renewable energy mix.



Ethanol, A Step Towards Sustainable Transportation

We are partially shifting from Gasoline to ethanol. We are blending ethanol in Gasoline and gradually increasing its percentage. Ethanol is produced from the starch of sugarcane and corn. It contains more oxygen; therefore, it goes through complete combustion, reducing tailpipe emissions. Further, some carbon dioxide is absorbed when crops used to make the ethanol are grown. "Natural gas and electricity use at dry mill ethanol plants has fallen nearly 40 per cent since 1995, while consumptive water use has been cut in half" (Renewable Fuel Association)



When using ethanol-blended fuel, it is important to understand the different impacts on vehicles based on their compatibility. Cars that are not explicitly designed or adapted for higher ethanol content (such as older vehicles or those designed only for E10) can experience a noticeable drop in mileage. This occurs because ethanol has a lower energy density than petrol, meaning more fuel must be burned to generate the same amount of power. Conversely, cars equipped to handle higher ethanol blends (such as modern E20-compliant or flex-fuel vehicles) can experience better acceleration and smoother performance. This is due to ethanol's higher octane rating (roughly 108.5 compared to petrol's 84.4), which allows for higher compression ratios, prevents engine knocking, and increases air-fuel mixture density. In summary, while the fuel can reduce fuel economy

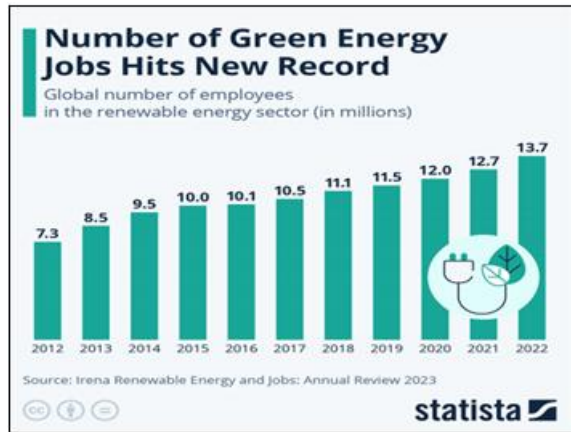
in older engines, it offers performance advantages in modern engines properly tuned for it.

Green Hydrogen

Hydrogen is a versatile source of fuel and can help combat our growing concerns about energy security, urban pollution, and climate change. Emre Gençer, a principal research scientist at the MIT Energy Initiative, says 'the best option for the climate is so-called "green" hydrogen'. Producers use electricity from a renewable source that splits water molecules to produce green hydrogen. This process emits less carbon dioxide per kilogram of hydrogen produced, depending on the supply chain and the overall process efficiency. This prize surely warrants the resources currently being directed toward hydrogen, even if the prospects for widespread commercialisation in the future are uncertain. Hydrogen fuel cells are increasingly becoming the superior choice for large-scale energy projects and heavy-duty transportation, largely because they offer a significantly higher energy-to-weight ratio than conventional Lithium-ion (Li-ion) batteries. As highlighted by Think School analysis, while Li-ion batteries are ideal for short-range passenger vehicles, they become counterproductive for heavy, long-distance, or high-power applications.

Water, As a Source of Energy

Hydropower is another significant sustainable replacement for generating electricity. Hydropower plants use natural water from rivers and streams to generate electricity and return the water to the environment after use, thereby providing a stable, reliable, and renewable source of energy. However, switching to hydropower should be part of a broader strategy that includes other renewable sources, such as solar and wind, since over-reliance on hydropower can lead to missed opportunities to diversify energy sources.



Innovation and Business Opportunities

The Businesses and the Indian government are focusing on sustainable technologies, such as biodegradable products, pollution-reducing devices, and recycling. For example, coconut leaves (agricultural waste) and straw offer a biodegradable alternative to plastic straws; the Kaalink device collects carbon emissions from vehicle exhaust and converts them into ink. Twin-cylinder technology in CNG cars BY TATA Motors allows the cylinders to sit under the luggage floor, solving the primary consumer complaint (lack of boot space) and accelerating the shift away from diesel. Goonj, an NGO, recycles discarded cloth material into valuable products. Sluges (from Zinc, silica, etc.) are being directed for sale. These examples showcase the potential for eco-friendly initiatives to drive growth in both the formal and informal sectors, while forming a circular economy.

The budget proposes a shift from the 'Performed, Achieved and Trade' scheme, focusing on reducing the carbon footprint of heavy polluter industries like steel, cement, and chemicals. It also aims to facilitate the transition towards cleaner energy, especially in smaller industries, promoting inclusive sustainability and local economies. The budget also proposes exemptions in customs duties on critical minerals, such as lithium, copper, and rare elements, for nuclear energy technologies and high-tech electronics, highlighting a diversification in the energy portfolio. Overall, increasing emphasis on renewable resources, waste to wealth generation, climate adaptation and mitigation, and a low-carbon economy signals that India commitment to sustainable development, inviting domestic and international investment in its green initiatives. It emphasizes the interconnectedness of sustainability, innovation, and socio-economic development in achieving long-term benefits, thereby positioning itself at the forefront of the global energy transition.

6. Reflection and Learning Outcome

Previously, I associated sustainability with environmental concerns. However, I learned that sustainability encompasses socio-economic, cultural, political, legal, and implementation dimensions, making it multifaceted. The impact that the process has on all beings in a shared ecosystem highlights coexistence, partnership, and collaboration at local, national, and global levels. Through this study, I understood that there are short-term costs and challenges, and these can be mitigated significantly through innovation, technology, education, and strategic implementation. This study

emphasized that the long-term benefits of sustainability outweigh the initial hurdles, thereby steering the transition to a sustainable future, in my perspective.

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