Green Energy Innovation

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Contributor: Samuel Asumadu Sarkodie

energy research and development in expanding green energy innovations while reducing long-term emissions is significant. Continual dependence on obsolete energy research and development may worsen environmental sustainability. However, the inclusion of green energy technologies offset environmental pollution without compromising economic productivity. Besides, the mitigation effect of energy research and development is channeled through a decline in energy intensity and technological advancement. Green energy-based innovations and energy research and development play a critical role in achieving environmental sustainability in OECD countries.

Keywords: green energy innovations ; green growth

1. Background

Reducing biodiversity, declining global food production, rising sea levels, and higher morbidity rates are examples of the possible problems associated with global warming [1][2]. In recent years, the transition from carbon-intensive driven economic development to low-carbon economy has been examined through the lens of clean and renewable energy and improvement in energy efficiency [1][3][4]. Energy acts as a double-edged sword by serving as a vital condiment of economic growth and development—whereas driving environmental degradation [4]. As a result of the triple-headed scourge of climate change, resource depletion, and environmental degradation, green industries are on the rise [5]. Green industries are industries that adopt green innovation in production processes. Accordingly, green innovation connotes a series of introduced practices, techniques, technologies, and systems as well as products resulting from reduced environmental degradation [6]. Green innovation is reported to play a major part in energy development, especially in the industrial sector. The number of technological innovations is roughly measured using green patents issued in the region. Patents are momentous gauge of innovations in a country, thus, those issued on reducing energy consumption and environmental concerns are regarded as green patents [3].

However, energy utilization is part of the production process with long-term effects on environmental quality—if the composition of fossil fuels is dominant in the energy portfolio. The realization of high carbon is due to limited clean technologies, high consumption of fossil fuels, and industrial development [7]. This phenomenon is perfectly encapsulated by China's primary energy annual growth rate use of about 3.9% in contrast with the world's figure of 1.5%, making them the world's largest energy consumer [7][8]. Hence, the laws implemented in China to stimulate sustainable development include Environmental Protection Law (revised in 2014) and Urban Greening Ordinance (revised in 2017) [9]. Therefore, reducing energy consumption and seeking ways to shrink the amount of energy used per unit of input are vital strategies in reducing carbon emissions [3][9]. It is reported that energy intensity in heavily industrialized OECD nations has plummeted by four times between 1970–2005. Energy used per unit of input is classified as high if more energy is used in the production of one unit of output [7]. Consequently, 1% rise in green patenting activities leads to 0.03% decline in energy intensity. Against this backdrop, research and development, technological acquisition, and a rise in technological innovations are reported to reduce energy intensity [3].

Energy structure and utilization have morphed in recent times, with green energy coming to the fore globally. Revamping the energy sector across countries is rife, chiefly due to adverse effects of conventional energy forms. Environmental degradation in the form of climate change due to global warming has heightened research into green energy. Energy research development has manifested in green restructuring and environmental regulation [6][10]. This is explained by the greening of industries and environmental protection allied with sustainable development. The greening of existing industries refers to the transformation of existing manufacturing sectors to create products in more environmentally friendly ways [5]. Paradigm shifts in industrial structure hinge on the composition, production, and consumption of energy. Energy research development and demonstration have manifested in four major forms namely path creation, path renewal, path diversification, and path importation. Path creation is the rise of totally new green industries whereas path renewal connotes the adoption of green innovations in established sectors. In contrast, path diversification refers to a spillover of knowledge and expertise from existing green industry to emerging green industry whereas path importation is

the settlement of green industries new to a region as a result of inflows of expertise [5][11]. These techniques are paramount especially across heavily industrialized countries in Europe. Among these include the greening of metallurgical and chemical processes in Agder, Norway—where Eyde Zero-Waste initiative and Eyde Biocarbon program were carried out. The former focused on the transformation of waste into useful raw material, while the latter dealt with replacing fossils, viz. coal, used in the smelting industry with biocoal gleaned from Norwegian forests. Germany is in the process to adopt path diversification to its offshore wind power industry [5]. These countries are equipped with modern industrial structures to accommodate the reforms.

Despite these great strides in energy restructuring and development, a burgeoning and efficient industrial sector can act as a double-edged sword by either fostering or hindering green paths by resisting change and protecting past investments. Although development plans in recent years have had more energy-related goals across OECD countries, signifying the burgeoning appeal of cleaner energy sources. However, technological obsolescence and other existing factors may hamper the improvements in green energy innovations.

2. Energy Research & Development vs. Green Energy Innovation

Heightened research and development (R&D) are highly regarded among several countries, especially the more developed countries (MDCs)—due to the realization that R&D is the wheel of technological advancement. Energy R&D has received much attention and adoption, due to the harmful effects of conventional energy sources namely coal, oil, and gas. Concerns of global warming, climate change, rapid deforestation, and resource depletion have spurred research into sourcing for clean and sustainable options. The influence of energy R&D is given much priority in the extant literature. For example, a study adopted linear regression analysis and dynamic panel threshold model to assess the effects of technological progress and structural change on energy intensity [7]. Domestic R&D is found to have the highest effect on energy intensity reduction, along with both internal and external technological acquisition. The findings showed 1% rise in home-grown R&D capital stock leads to 0.31% decline in energy intensity. Other studies are not far off with their submission that technological innovation through research and development is a vital tool in propagating sustainable energy in industries [12]. However, the high costs of R&D coupled with low levels of investment are two key factors behind stunted technological innovation in least developed countries (LDCs). In contrast, rising energy prices have a knockback effect on R&D investment by reducing profits. However, the rising costs could spur more firms into energy-saving efforts, which would later increase firm innovation [8]. Despite the considerable efforts made by other countries in research into driving green innovation, it pales in contrast to OECD countries at the zenith of industrialization—with implementation of other technical indicators requiring further development and progress [11]. From another perspective, the influence of government control in addition to economic interference in making strides to drive research and development include tax holidays, tax reliefs, incentives, and subsidies. Although, they could have uncertain effects as the funds allocated or saved could either be used in green R&D or non-green R&D. For instance, firms with more environmental subsidies were found to engage in more non-green innovation than green innovation [13].

3. Industrial Structure vs. Green Energy Innovation

The strength, manner, and pattern of industries can either spur or impede green energy innovation in myriad ways. Both MDCs and LDCs seek to adopt more environmentally-friendly means of energy in the face of climate change and environmental degradation. Nevertheless, the transitional process differs from region to region. Gathering data from 282 respondents in a manufacturing sector in Pakistan, Shahbaz, Raghutla [1] concluded that industrial growth has improved demand for natural resources, hastening environmental degradation. In another study on heterogeneous effects of green technology innovations on carbon productivity across 71 economies with different income levels, empirical evidence supporting the validity of the environmental Kuznets curve (EKC) was found [14]. Thus, many large LDCs are at the peak on the EKC, thereby slowing down green energy innovation due to heavy reliance on fossil fuels. Another industrial-based study that explores how green restructuring unfolds in regions across countries found a structural deficit that requires attention [5]. The study noted that a binding similarity among LDCs is weak industrial structure coupled with deficiency in expertise and assets, which are inimical to green path development. The concept of linkages and supply chains has not been left out in the literature. The interdependence of industries and smooth supply chain are crucial for the efficient operation of economies, especially in output creation. A case study of an automobile firm in China concluded that green innovation is more effective when support from supply chains is present and more evident in industries with lots of linkages [10]. This resonates with current research that examined the factors behind green innovation in the Peruvian mining industry [15]. Findings show that suppliers in the mining value chain have a high level of human capital and significant technology driving innovations. Green innovation is reported to develop in industries where firms are more embedded and engaged in more knowledge-sharing activities [16].

4. Energy Intensity vs. Green Energy Innovation

The concept of energy intensity has certainly intensified in recent years, with a rising number of studies on the theme. Reducing the amount of energy consumed in manufacturing is a mainstay of developmental plan of governments across the globe—leading to increased attention on green innovations [6]. The vast majority of literature attempts to ascertain factors behind the rise and fall, determinants, and relationship with other sources and dynamics of energy. A common observation exists among countries like the US, China, and Korea. These countries are among the highest energy consumers and unsurprisingly, are among the highest global polluter of CO_2 emissions. The US is second only to China in terms of carbon emission, and these countries are among the leaders in green innovation, with inventions like artificial photosynthesis, 3D-printed wind-solar energy tubes, and carbon nanotube electricity [17]. Green technology innovations can enhance energy efficiency by improving total factor carbon productivity through its mitigation effects [14]. However, a study on the impact of green innovation on energy intensity in OECD nations found that the falling energy intensity across OECD countries was associated with industrial energy efficiency rather than the utilization of environmentally-friendly energy sources [3]. A study found a feedback relationship between energy intensity and green energy innovation, implying a positive monotonic effect of increasing energy intensity to technological innovations [9]. Conversely, soaring levels of green innovation decrease energy intensity. In curbing intensity, measures put in place to reduce energy intensity have both short and long-run effects, thereby breeding uncertainty. The negative short-run effect refers to the cost increment due to compliance with government regulatory efforts alongside the disruption of current operational activities. However, the long-run effect, which is more significant, involves switching to technological innovation—which allows firms to offset earlier costs incurred [6]. In contrast, trade openness, government environmental spending, and income-induced technique effect are reported to improve energy efficiency in Korea [18]. Surprisingly, the green growth strategy implemented in 2009 has had less impact in reducing energy intensity than the aforementioned factors. Beyond energy intensity, other authors outline the impact of environmental regulation on green innovation. Though originally implemented to combat climate change and other ill-effects of carbon emissions, environmental regulation has been discovered to propel green innovation. Environmental regulation is regarded to project a middle course between economic progress and environmental pollution whereas technological innovation is regarded to reduce green total factor efficiency [6][19].

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