COMPARATIVE LIFECYCLE IMPACTS OF RENEWABLE VS. CONVENTIONAL ENERGY SOURCES

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Abstract:

The paper considers the alterations in lifespan environmental, economic, and social effects between renewable energy sources (solar, wind, hydro, biomass, geothermal) and conservative fossil fuel-based sources (coal, oil, natural gas). The economic growth of a country depends upon a powerfull energy sector. In the past few decades, the power generation sector is facing the multiple problem like affecting environment, health and energy security. consumption of conventional energy resources like coal, oil natural gas; make financial burden on economy and continued significant drawbacks. The higher emission of carbon cause global warming and climate change. The study highlights the urgent need to changeover towards renewables to alleviate climate change while balancing energy security and economic possibility.

Keywords: Lifecycle, Renewable Energy, Conventional Energy Resources.

Introduction

The international energy sector is undertaking a crucial changeover from dependance on conventional fossil fuels toward eco-friendly renewable sources. Conventional energy, mostly driven by coal, oil, and gas, has fueled industrialized progress but at substantial environmental and health costs. Renewables offer a cleaner alternate but are frequently questioned by intermittency, original costs, and land use impacts. Estimating the full lifespan impacts permits a broad sympathetic of each source's true sustainability. Energy production is essential to modern-day society, but special technologies arise with hugely diverse impacts throughout their lifecycle, from raw material abstraction to neutralizing. lifecycle evaluation Is the comprehensively acknowledged methodology for scientifically evaluating the direct and indirect ecological outcomes of energy system, offering a universal assessment often ignored by narrowly absorbed efficacy or emissions analyses.

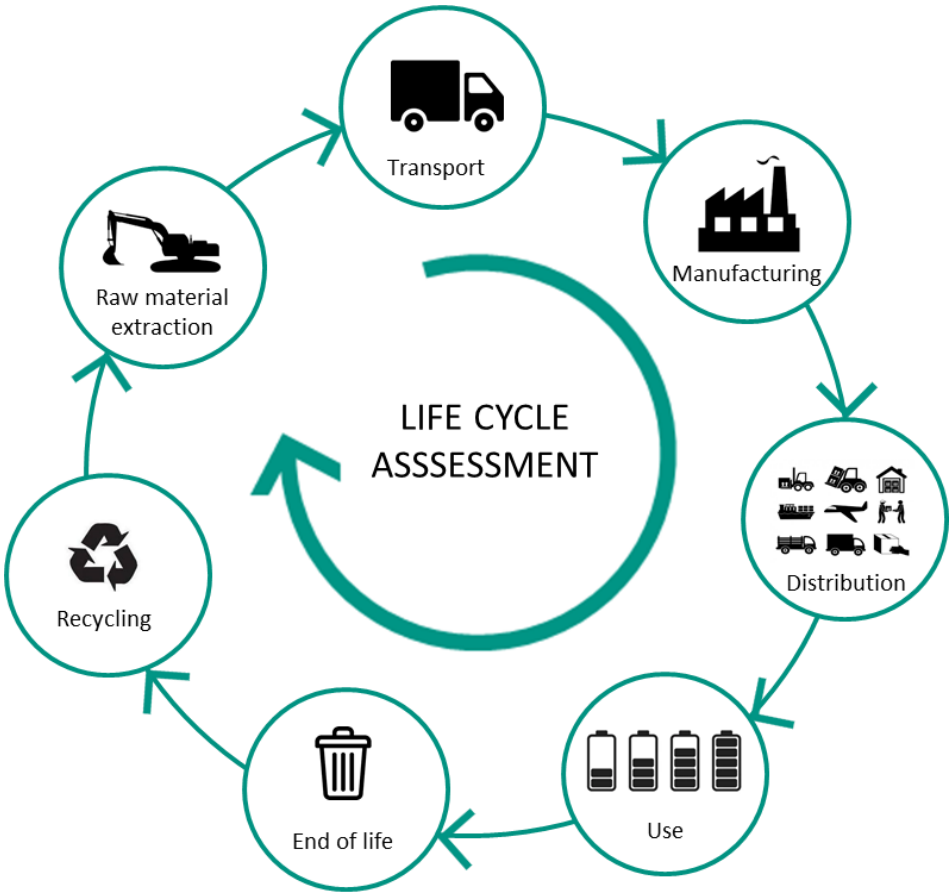
What is Lifecycle Evaluation?

Lifecycle Evaluation is a systematized process used to enumerate the efforts, end product, and conceivable effects of a produce or system above its comprehensive presence: material abstraction, production, transport, process, preservation, and dumping. For energy systems, this means bearing in mind not only operative emissions but also effects from plant manufacture, fuel abstraction or extracting, end-of-life scrape managing, and equipment

processing. Energy manufacture supports modern-day society, but the sustainability of diverse technologies remainders a serious concern. Lifecycle Assessment (LCA) is the gold standard for assessing comprehensive environmental effects, from resource abstraction and infra construction to operation, neutralizing, and dumping.

Main Impact Type:

- Greenhouse gas emanations (GHGs)
- Source utilization (minerals, water, energy)
- Air and water effluence
- Lethal releases (e.g., heavy metals, particulate matter)
- Environmental disruption and Land use.
- Numerous analytical tools and archives (e.g.SimaPro) are used to organize these evaluations,.



Lifecycle Phases of Energy Systems

Conventional Energy Systems

Conventional systems mainly contain fossil fuel products—coal, natural gas, nuclear energy, oil.

- **Raw Material Extraction:** this is the most critical phase in the life cycle of conventional energy resources it consists extraction of coal and drilling for oil/gas and preparing them for further processing to use in power generation activity. The extraction process of conventional energy resources is very intensive and environmentally impactful. This stage of life cycle represents one of the largest contributors to the total life cycle environmental foot prints of fossil fuel-based energy process. It involves desertification, environment interruption, and harmful scrape generation. It harms not only the environment but also our ecological institution like land degradation, water pollution, co2 emission, methane leaks etc.

- **Energy Processing and Conveyance:** this stage plays a crucial role that the fossils fuel are converted into usable form and deliver safely to plant or construction site. It refers all the activities that perfumed refine, and transport fossils fuel from the extraction site. It enables the long distance and safe transport and provide the link between the extraction and generation. It is a high impact phase of life cycle of conventional energy resources. In this stage it requires the heavy energy inputs and there is a significant CO2 emission and environmental risk. Adds significant Greenhouse Gas emanations and possibilities for oil leaks and seepages, energy use, chemical waste.

- **Plant Formation:** this stage sets the establishment of operating efficiency of life cycle of the power plant. the plant formation stage refers to the planning, design building, and installation of all infrastructure and high-end equipment require for plant to operate. It shows that the initial investment in the life cycle of conventional energy system. Normally heavy supply demand, mainly for nuclear-powered with large security requirements. It causes short-term but significant impact on environment before operation begins.

- **Operative stage:** the operative stage of conventional energy system is the energy generation phase in that transformation of fossils fuel into electricity through combustion and turbine operations. It is centric to energy generation and energy supply and majorly contributor to GDP, employment and industrialization. The duration of operative stage is approx. 25-50 years. While it is crucial for meeting the global energy demands it is also the environment intensive phase that is responsible for greenhouse gas emission, significant air and water pollution and large-scale resource consumption Majorly nonstop emissions of CO_2, NOx, SO_2, particulate matter, harmful waste (for nuclear).

- **End-of-Life:** the end of lie stage refers all the administrative, technical and environmental activities undertaken when a conventional energy plant is decommissioned after following reasons like end of useful life, environmental regulation, transition to renewable energy, accident or safety risk or economic non-viability. It requires the ongoing monitoring and post closure monitoring also and regular inspection for several year after closer. Coal dust dumping, nuclear-powered waste controlling (long-term storage), neutralizing challenges and indirect environmental impact depending on efficiency and demand of energy.

These are the main lifecycle phases of conventional energy system.

Renewable Energy Systems

Renewable systems assessed include solar photovoltaic (PV), wind, biomass, and hydropower.

- **Raw Material Extraction:** this is the initial and crucial stage in life cycle of renewable energy system where the natural resources needed for the production of energy technologies are obtained. This consists mining, harvesting or collection of basic material to produce the renewable energy infrastructure. There are some large environmental impacts before the production to energy like land degradation because of mining of metals like lithium or rare earth elements and habitants destruction, extraction of materials consume large amount of water that release toxic chemicals and some waste generation due to by-product of process. Production of turbines, PV plates etc., needs metallic element (silicon, copper, rare earth minerals). Excavating effects occur but are commonly lesser than fossil fuel extraction.

- **Production:** the production stage involves converting raw material into usable renewable energy technology. Essentially, manufacturing the component that will generate energy. In manufacturing solar plates involves silicon, producing cells, assembling modules and protective glass layer. While production of solar, steel, silicon and mechanical equipment there are some significant emission of CO2 and chemical waste.

- **Transportation:** the transportation phase consists movement of raw and finished energy component to their production site material like-steel, copper, rare earth elements, from extraction site to factory and finished components to project site like-wind turbine blades, solar panels. There are some fuel consumption and greenhouse gas emission and transport take a little impact on environment.

- **Induction:** induction is the point where the renewable energy systems are connected to grid and begin power supply to its consumers. There are some temporary disturbance of this process. It provides local employment and market reach. It could

be energy-intensive; ecological impacts be contingent on supply chain "spotlessness."

- **Operative stage:** operative stage refers the point in which the installed plant in position of functioning and ready to produce the energy. It begins after the installation and run till the decommission to the plant. The main activities of operative stage is energy generation from solar panel, wind turbine, hydropower, biomass and geothermal plants. Other function are grid integration for electricity transmission and monitoring and controlling of plant. Mainly insignificant emissions, but not absolutely nil; e.g., special lubricants for wind turbines, environmental effects (reservoirs) for hydro. The main advantages of operative stage is low environmental impact, sustainable energy supply, reduce the dependency on fossils fuels in long term prospective. The operative stage is essentially transferring the main benefits of renewable energy.

- **End-of-Life:** this stage refers the period when renewable energy technology are no longer to function for production of energy. This situation shows that the plant has to decommission or dismantle due to completion of useful life. After the dismantle of plant some elements are hard to recycle and require more cost to recycle. Material provides for recycle is secondary raw material for another renewable technologies. Reutilizing and dumping of microchip technology, turbine blades, solar panels pose challenges but are refining with developing technologies. There is proper planning require to close the loop and reduce the long-term ecological footprints.

Comparative Analysis of Environmental Impacts

Operative radiations after renewables are strictly lower than conservative sources. For example, the solar PV technique produces about 1.35 kg CO_2 per kWh above its lifespan, vs. coal's 4.81 kg CO_2 per kWh. This difference justifies why hybrid solar installations lead to multi-ton decreases in carbon emissions for households over decades. Hybrid solar systems can decrease releases thousands of kilos yearly competed to grid or diesel power. Fossil fuel ignition discharges NOx, SO_2, mercury, and particulate matter, affecting air and water property. Renewables are cleaner in consumption but need responsiveness to metals pollution in production and end-of-life dumping for solar and wind. Conventional resources Mining, drilling, and extraction dislocate landscapes and surroundings. Renewable resources wind and solar are less disruptive; hydroelectric dams have major ecological impacts-reservoir creation, aquatic ecosystem changes. It has lesser effect on nature and higher lifespan from conventional.

Use of conventional resources is uninterrupted; extraction of it damages land and water. Renewables Straightforward resource use (metals, materials), but low continuing abstraction post-installation. Coal and nuclear plants require vast water volume for cooling, raising issues of local scarcity and thermal pollution.Wind and solar generally have negligible water footprint during operation, means no use of water in power generation.

LCA permits for right cost accounting system-investment, functions, maintenance, fuel,

externalities (pollution, healthiness impacts). Renewables are progressively cost-competitive due to decreasing induction prices and low-slung operating costs. Solar and wind energy sources pay back induction costs quicker than conservative systems; long-standing funds are higher due to nominal fuel requests. Health impacts from fossils fuel emissions, dangerous working conditions, mining accidents etc. renewables energy make local environment cleaner and, new green jobs, but manufacturing may rise worries if not dutifully obtained.

LITERATURE REVIEW

Moein Shamoushaki, S.C. Lenny Koh, (2024), Integrated Renewable Energy Plants Like Wind And Solar, Geothermic And Solar Show How Growing Lifespan And Effectiveness Decrease Ecological Effect Significant.
The study consists psc in an integrated power plant is the main novelty of work, climate change and ozone degrade in solar and wind energy production are lower in comparison of other energy sources.

Francisco Portillo, et.al. (2024), The Report Of Life Cycle Assessment Findings Of Solar And Wind Technologies Indicate That Solar Pv Models Production Is A Main Contributor To Ecological Effects; Comparison Between Various Articles Indicate A Wide Difference Due To Diverse Method Options. The review highlight the significant environmental burdon of solar energy production stage, mainly prduce photovoltaic cells and modules.

Harmonization work by NREL(2021),renewable technologies have normally much lesser life cycle GHG emanations than fossil fuel technologies; normal savings on the demand of 400-1000 g CO_2e/kWh relation to coal/gas, etc. Relative analyses show that conservative natural gas combined cycle has lesser emissions than coal, but quiet significantly greater than renewables, however renewables sometimes be affected by larger effects in non-GHG groups (mineral, land use, depletion) be contingent upon technology.

Conclusion

Conclusively renewable energy promise to reduce dependency on fossils fuel and the climate changing. To understand its complex ecological effects, we have to understand them and need to standard evaluation. Lifecycle comparison between renewable and conventional energy tells us renewable energy mostly-solar, wind energy, hydropower, biomass reduce the CO2 emission, greenhouse gases, pollution, natural resources depletion, water use, and ecological footprints. There benefits are visible not only during operation but also in extensive life span. In comparison of renewable resources conventional energy sources like fossils fuel effect ecological system and economy heavily at every stage. Directing sustainable plans, commercial tactics, and distinctive selections for a clean and fairer outlook. Therefore, LCA supports and encourages renewable energy for the transition phase.

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