

Determinants Factors of the Energy Transition: An Empirical Approach

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Abstract:

Analyzing the factors that influence energy transition is the aim of this study. Through the research's determining factors, this study seeks to comprehend how these variables affect the adoption of renewable energies. The results indicate that technological investments have a significant effect on energy transition.

Key Words: Energy; Renewable; Transition; Technology; Factors.

JEL Classification : Q42, Q55, O44.

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1. Introduction

The worldwide shift to renewable energy highlights the possibility of a broad paradigm shift in energy while also revealing notable differences in adoption rates and technological advancements amongst countries. By 2050, renewable energy sources may provide up to two thirds of the world's primary energy supply, according to estimates based on data from the renewable energy map scenario (Qusay et al., 2024). One of the main concerns in national policy is how human activity affects changes in the environment. Many research centers that feel accountable for the condition and caliber between the human and environnement.

The ever-evolving demands of humanity have driven an exponential rise in global production, while the relentless pursuit of profit by corporations has often marginalized environmental concerns. To foster sustainable economies, nations must implement robust regulatory frameworks that prioritize ecological stewardship across all industries. Strategic energy investments are pivotal in this transformation, as they not only influence economic trajectories but also serve as critical tools for mitigating emissions and preserving ecological balance. Without such measures, the tension between economic growth and environmental preservation risks undermining long-term planetary health. Until the 1950s, the natural environment was considered a common good. This system, which does not require payment for the use of natural environment resources, has led to increased pollution, water degradation and the production of large quantities of non-biodegradable waste (Poszwa, 2021). The challenge of climate change is the biggest issues of our day in order to accomplish. This is largely influenced by the shift from fossil-fuel to renewable energy. The role played by various forms of renewable energy is essential in directing of this international energy transfer. Sources of energy are not only practical cures, it's a fundamental shift in how we generate and consume power.

This transformation embodies a strong commitment to sustainability, resilience, and a more balanced relationship with nature. Driving the energy transition is essential to meeting the UN's sustainable development goals, not only by addressing climate change with urgency but also by ensuring universal access to affordable, reliable, and sustainable energy. This analysis highlights the revolutionary effects of renewable energy investments.

2. The literature review

2.1 The Energy Transition

Predicting the exact cost of energy transitions their pace, scale and tipping points-is fraught with uncertainty, as these shifts hinge on the volatile interplay of technological innovation, geopolitical agendas, market dynamics, and cultural values. History reveals that transformative energy shifts, like the displacement of biomass by coal or coal by oil, were never mere byproducts of technological breakthroughs. Instead, they unfolded through a mosaic of forces: resource scarcity, industrial lobbying, policy frameworks, and even societal acceptance of new energy "norms." Recognizing this complexity is critical for policymakers today. A sustainable energy future demands not just cleaner technologies but agile governance, incentivized behavioral shifts, and global cooperation to align competing interests with planetary boundaries (Griffiths et al., 2022). The energy transitions are complex processes influenced by a wide range

of local and global factors, they are neither linear nor predictable, making precise forecasting a challenging task. (Qusay et al, 2024). This requires a more detailed analysis of the policy frameworks and market mechanisms that effectively support the transition to renewable energy, and an understanding of how these vary globally. In addition, the research often neglects the socio-cultural implications of the transition to renewable energy, such as public acceptance, changes in employment patterns and impact on local communities. A change from one major energy resource to another can be caused by a number of interconnected factors.

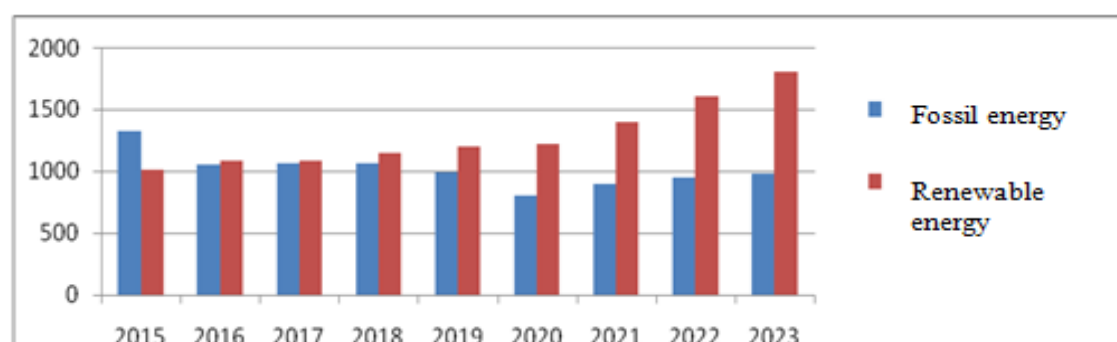
First, shortages may occur after local or regional supplies run out. This can take place with both non-renewable fossil fuels and renewable resources like forests and other biomass sources. (Barry, Karthik, 2011). The change from a largely fossil fuel-based energy system to a more effective renewable energy system is known as the energy transition process. In fact, British urbanization, trade, technological advancements, and the discovery of significant fossil fuel reserves were the main drivers of the transition from wood to fossil fuels. Fossil fuels surpassed the entire supply of biomass fuels to become the world's primary energy source at the end of the 19th century, nearly two centuries after the transition started in earnest in the early 1700s. (Fouquet 2010). The objective of this process is to reduce greenhouse gas emissions, increase the share of clean energy in the energy mix and improve countries' energy self-sufficiency. It is crucial to move towards an energy transition in order to achieve the climate targets set by international agreements such as the Paris Agreement. All things considered, the energy transition is a topic of academic significance. There is a sizable knowledge and quantitative gap regarding the measurable impact of guidelines geopolitical and socioeconomic contexts.

The technical and economic aspects of renewable energy sources are well demonstrated, but their inclusion and adjustment of current energy infrastructures receives less attention, mainly in developing countries that face unique challenges. Energy transitions have been emerging at an unprecedented rate in recent decades, which has led to the growth of a sizable body of literature on the subject (Yang et al, 2024). Number of factors, including income, urbanization, the intensity of electrification and access to running water, education, fuel prices, and opportunity costs associated with gathering traditional fuels, all has an impact on the shift to energy sources (Pachauri and Jiang, 2008). Energy transitions can be predicted and managed with the aid of various perspectives on energy transitions. Numerous economists have studied recent transition experiences in developing economies, frequently using cross-sectional data. (Fouquet, 2010). The context of many of these studies was the severe constraints, as well as the economic, social and environmental impacts associated with the use of traditional energy sources. In households, for example, the shift to energy scale (generally from biomass to commercial intermediate fuels such as coal or kerosene, to higher fuels such as natural gas, LPG or electricity) has often improved well-being and economic and social (Fouquet, 2010). To synthesize the concept of energy transition we can then define this transition by a structural change towards a global energy system mainly based on renewable energies, the time between the introduction of a new primary energy source, or a major engine, and its rise to claim a substantial share of the global market.

2.1 Financial investments related to the energy transition

The International Energy Agency (IEA, 2023) notes a notable increase in investments in renewable energy worldwide. Significantly, investments in coal supply increased by 10%, mostly due to worries about energy security in the wake of Russia's invasion of Ukraine. An important change can be seen in the investment ratio, which has evolved from fossil fuels and renewables being funded equally five years ago (1:1) to renewables now dominating at a ratio of 1:1.8. This rebalancing emphasizes increased international commitments to infrastructure and cleaner technologies. Importantly, despite growing expenditures on fossil fuels, renewable energy is still growing faster than it is thanks to international initiatives, cost-effective innovations, and regulations that aim to achieve sustainable energy systems and lower carbon emissions (IEA, 2023).

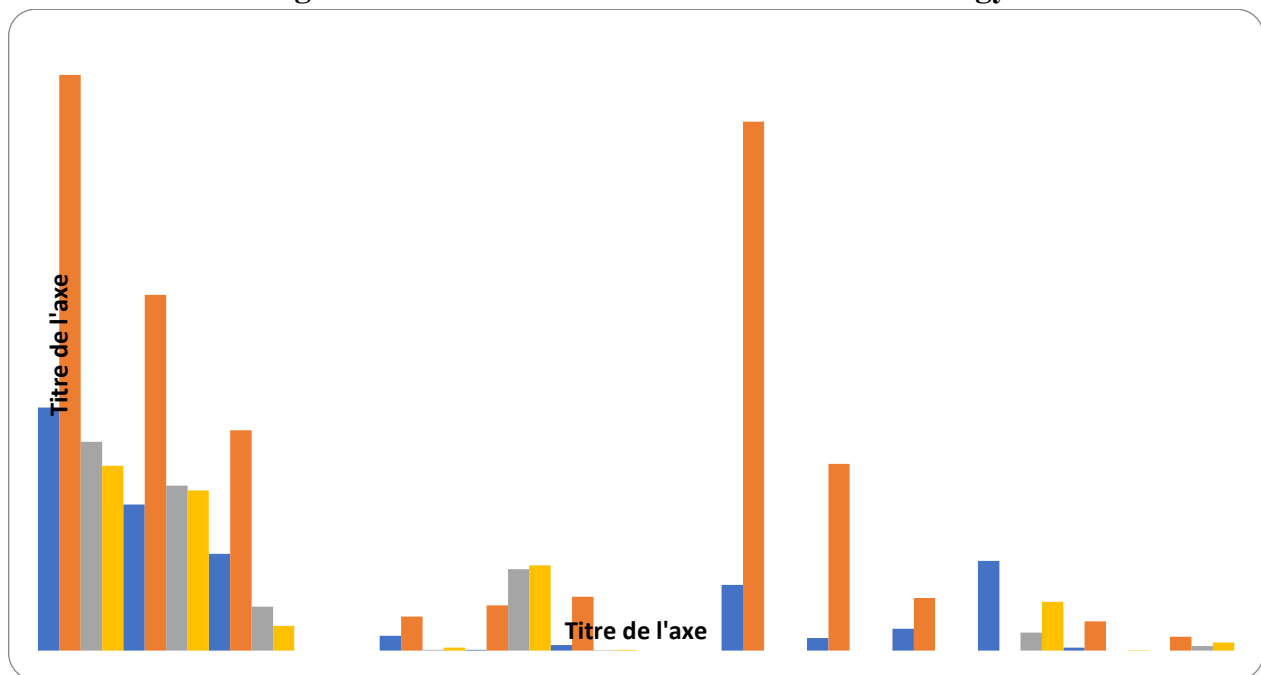
Fig.1. Fossil and renewable energy investments evolution



Source : Agence International d'Energie, Mai 2023

According to the International Energy Agency (IEA, 2023), global investment in clean energy has surged in recent years due to a combination of factors, including strong economic growth, volatile fossil fuel prices, and heightened energy security concerns following Russia's invasion of Ukraine. Supportive policy frameworks have further accelerated this trend. The IEA highlights that solar energy investment alone is projected to reach \$380 billion in 2023, surpassing spending in the oil sector. However, these investments remain heavily concentrated in three key regions: China, the European Union, and the United States. A significant driver of rising costs in clean energy initiatives has been the increased prices of critical materials, such as semiconductors and metals essential for production. This aligns with the IEA's 2022 forecast, which anticipated upward price pressures for components used in photovoltaic solar modules.

Fig.2. Financial commitments in renewable energy



Source : IRENA CPI and IRENA (2023)

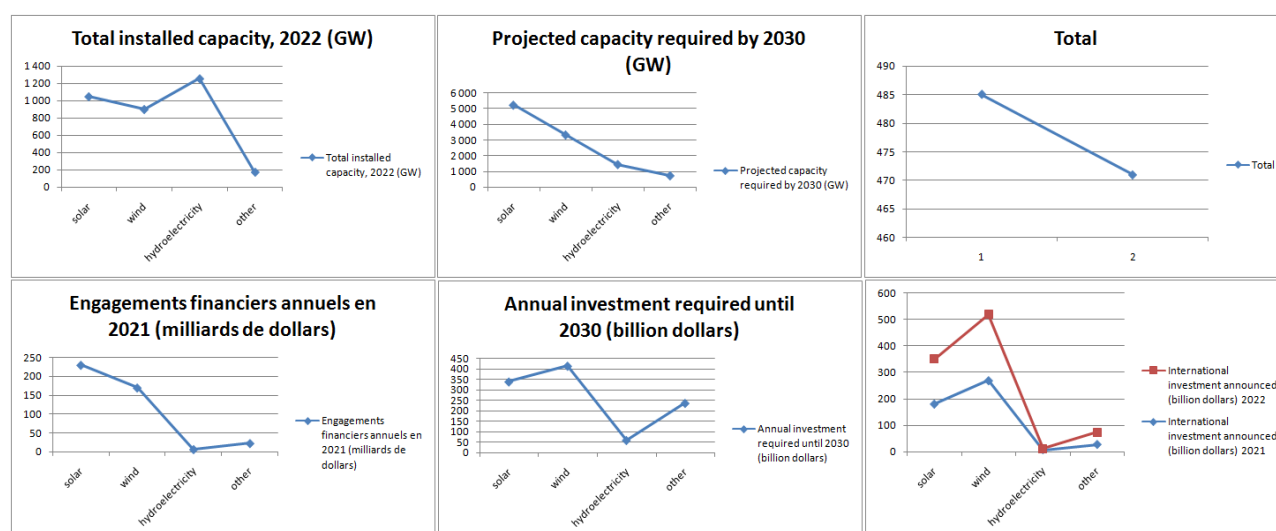
Investment in the sector, including financial and startup funding, exceeded \$470 billion in 2021 and 2022. It is essential to distinguish between "financial commitments" and "announcements": \$430 billion represents projects that have reached financial close, where funds are contractually secured, while the \$470 billion reflects newly announced initiatives. However, these announcements signal a robust investment pipeline, with capital flows increasingly aligning with projected needs.

2.3 The factors of the energy transition

2.3.1 The Energy Technology

It is evident that the energy transition is being fueled by both excellent technological advancements that have paved the way for the emergence of low-carbon energy technologies and growing environmental concerns. Globally, there is a growing convergence of vision toward a more sustainable and clean energy matrix. Leading technologies for energy efficiency and renewable energy are at the center of this development.

Fig. 3. The capacity and global electricity generation investment needs



Source: International Renewable Energy Agency, Renewable Energy Statistics, 2022

The figure below outlines key energy transition technologies, their advantages, and challenges. Hydropower remained the largest source of installed renewable capacity in 2022, but its future role is constrained by high land and water demands, alongside significant environmental and social impacts. Consequently, solar and wind energy are poised to meet the majority of future renewable capacity needs. Solar energy, in particular, must expand fivefold by 2030 to meet global targets. Solar photovoltaic (PV) technology is positioned to dominate electricity generation, driven by plummeting costs from technological innovation, rapid learning curves, policy incentives, and creative financing mechanisms (IRENA, 2022). Wind energy also holds critical potential, though scaling solar remains central to displacing fossil fuels and accelerating the energy transition.

2.3.2 Economic Growth

Mogode (2019) reviewed studies exploring the interplay between renewable energy adoption and economic growth. For instance, Ebohon (1996) identified a bidirectional causal relationship between energy consumption and economic growth, a finding later reinforced by Apergis and Payne (2010), who demonstrated this two-way linkage persists in both short- and long-term contexts. However, Apergis and Payne caution that renewable energy deployment does not automatically reduce carbon emissions, as challenges like intermittency and storage limitations often necessitate reliance on polluting backup energy sources. Aguirre and Ibikunle (2014) expanded this analysis by identifying three key drivers of renewable energy adoption: political frameworks, socio-economic conditions, and country-specific factors. They emphasized that wealthier nations are better positioned to subsidize renewable technologies and incentivize their adoption. Similarly, Da Silva et al. (2018) observed that economic growth fuels energy demand, which in turn accelerates renewable energy development. Yet, they stress that this relationship is not universal; institutional quality and region-specific barriers (e.g., infrastructure gaps, policy instability) critically influence the effectiveness of renewable energy transitions. Collectively, these studies highlight the complex, context-dependent nexus between

renewables and economic progress, underscoring the need for tailored strategies to maximize sustainability outcomes.

2.3.3 *Energy efficiency*

While renewable energy technologies often entail high upfront costs, they are increasingly supported by public policies such as subsidies, tax incentives, and regulatory frameworks. These measures not only reduce electricity costs but also stimulate economic growth, particularly in developing regions like Francophone Africa. For instance, decentralized solutions such as mini-solar grids—installed in rural areas to power homes, schools, and healthcare facilities—demonstrate how targeted investments can drive local development and enhance quality of life (Mogode, 2019). To scale such initiatives, fostering foreign direct investment (FDI) and supporting electrification projects are critical for stabilizing energy supply and revitalizing fragmented markets. The transition to renewables is unevenly shaped by institutional and economic factors. Institutional quality, including governance standards and corruption levels, significantly influences investment security; weak institutions heighten risks of economic marginalization. Higher-income nations are better positioned to absorb renewable technology costs and incentivize adoption, while low-income countries face barriers like inadequate infrastructure and financial constraints (Mogode, 2019). Additionally, reducing energy intensity (energy use per GDP unit) enhances a country's capacity to adopt renewables, though progress depends on regional context. Renewable energy deployment does not universally guarantee emission reductions. Storage limitations and intermittency often necessitate backup reliance on fossil fuels, inadvertently prolonging carbon emissions. Furthermore, uneven resource distribution—such as the Sahara's vast solar potential versus localized expertise gaps—complicates exploitation. These technical and geographic challenges underscore the need for adaptive strategies. Renewable energy performance hinges on robust public policies, energy efficiency gains, and institutional integrity. Despite high initial costs and socio-economic hurdles, long-term benefits include sustained economic growth, lower electricity expenses, and reduced greenhouse gas emissions. Risks tied to governance, financing, and technical barriers can be mitigated through strategic policy design and resource management (Mogode, 2019). In regions like Francophone Africa, prioritizing renewable-coupled with international support-offers a pathway to inclusive, sustainable development.

3. *The research Methodology*

The methodology used in this research is based on a data-driven approach, using comprehensive datasets to develop a Renewable Energy Map (SER). This approach is essential to interpret the role of energy transition towards renewable energies and to formulate policies that exploit their potential. Our methodology will help us in the process of analyzing the factors influencing the energy transition, taking into account three independent variables: technology, economic growth and energy efficiency. Energy transition refers to the process by which an economy moves from using non-renewable energy sources to more efficient or renewable sources.

3.1 The Choice of Variables

Our empirical study will focus on four variables presented as follows :

Table 1. The variables of research

dependent variable	La Variable dépendante
Energy Transition (ET)	Technology (TECH) Economic growth (GDP) Energy efficiency (EFF)

Source : Written by the researchers

The energy transition (ET) is represented by the dependent variable. This variable, which is determined by limiting gas emissions or by the proportion of renewable energy intensity in the use of fossil and renewable energies, represents the shift towards a greener economy. The transition factors that will be adopted in our research as independent variables entitled, **Technology (TECH)**, which reflects technological innovation in the field of energy. It can be measured by research and development (R&D) spending, technology patents in renewable energies. **Economic growth (GDP)** is represented by the rate of growth of GDP and is considered as an indicator of a country's economic conditions. The relationship between growth and energy transition can be either positive (more resources to invest in green energies) or negative (more conventional energy production). And finally, a third independent variable that is the **Energy Efficiency (EFF)** which measures the efficiency with which an economy uses its energy to generate GDP. This variable is often expressed in terms of energy intensity.

3.2 Data Research

Our study data illustrates the spatiotemporal dimension of this paper, by researching the Organization for Economic Co-operation and Development's (OECD) member states over a ten-year span. This period allows observing long-term trends in energy transition, and includes the following variables: Percentage of renewable energy (TE), Research and Development (TECH) expenditures, and the percentage of economic growth. Lastly, the energy transition (ET) is signified by the renewable energy intensity. The aspect of our methodology is to assess how technology, GDP and energy efficiency can play a transformative role in the global energy transition.

4. Results and Discussion

4.1. The research model

We are building a multiple linear regression model to estimate the technology, economic expansion, and energy efficiency's impact on the energy transition. The model is estimated as a multiple linear regression. The functional relationship can be expressed as:

The shape of the template:

$$TE_t = \alpha + \beta 1 * TECH_t + \beta 2 * GDP_t + \beta 3 * EFF_t + \varepsilon_t$$

Where:

- α is the ordinate at origin (constant).
- $\beta 1 * TECH_t + \beta 2 * GDP_t + \beta 3 * EFF_t$ are the coefficients to be estimated, representing the marginal effect of each explanatory variable on the energy transition.
- ε_t is the error term that accounts for the energy transition's influencing unmodeled factors.

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Table 2. Statistical analysis

Log-Likelihood		-9.824		F-statistic		104.3
AIC: 27.65		BIC:	28.87	Prob (F-statistic)		1.17e-05
F-statistic		104.3		R-squared		0.976
S Err		t		P>(t)		[0.025 0.975]
Cont	5.1324	0.832	6.164	0.001	3.121	7.144
TECH	2.4535	0.236	10.393	0.000	1.910	2.997
DGP	-0.7546	0.378	-1.997	0.096	-1.675	0.166
EFF	-0.0356	0.011	-3.234	0.018	-0.063	-0.008
Omnibus:	0.154		Durbin-Watson:			2.784
Prob(Omnibus)	0.926		(JB)			0.313
Skew	-0.184		Prob (JB)			0.855
Kurtosis	2.311		Cond. No.			1.97e+03

Source : Written by the researchers, using the Eviews software's outputs

The constant ($\alpha=5.1324$) represents the energy transition level when the other variables are zero. The constant term represents the baseline level of energy transition when all independent variables are set to zero. This indicates the inherent level of renewable energy adoption and greenhouse gas reduction independent of the factors analyzed. The Technology ($\beta_1=2.4535$) variable indicates that each additional billion dollars invested in technology (R&D) increases the energy transition by 2.45 percentage points, with a very significant effect ($p\text{-value} < 0.01$), this relationship is highly statistically significant, with a $p\text{-value}$ of less than 0.01, underscoring the vital role that innovation in technology plays in propelling the use of renewable energy. This finding highlights that countries prioritizing technological advancements are better positioned to accelerate their transition to cleaner energy systems. The economic growth variable ($\beta_2 = 0.7546$) indicates a 1% increase in economic growth slightly reduces the energy transition, but this effect is not significant with a $p\text{-value}$ of 0.096 (not significant at 5%). The lack of significance suggests that the relationship between economic growth and renewable energy adoption is complex and influenced by other factors not captured in this model. For instance, economic growth may drive increased energy consumption, which frequently uses fossil fuels, impeding the switch to renewable energy. The Energy efficiency ($\beta_3 = 0.0356$) indicates that for every 1 unit decrease in energy intensity (more efficiency), the energy transition increases by 0.0356 percentage points, with a significant effect ($p\text{-value} = 0.018$). This effect is statistically significant, with a $p\text{-value}$ of 0.018. The results emphasize that improving energy efficiency—by reducing energy use per unit of GDP positively contributes to the shift toward renewable energy. This finding aligns with global efforts to optimize energy use and reduce reliance on non-renewable energy sources. A very good adjustment, the coefficient of correlation explains 97.6% of the variation in the energy transition.

5. CONCLUSION:

The econometric analysis conducted in this article highlights that the energy transition, measured by renewable energy intensity, is significantly influenced by several determining factors. Indeed, investments in clean energy technologies (TECH) have proved to be the most powerful lever to support such a transition in energy. The more renewable energy technologies governments acquire, the more likely they are to diversify their energy mix towards renewable

sources. This effect is both strong and statistically significant, underlining the critical importance of technological innovation in combating climate change. Energy efficiency (EFF), measured by energy intensity, also plays an important role. A reduction in energy intensity (and therefore better efficiency) contributes positively to the energy transition. This confirms that energy efficiency makes it possible to limit dependence on fossil fuels. Economic growth (GDP) showed a negative but not significant effect in this model.

This may indicate that the relationship between economic growth and energy transition is more complex than expected, and that growth does not automatically translate into an increase in renewable energies. In theory, energy consumption could be positively influenced by economic growth which can lead to a strong correlation between economic growth and fossil energy consumption, thus reducing the transition to clean energy. A successful energy transition requires a multidimensional approach, combining innovation, efficiency and appropriate public policies to accelerate the transition to a low-carbon economy in order to clearly identify the key factors of such a transition.

In short, this study highlights the extent of research and technological development and energy efficiency as a key factor in the energy transition. Governments must consider the crucial role of clean energy technologies and improved energy efficiency. However, it would be appropriate to examine in more depth the impact of economic growth on the energy transition by taking into account other contextual and structural factors.

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