

Review

A Review of the Energy Sector as a Key Factor in Industry 4.0: The Case of Spain

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Abstract: Technological development has profoundly marked the evolution of the economy. The constant changes brought about by scientific and technological advances have been decisive in the transition from an analogue to a digital world. In this context, the impact of the fourth industrial revolution (or Industry 4.0) manifests itself in many ways. Environmental impact is one of these. The energy sector has been evolving and changing just like the economy and society. Therefore, a study of this sector, and of the other related elements, is of interest to better understand the 4.0 concept. The promotion of sustainability at both the political and social levels has led to changes in different areas, such as the productive vision, the use of green energies, and the implementation of green taxes. Energy as a key factor in Industry 4.0 involves studying it both quantitatively and qualitatively. This is to understand the lights and shadows that the concept currently presents. Therefore, this work aims to bring the reality of the energy sector closer to reality, both in its positive and negative aspects, considering the main factors of incidence, to show the strengths and weaknesses that can be deduced.

Keywords: Industry 4.0; technology; green taxes; green energy; sustainability



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1. Introduction

A single definition of Industry 4.0 does not exist. However, a starting point could be the concept standardized by UNE, a set of Spanish technical standards developed by AENOR, the Spanish Association for Standardization and Certification, which establish minimum quality and safety requirements in different fields such as construction, energy, environment, and health.

The UNE standardizes the definition of “Industry 4.0” as the extensive inclusion of information technology in all processes related to the value chain of the manufacturing industry, which represents the fourth industrial revolution. The implementation of this technology will improve the coordination and optimization of research and development, design, production, logistics, and associated services processes, in general optimization product lifecycle management [1–4].

This review originates from a broader investigation into the concept of Industry 4.0, its enabling elements, and the associated study of data to examine its implementation, positive and negative aspects. Special attention is given to the case of Spain, considering inquiries such as “What are the primary enabling factors of Industry 4.0 and how are they implemented? How does the energy sector influence Industry 4.0? What is the prevailing situation within the Spanish context?”

In order to comprehend the significance and far-reaching impact of such a revolutionary concept as Industry 4.0, it is imperative to approach it from a perspective that encompasses all levels. With a focus on economic sustainability and responsible, ethical development in harmony with the environment, the need arises to study the state of the energy sector within a 4.0 perspective. This review aims to delve into this subject, recognizing the paramount importance of aligning technological advancements with a commitment to a sustainable and environmentally conscious future.

To complete the research analyzing Industry 4.0, it is necessary to investigate the dark aspect related to its environmental impact and the evolving energy sector. This study aims to understand the strengths and weaknesses of energy's role in Industry 4.0 by examining its quantitative and qualitative aspects, shedding light on the concept's current realities.

The complexity and interest in the 4.0 concept have led to the creation of numerous reports, platforms, and initiatives to lay the foundations for its understanding and proper application, the most prominent of which are referenced throughout this article. The complexity of the concept and the need for a stable context have certainly been demonstrated.

Similarly, endeavors are undertaken to address the imperative of formulating efficacious strategies while concurrently focusing attention on specific domains of concern, notably encompassing security and the establishment of an aptly designed legal framework. Moreover, a substantial corpus of technical literature has been meticulously crafted, primarily centered on notable technological constituents such as cloud computing [5–8] and Big Data [9–12]. These encompass a wide-ranging assortment of instruments and resources precisely tailored for the acquisition, processing, and storage of voluminous datasets [13–15]. Furthermore, the paramount importance of cybersecurity [16,17] is emphasized as an indispensable collection of tools requisite for safeguarding cyber landscapes against a plethora of threats and cybercrimes, among a myriad of other pertinent facets.

At the same time, it must be said that since the end of the 20th century, attention has been focused on the environment, which until then had been practically nonexistent. This attention has turned into what could be expressed as concern in the present century. The main factor in the sociopolitical and cultural environment that has been stimulating this observance is the exponential standard of living that the vast majority of countries are experiencing. A need arises to ensure the maintenance of these standards of living, which include issues such as the quality of air and water, as well as the quality of the products consumed by individuals.

The implementation of all these changes produces alterations both in factories and in their production processes and even in the life cycles of products. Beyond this, the changes also reach political, economic, and social levels.

The purpose of this study is to shed light on the critical aspect of Industry 4.0 known as Sustainability 4.0, with a specific focus on the energy sector. To achieve this aim, an in-depth analysis of the concept will be conducted, exploring its fundamental characteristics and scope. Additionally, this study will examine various quantitative indicators to evaluate the Spanish case and to provide a comprehensive conclusion. To accomplish this, the paper will begin with an introduction that will present the context and significance of the topic, emphasizing the importance of Industry 4.0 and its implications for the energy sector.

Next, a literature review related to Industry 4.0 and the energy sector will be conducted, including definitions, key concepts, models, and relevant theories. Critical aspects will be developed, such as Industry 4.0 technologies applied to the energy sector (IoT, artificial intelligence, Big Data, etc.), the impact of Industry 4.0 on energy efficiency and sustainability, and the opportunities and challenges of Industry 4.0 in the energy sector.

Finally, the most relevant conclusions of the review will be presented, summarizing the main ideas and contributions.

2. Theoretical Foundations of Energy's Role in Industry 4.0: An In-Depth Examination of Materials and Methods

In this study, a comprehensive approach was employed to investigate the role of the energy sector in the context of Industry 4.0. The research aimed to shed light on both the quantitative and qualitative aspects of the energy sector, considering its positive and negative implications within the 4.0 concept. To achieve this, an extensive literature review and analysis of relevant data and information were conducted.

The materials utilized in this study included academic articles, reports, and other reliable sources that provided insights into the evolution and transformation of the energy sector in Spain. These materials were carefully selected based on their relevance and

contribution to understanding the key factors influencing the energy industry within the framework of Industry 4.0.

The methodology involved a systematic review of the literature, focusing on identifying and analyzing the main factors that impact the energy sector in the context of Industry 4.0. Various dimensions such as technological advancements, sustainable practices, policy implications, and the use of green energies were examined. By critically evaluating these factors, a comprehensive understanding of the strengths and weaknesses associated with the energy sector in the 4.0 era was aimed to be provided.

Overall, the study employed a rigorous approach to gather and analyze pertinent materials, enabling an insightful evaluation of the energy sector's role within the Industry 4.0 paradigm.

The objective of this review is to analyze the current situation of the energy sector in the context of Industry 4.0 and to determine future trends and perspectives. To achieve this, a systematic search was conducted in electronic databases, including DIALNET, SCOPUS, SPI, and WoS. Relevant studies published in the last 10 years were selected using keywords such as "Industry 4.0," "energy", "digital technologies", and "energy efficiency". Inclusion and exclusion criteria were applied to select the most relevant articles, and a critical synthesis of the results was performed.

The review's findings are presented in different sections, including Industry 4.0 technologies, impact on energy efficiency and sustainability, and opportunities and challenges in the energy sector. It is expected that this review will contribute to a better understanding of the interaction between the energy sector and Industry 4.0 and identify areas for future research.

This paper is based on the review and study of numerous research studies, all of which are referenced in the bibliography section. According to the current state of the art, the object of the present work was developed.

An essential part is the specialized literature of both a national and international nature, these being resources used in both physical and digital format. For the search of the resources in digital format, it is worth mentioning that different digital sources have been used: ProQuest, EBSCOhost, and ResearchGate, among others. These databases stand out for their extensive catalogue of articles, reviews, and scientific and academic publications by authors from all over the world.

However, for the collection of the data necessary for the quantitative analysis, different databases have been used, including "INE" (National Institute of Statistics of Spain), "OECD" (Organization for Economic Co-operation and Development), World Bank Open Data, and "EUROSTAT" (the statistical office of the European Union), whose routes used for data extraction are cited throughout the article. In general terms, data items on innovation, energy, pollution, and taxes have been used.

2.1. Industry 4.0: Origin: Energy as a Factor in 4.0

Energy is a critical component of the Industry 4.0 landscape [18], as it plays a vital role in powering the technologies and systems that drive this new era of manufacturing. As companies move toward greater automation and digitization, they will require more energy to power their operations, as well as to support the increased demand for data processing and storage.

To meet these needs, companies will need to adopt new and innovative approaches to energy management, including the use of renewable energy sources, energy storage systems, and advanced energy management technologies. This will require significant investment and collaboration between industry, government, and academia, as well as the development of new policies and regulations to support the transition to a more sustainable energy future.

In the larger context, the significance of energy cannot be overstated when it comes to the ultimate success of Industry 4.0 [19]. Enterprises that possess the ability to embrace and implement cutting-edge energy solutions will find themselves in a favorable position to thrive in the years to come.

Manufacturing can be defined as the creation of intricate objects through the integration of various interconnected components, achieved by employing diverse manufacturing processes. The transformation from raw materials to finished goods represents a key aspect of manufacturing [20]. However, production also encompasses the utilization of pre-existing manufactured items, with the objective of advancing the development of new products. These production systems necessitate the adoption of contemporary technologies for continuous progression. In parallel, the availability of energy becomes imperative in enabling the manufacturing processes [21].

Production systems must observe their general and specific objectives, as economic, political, and social situations mark the main points of attention of production [22]. A correct system must address purely technical issues such as design needs, product standards, and specifications, but beyond that it must address standards of sustainability and respect for the environment [23].

The Industrial Revolution has influenced the way goods are produced. However, the term “Industrial Revolution” may be inappropriate as it does not adequately reflect the gradual progression of changes that occurred [24]. Furthermore, the importance of other factors beyond changes in industrial production has been demonstrated when analyzing national income and its corresponding variables.

Industry 4.0 traces its origins back to the inaugural industrial revolution that commenced in 18th-century Britain, subsequently disseminating across Europe and North America during the 19th century. This transformative revolution ushered in innovations such as the steam engine and novel production techniques, yielding heightened productivity and diminished costs. The utilization of steam and water as energy sources engendered mechanized production systems, while concurrently giving rise to novel social strata, including the industrial bourgeoisie and proletariat [25]. Furthermore, the first industrial revolution engendered the establishment of modern factories, specialization of tasks, and instigation of substantial economic and societal transformations.

Consequently, the onset of the second industrial revolution occurred during the latter part of the 19th century and extended into the initial decades of the 20th century. It brought about significant socioeconomic and technological changes [26] such as electrification, assembly-line production [27], mass production, automation of production processes [28], the invention of the automobile and airplane [29], emergence of oil, introduction of new materials, and expansion of international trade. These changes led to greater efficiency in production and an increase in material well-being. The labor movement played a strong role in defending workers’ rights and fighting for social protection. This period of innovation and scientific research generated significant changes in the industrial, economic [30], and social realms [31].

The third industrial revolution, recognized as the digital revolution, transpired during the mid- to late-20th century, propelled by the advent of electronics and computing. This transformative phase has been distinguished by the emergence and advancement of information and communication technologies (ICT) [32], enabling enhanced connectivity and unfettered access to information.

The third industrial revolution, commonly referred to as the digital revolution, was characterized by the progressive advancements in information and communication technologies. The scientific–technical revolution, or intelligence revolution, is a concept coined by Jeremy Rifkin, who argues that the second industrial revolution based on fossil fuels is declining due to rising energy and food prices, high unemployment, increasing debt, and climate change caused by industrial activity based on fossil fuels [33]. This era of digital revolution includes advances such as the World Wide Web (WWW), created in 1989 [34,35].

This leads us to the fourth industrial revolution, commonly referred to as Industry 4.0, which encompasses the convergence of digital and physical technologies to revolutionize production and economic systems [36,37]. It involves the integration of various technologies, such as artificial intelligence (AI) and the implementation of machine learning algorithms, which in turn unlock a wide array of applications, including energy management

system control [38–44], the Internet of Things (IoT) [45], advanced robotics, and additive manufacturing (3D printing), all aimed at enhancing the efficiency, cost-effectiveness, and flexibility of production processes [46,47].

Industry 4.0 entails the incorporation of digital technologies within the manufacturing industry, leading to a profound transformation of production processes. Multiple definitions of this concept exist, including those put forth by the University of Aachen, the German Ministry of Economics and Energy, the German Ministry of Education and Research, the Organization for Economic Co-operation and Development (OECD), and the World Economic Forum [48,49]. These definitions collectively emphasize the crucial significance of integrating cyber-physical systems into production to foster enhanced efficiency, flexibility, and customization within processes [47,50].

Industry 4.0 encapsulates a wide range of technologies and principles aimed at effectively organizing the value chain. It revolves around the integration of cyber-physical systems, the Internet of Things (IoT), and online services to establish a smart factory. This approach optimizes production, logistics, and maintenance through the intelligent interconnection of machines and processes. Industry 4.0 signifies an evolutionary progression in industrial automation, fostering the development of an intelligent and interconnected ecosystem comprising individuals, machinery, and objects. The overarching objective is to create a smart factory wherein cyber-physical systems monitor operations and make decentralized decisions to enhance efficiency and customization [51–56].

The concept of Industry 4.0 was officially presented at the Hannover-Messe 2011, where the digitalization, automation, and connectivity of production were championed, paving the way for smart factories and connected industry [57]. Germany is leading the 4.0 initiative due to its vast experience in complex industrial processes, which has positioned the country as a pioneer in this field [58].

During the Hannover industrial fair in 2013, the German government presented its official Industry 4.0 initiative. ACATECH, DFKI, and major German companies published a foundational document highlighting how Industry 4.0 can improve business, infrastructure, and work (“Recommendations for Implementing the Strategic Initiative Industrie 4.0”, which included the associated platform “Platform Industrie 4.0”). Solid strategies are provided to implement the transition to 4.0, including examples of customized manufacturing.

The report emphasizes that Germany must integrate ICT into its traditional strategies to maintain its leadership in the global market [59]. The main purpose of this report is to present Germany as a state with sufficient potential and the right technological and production bases for the development of a new type of industrialization. It points out how the country must strive to include ICTs in “traditional” strategies on an ongoing basis to maintain its global market leadership [60].

The document said that Germany, as a leader, must implement three critical points: vertical and horizontal integration, networked manufacturing systems, and digital integration of engineering factors in the value chain [51,61,62].

The German Industry 4.0 initiative has received support from several countries. For example, the United States developed the initiative “2010-Plan Advanced Manufacturing”, with the aim of developing its manufacturing industry and digital transformation. It creates a network of institutes (IMIs). For its part, and by way of illustration, France has the “2013-La Nouvelle France Industrielle” initiative, with specific plans and the development of priority technologies (cloud computing, cybersecurity, etc.) with the aim of boosting innovation and competitiveness.

The concept of Industry 4.0 has garnered attention at the European level, prompting initiatives such as the Europe 2020 Framework—Innovation Union, the digital agenda for Europe, and an industrial policy for the globalization era. Europe has asserted its commitment to spearheading and fostering the digital transformation of its enterprises while modernizing its infrastructure to sustain competitiveness in the global market. Various reports, including “Industry 4.0, The New Industrial Revolution” [63], have underscored Europe’s dedication to this endeavor. Moreover, Europe must also confront challenges

pertaining to privacy and security, meticulously examining the boundaries of cybersecurity within the context of 4.0 development [64].

2.2. Industry 4.0: The Case of Spain

In the case of Spain, the “Connected Industry 4.0” platform should be highlighted, which seeks to improve the competitiveness and economic growth of national industry through the integration of advanced digital technologies in production processes and the value chain. It seeks to increase the efficiency and productivity of companies, promote skilled employment, and generate new business and export opportunities.

To achieve these objectives, different measures are being conducted, such as the creation of research and development centers, the promotion of training in digital skills, the financing of innovative projects, and public–private collaboration. The initiative has received the support of both sectors and is expected to have a significant impact on the economy and on the competitiveness of Spanish companies in the global market.

It is important to consider that the adoption of Industry 4.0 will not solely bring benefits, and it is crucial to have a clear understanding of the underlying factors and prerequisites for successful implementation. Technology and knowledge generate wealth, and there is a positive relationship between a country’s hidden wealth and its GDP [65]. The adaptation of a complex concept such as Industry 4.0 entails both opportunities and challenges for countries. Therefore, countries must make an effort to understand its defining features and how they can adapt, including attention to fiscal policies and addressing issues such as tax evasion and the lack of adaptation of factors such as human capital in terms of education and the labor market, among others [66].

The impact of Industry 4.0 may not be entirely positive, and it is therefore necessary to comprehensively assess the factors that facilitate or hinder its success [67]. In general terms, it can be summarized that the technological basis of 4.0 is in the elements of cloud computing [68], Big Data [9,69–72], cybersecurity [73], IoT, simulation [74], and 3D printing [75] and robotic [76]. Alongside the enablers of 4.0 are the factors that play a decisive role in its implementation. One of these is energy, which is the subject of this article.

The compositional framework or contributions of the research are as follows:

- Industry 4.0 in Spain drives energy demand through automation and digitalization, while the adoption of renewable energy sources offers cost savings and sustainability benefits.
- Despite Industry 4.0’s adoption in Spain, fossil fuel dependence persists. To achieve sustainability goals, effective policies such as environmental taxes and incentives are crucial to promote cleaner technology adoption and to reduce reliance on fossil fuels.
- Industry 4.0 offers opportunities for efficiency and innovation, but challenges still exist in infrastructure, sustainable growth, and cultural change.
- Effective environmental policies are needed for a sustainable Industry 4.0, addressing taxation and regulatory limitations. Coercive measures’ unintended consequences require further research.

3. Result and Discussions: Energy and Industry 4.0 Nexus in Spain—In-Depth Insights

Energy is a key factor in Industry 4.0, as it is necessary to drive the production processes and technologies used in it [77]. Industry 4.0 is characterized by increased automation and digitalization of industrial processes, which requires a higher demand for electricity [78]. In general terms, 4.0 should aim to reduce energy consumption and increase energy efficiency in industrial processes. To this end, technologies such as sensors and energy control systems are used to monitor and optimize energy consumption in real time [79,80].

In Industry 4.0, the utilization of renewable energy sources, such as solar, wind, and hydropower, represents a noteworthy facet concerning energy. These renewable sources are assuming growing significance within the context of Industry 4.0, offering the potential to diminish energy expenses and enhance the environmental sustainability of production processes.

Globally, the energy sector is in a process of transition toward Industry 4.0. In Europe, various initiatives and strategies are being implemented to drive the digital transformation of the energy sector. For example, the European Union has established the Horizon 2020 program, which funds research and innovation projects in energy and technology. Initiatives such as the European Green Pact, which seeks to achieve climate neutrality in Europe by 2050, have also been launched.

In the case of Spain, the energy sector is also undergoing a transformation toward Industry 4.0. In 2019, the Just Transition Strategy was approved, which lays the foundation for a sustainable and just energy transition in Spain. In addition, initiatives such as the National Integrated Energy and Climate Plan 2021–2030 have been implemented, which sets out the objectives and measures needed to achieve a low-carbon economy. On the business side, several Spanish energy companies are implementing digital technologies in their production processes. For example, the Spanish company Endesa has developed digitalization projects in its power plants and in the management of smart grids. Another Spanish company, Acciona, has implemented technologies such as virtual and augmented reality in the construction of wind farms.

In Spain, the arrival of 4.0 could be marked in 2015, when the “Industria conectada 4.0” (Connected Industry 4.0) initiative was launched at the state level, with the collaboration of private entities such as Telefónica. In this year, the platform published the report “The Digital Transformation of the Spanish Manufacturing Sector”, which sought to highlight the importance of industry for the growth of the entire Spanish economy. Already in this report [81], the concept of guaranteeing the sustainability of the production process only appears in the appendix and in any case not in a long-term projection.

Furthermore, we can observe the following trend when comparing the final energy consumption data for Spain to the total consumption of the Spanish industrial sector since the beginning of 4.0 (Figure 1, based on data from Energia.gob.es, accessed on 20 March 2023).

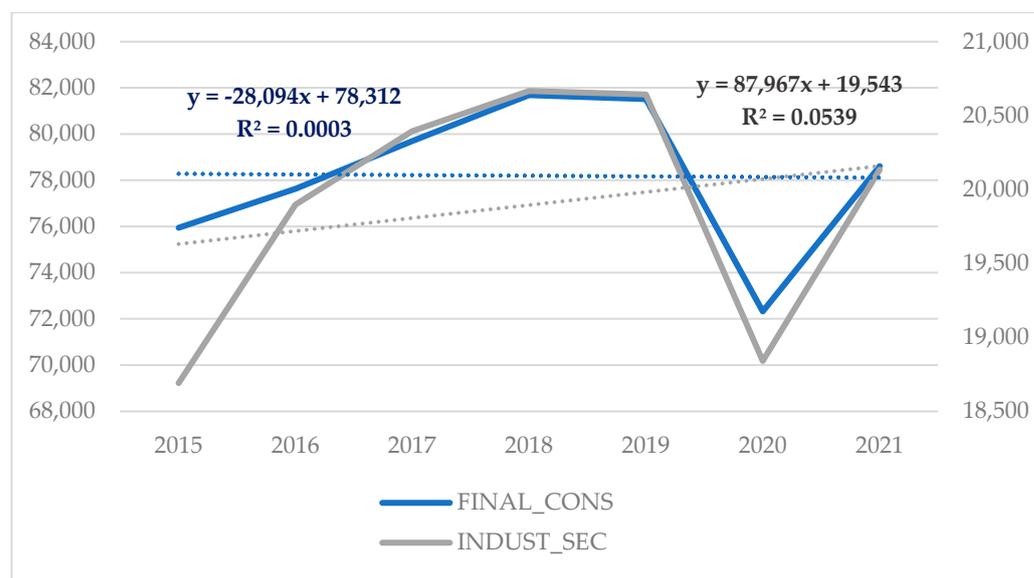


Figure 1. Final energy consumption in Spain (2015–2021).

Since the introduction of 4.0, the trend in energy consumption by both the Spanish economy as a whole and the industrial sector has shown a rise to 2020, a cause attributed, among others, to the impact of the health crisis COVID-19. A closer examination of Spain’s economic growth reveals a startling reality. Figure 2 shows Spanish economic growth in terms of GDP at constant prices, deflated based on 2015 (based on data from INEbase).

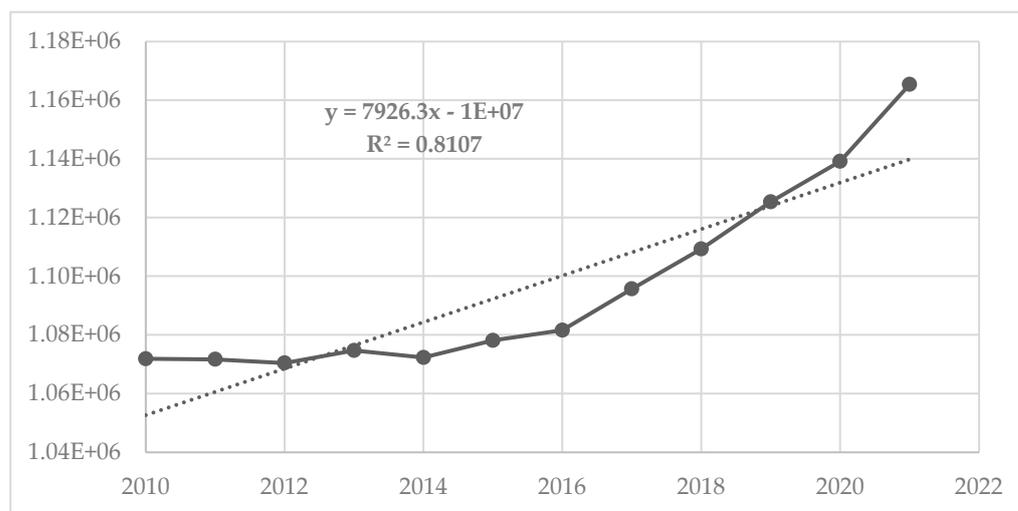


Figure 2. GDP constant prices in Spain (2010–2021).

Regarding the country's economic growth, the health crisis caused by COVID-19 initially did not lead to a decrease in growth levels. By observing the linear correlation coefficient (LCC) between the GDP variable at constant prices and analyzing its correlation with respect to final energy expenditure, as well as with the final energy expenditure of the industrial sector, two models emerge, which are described below.

$$LCC (GDP\text{-}final\ energy\ consumption) = -0.05 [R^2] \quad (1)$$

This expression is likely from a study that examines the relationship between the levelized cost of energy (LCC), gross domestic product (GDP, constant prices), and final energy consumption. The value of -0.05 indicates that there is a negative correlation between LCC and GDP (constant prices)-final energy consumption, which means that as the LCC decreases, GDP (constant prices) and final energy consumption tend to increase. The value in brackets, $[R^2]$, indicates the coefficient of determination, which measures how well the model fits the data. In this case, an R^2 of 0.05 means that the model explains only 5% of the variance in the data.

$$LCC (GDP\text{-}final\ energy\ consumption\ industry) = 0.16 [R^2] \quad (2)$$

This expression is like the first one, but it focuses specifically on the relationship between LCC, GDP (constant prices), final energy consumption, and the industrial sector. The value of 0.16 indicates a positive correlation between LCC and GDP (constant prices)-final energy consumption industry, which means that as the LCC increases, GDP (constant prices) and final energy consumption in the industrial sector tend to increase as well. The value in brackets, $[R^2]$, represents the coefficient of determination, which, in this case, is 0.16, meaning that the model explains 16% of the variance in the data.

The research examined the correlation between the levelized cost of energy (LCC), gross domestic product (GDP, constant prices), and final energy consumption, with a specific focus on the industrial sector. The outcomes of our analysis revealed that LCC and GDP were positively correlated with the final energy consumption in the industrial sector ($LCC (GDP\text{-}final\ energy\ consumption\ industry) = 0.16 [R^2]$). This result implies that an increase in LCC would lead to an increase in GDP and final energy consumption in the industrial sector. Nonetheless, a negative relationship was also detected between LCC and GDP (constant prices)-final energy consumption in all sectors ($LCC (GDP\text{-}final\ energy\ consumption) = -0.05 [R^2]$), suggesting that a decrease in LCC would lead to an increase in GDP and final energy consumption across all industries. In summary, the findings indicate that a reduction in LCC could have significant implications in promoting economic growth and decreasing energy consumption in diverse sectors.

Thus, initially, energy consumption and growth do not seem to have a satisfactory level of relationship. This may have an impact on policies and measures to be taken in the energy sector as what happens will not result in further growth of the economy. This may discourage the development of new and better energy policies and energy consumption.

3.1. Sustainability 4.0: Types of Energy Used in Spain

Globally, there is a trend from high to low carbon emissions, just as there is a trend from fossil to non-fossil energy [82]. The application of technology also enables energy to be harnessed and energy-efficient and low-emission production methods to be generated. Thanks to this 4.0 technology, among other benefits, there are better safety protocols [83] that seek to prevent incidents affecting the environment [84]. However, due to the production activity itself, the probability of suffering these incidents is still high. Therefore, the consumption of this non-green energy will perpetuate a problem of industrial sustainability.

Energy consumption in Spain is high compared to other EU countries. According to data from the European Environment Agency, energy consumption per capita in Spain is about 10%, according to the data published by eea.europa.eu on the energy consumption of the EU—higher than the European average. The transport and residential sectors are the largest consumers of energy in Spain, followed by industry and the services sector. In terms of the source of energy used, oil and its derivatives are the most widely used in the country, followed by electricity and natural gas.

The study of the data relating to the several types of energy currently used by Spanish industry provides a snapshot of the state of this issue and the level of progress made since the advent of the 4.0 concept. In Table 1, it can be seen how Spain has not modified its levels of fossil energy consumption at all, these being absolutely the majority in the common use of the industrial fabric. According to official data from energia.gob.es (energy balance), petrol and natural gas make up 61% of the energy used by industry, neither of which is green energy nor a driver of sustainability.

Table 1. Percentage presence of each type of energy in Spanish industry (2015–2021).

Year	Total Cons.	Fossil Energy	%	Bioenergy	%
2015	15,017.20	13,538.90	90.16	1478.30	9.84
2016	15,814.40	14,007.20	88.57	1807.20	11.43
2017	16,614.60	14,742.70	88.73	1871.90	11.27
2018	16,619.70	14,723.00	88.59	1896.70	11.41
2019	16,696.60	14,693.50	88.00	2003.10	12.00
2020	14,790.80	12,943.30	87.51	1847.50	12.49
2021	15,626.50	13,723.60	87.82	1902.90	12.18

If we analyze the data on the consumption of fossil fuels and bioenergy in the period between 2015 (the start of 4.0 in Spain) and 2021, the following can be observed (Table 1, based on data from Energy.gob.es):

There is a subtle trend toward reducing the presence of fossil fuels in Spanish industry. However, the percentage of fossil fuels is extremely high and is still a long way from sustainability standards, as it is still 2021, six years after the start of 4.0 and practically two decades since the changes in the consumption of these energies began to be considered.

It is evident that a truly effective economic and political plan is necessary for the gradual elimination of the use of fossil fuels, as was done in Germany with the *Energiewende* initiative [58], and periodic monitoring of data is necessary to evaluate whether this transition is taking place.

3.2. Policies on Renewable Energies: Green Taxes

The features of the industries and companies in Spain should be considered. Thus, there is a high presence of small and medium-sized enterprises, so policies should focus on innovation and promotion of cleaner technologies, considering the size, knowledge intensity, and inter-company cooperation of the Spanish fabric [85].

The objective of sustainable development is to achieve a harmonious equilibrium between economic advancement, environmental preservation, and social well-being, with the goal of ensuring that future generations can meet their needs [86]. Other scholars emphasize the significance of conducting meticulous assessments of energy sectors to inform the planning and decision-making processes associated with energy policies [87].

However, economic growth has led to the exploitation of natural resources and pollution, which is a challenge for sustainable development. Environmental taxes can contribute to sustainable development by internalizing environmental costs in the price of goods and services, encouraging the adoption of more sustainable practices, and generating revenue for environmental protection policies and sustainable development programs [86]. Related to the above is a change in business culture, as well as a need for investment in resources and infrastructure [88].

By way of illustration, the case of European small and medium-sized enterprises in terms of the adoption of clean technologies and recycling is discussed. Studies indicate that energy prices have a strong influence on the adoption of clean technologies and recycling by SMEs. In addition, the capacity of SMEs to innovate and the existence of supportive policies also influence their adoption of clean technologies and recycling [89].

This indicates that EU energy and environmental policy must be coherent and coordinated to support sustainable development and the adoption of clean technologies by SMEs.

Thus, it is argued that environmental taxes can be an effective tool for tackling climate change and promoting sustainable development, as they allow environmental costs to be included in the price of goods and services, providing incentives for the adoption of more sustainable practices [90]. In addition, revenues generated by environmental taxes can be used to finance environmental protection policies and sustainable development programs.

The implementation of environmental fiscal policies should be accompanied by measures to support and promote sustainable practices and technologies, as well as environmental education and awareness programs [91].

However, the definition of environmental taxes and their application, specifying their objectives and design criteria (such as their tax base), as well as the relationship between environmental taxes and other environmental policy instruments, need to be properly studied and precisely defined [91].

In this context, the reality is that Spanish industry, despite adapting changes in terms of technology, connectivity, and managing increasingly smart factory units, has not applied protocols for switching from traditional energy sources.

One of the causes may be the lack of economic return in the short and medium term of applying these changes. On the contrary, they imply economic and human costs that make companies decide not to implement the changes. National expenditure on environmental protection applied to the industrial sector in Spain in 2010 amounted to EUR 18,636.50 million, according to the data published by the OECD (about environmental protection expenditure accounts).

It is true that since the implementation of 4.0 in Spain, there has been an increase in this type of expenditure, rising by more than 13.00% (Figure 3, based on data from OECD STAT). The use of modern technologies together with European environmental policies can therefore justify this.

In this sense, to give an overall picture of the attention paid to the environment, it is worth contrasting these data with Spain's attitude toward measures to control the negative externalities that affect the environment. On the one hand, Table 2 shows the millions of euros that have been paid up to 2021 in energy taxes.

On the other hand, it shows the data corresponding to pollution and resource taxes. There is no change in the taxes paid for pollution. This indicates that, on the one hand, the industry has not changed its attitude and way of production. On the other hand, it seems that all the effort to generate an environmental culture among the agents involved in the industry is not yielding results.

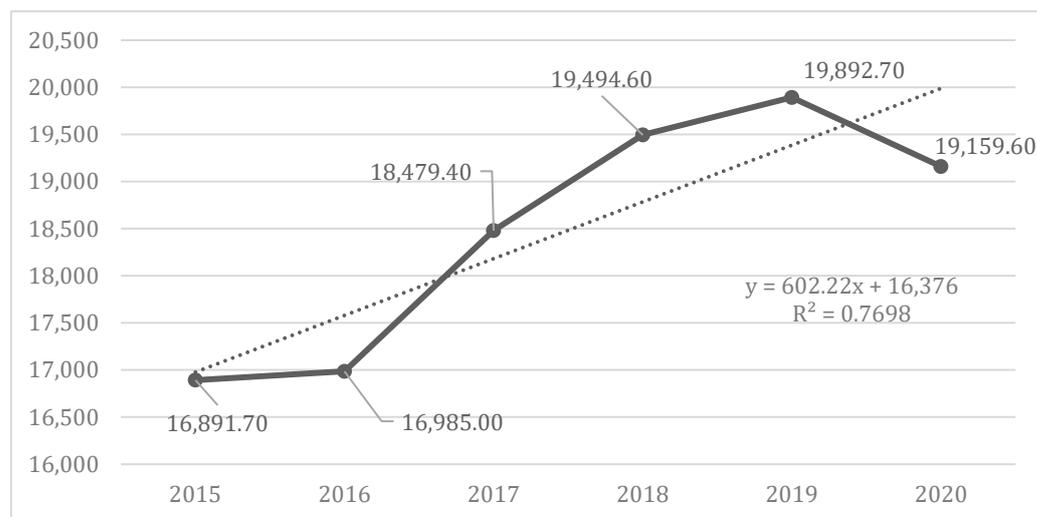


Figure 3. National expenditure on environmental protection. Total economy. Spain (2015–2020). Solid line: National expenditure on environmental protection; dashed line: trend line.

Table 2. Variation rates from energy taxes and pollution taxes in Spain (2015–2021). Base 2015.

Year	Energy Taxes (M€)	Variation Rate	Pollution and Resource Taxes (M€)	Variation Rate
2021	4413.80	0.11	428.40	0.04
2020	3989.20	−0.03	413.40	−0.09
2019	4097.20	0.00	449.80	−0.01
2018	4104.60	0.11	453.20	0.05
2017	3704.20	0.06	431.60	0.04
2016	3481.20	−0.03	415.20	0.02
2015	3600.00	-	406.20	-

The use of taxation tools comes to tax certain behaviors. Already in the neoclassical approach to growth, with authors such as Solow in 1956 [92] or later visions of endogenous growth with authors such as Romer [93,94], the intervention of the public sector is the object of study.

Historically, public intervention has had the objective of stable economic growth (in addition to others such as the correct distribution of income or equity) [95]. However, when it comes to environmental taxes (green taxes), the focus is on the behavior of the agents. The presence of both positive and negative externalities must be analyzed, as far as it marks the existence of both economic and non-economic (or extra-economic) consequences. In the case of environmental externalities, public intervention is a political decision, not an economic one.

As these externalities are not measured in terms of costs and benefits for market actors, other issues must be addressed. One option is to apply the Polluter Pays Principle (PPP) [96], which has been widely applied by the European community in cases such as A. Stanley [97]; the case deals with Directive 91/676/EEC, which aims to protect waters from pollution caused by nitrates from agricultural sources. The case focuses on the identification and designation of vulnerable zones to pollution and their validity in relation to principles such as the PPP, the principle of rectification of environmental damage at the source, and the principle of proportionality. This case has been used as a basis for subsequent decisions, but difficulties in its application have been noted due to problems of identification and proportionality in the risk relationship.

Although this method suffers from problems such as the proportionality of the sanction, the standards of liability for both the risks of pollution and the damage caused must be very well defined. The limitations of the PPP approach have led to the exploration of new options. These include the use of market-based instruments such as subsidies or taxes. In the case of

environmental taxes, their objective is to penalize negative externalities. The purpose of this type of tax is to modify behavior, to correct the negative externalities of the activity.

It is true that despite the above, Spain is making efforts to adjust the tax system—for example, the “Libro Blanco para la Reforma del Sistema Tributario” (White Paper for Tax System Reform) [98], in which a diagnosis of the Spanish tax system is made, by which a series of recommendations are articulated; the text also offers different proposals on several areas, among which is environmental taxation, with proposals such as the abolition of the Tax on the Value of Electricity Production, or the reform of the special tax on electricity to promote electrification and energy efficiency.

In the same sense, attention must be paid to the situation of Spanish fiscal decentralization, as it has usually had a negative impact on environmental taxation (e.g., in the case of water taxes [99]) and has resulted in a lack of coordination between the different public administrations involved in management and a lack of coherence in the related tax policies.

Considering the structure of the tax itself, and the percentage of impact that this type of tax has, the conclusion is that it is inefficient. It does not incentivize behavioral change because it treats all products in an excessively generic way.

4. Discussion: Final Issues

Industry 4.0, commonly referred to as the fourth industrial revolution, pertains to the integration and application of sophisticated digital technologies within the realm of manufacturing and industrial process automation. Its arrival presents opportunities and challenges. It is fundamental that stakeholders make efforts to create models that allow for the evaluation of the implementation of Industry 4.0 technology to study its real impact [100].

On the one hand, it presents an opportunity to achieve greater efficiency, as the implementation of advanced technologies such as the IoT, artificial intelligence, and robotics can enhance the efficiency and productivity of industrial operations, leading to cost reduction and increased competitiveness. Additionally, it offers other opportunities such as mass customization of products and stimulation of innovation by unlocking new opportunities for business models, services, and products. Furthermore, real-time data access, including real-time data collection and analysis, can assist companies in making informed decisions and improving the decision-making process.

On the other hand, its arrival also brings challenges that require a proper understanding of the factors that define and shape the fourth industrial revolution. These challenges include the need for significant investment in infrastructure and personnel training, as well as others such as the rise of cyberattacks and security breaches. Another challenge is the need for cultural change, as Industry 4.0 requires a business culture focused on innovation, collaboration, and experimentation, among other things.

Thus, the optimization of factory production systems, as well as affecting the machinery and human factors involved in the product production process, also affects the external level. These include the environment. The dimension of the effect is absolute, as it has an impact on production, as well as on the other main agents of interest, which is none other than the client or end consumer [101]. This is because if an environment is not sustainable, beyond the product produced, basic issues such as water or air quality will be affected, and this will have a direct impact on the quality of life of the agents.

It is a reality that there are many initiatives to implement an industry based on technology, digitalization, and connectivity within a context of environmental sustainability. The policies implemented seem to result in economic growth for the country. When this is related to the level of performance and emissions, it is observed that it has been reduced by 14.94% in Spain in 2021 compared to the levels existing in 2015. The calculation is based on official data from the INE, specifically on emissions of gases into the atmosphere (annual levels for the Spanish economy).

On the other side, if the level of hazardous waste generated by Spanish industry is analyzed, it is observed that the variation from 2014 to 2020 is 8.23% (1310 to 10,201 units).

This calculation is based on official data from the INE, specifically on waste generated by the industry considered dangerous (annual levels). There does not seem to be a reduction in the emission of environmentally hazardous waste. This behavior has remained at remarkably similar levels.

The previous section explained how this problem is connected to the main tool for correcting behavior, which is the environmental tax. However, the design of this tax in Spain falls short of achieving its objectives. Additionally, the PPP principle is still in effect, which, combined with penalties and the high cost of changing production fundamentals, hinders the transition to cleaner energy and the optimization of processes to decrease pollution levels.

The creation of policies and tools for environmental sustainability in industry has taken place at the European level (e.g., Next Generation EU, as a temporary palliative, with a strong economic envelope proposed for repair at two levels, economic and social [102]), the national level (Connected Industry 4.0), the autonomous community level, and the local level. In this regard, the case of Castilla-La Mancha, a region of Spain, serves as an example, with the “Plan Adelante 2020–2023” [103] plans for investment and innovation, among others.

As it has happened in other cases [99,104], in this one, an analysis of energy taxation and pollution in Spain, and its impact on the management of energy resources at different levels of administrative organization in the country, is configured as a fundamental step, which must always be a constant and transparent study to be useful.

Beyond these tools, Spain is trying to stimulate Industry 4.0 and “Sustainability 4.0” through regulations. On the one hand, specific tax rates are created for environmental protection, which tax both energy and waste. The impact of these taxes does not meet the objective, because industry continues to use mostly fossil fuels, and, on the other hand, there has been no real reduction in atmospheric emissions or waste.

Therefore, to develop an energy sector in line with current sustainability policies and, on the other hand, a set of consumers who understand and adopt this culture of sustainability, it is necessary to review the tools, beyond attending to the macroeconomic levels of technological investment, with its relevant study of economic growth.

On the one hand, tools and plans are nothing if there is no investment in innovation and R&D expenditure (research and development expenditure), and, on the other hand, behavior cannot be corrected if there are no effective sanction systems, so in this sense one of the first issues that should be reviewed is the structure of the green tax base, as the taxpayer cannot “run away” from their responsibility.

In short, it is a matter of creating a sufficiently coercive barrier for industry to opt for a shift toward sustainability.

Sustainability 4.0 presents limitations, as do green taxes, as advanced technologies such as IoT or artificial intelligence may require significant initial investment. This may be a challenge for small and medium-sized enterprises without the necessary budget. The complexity of the technology and the need to hire specialized and trained personnel can be an additional challenge. Furthermore, there is a real lack of regulation and standardization, as regulations have proved to be ineffective in changing agent behavior.

There has been a growing interest in promoting sustainable practices within industries in recent years, and one strategy is to create a coercive enough barrier for industries to adopt sustainable production methods. However, it is important to note that this strategy has its limitations, and the effectiveness of these coercive measures, especially in terms of achieving long-term and sustainable results, can be difficult to quantify. Furthermore, these measures can have unintended consequences, such as the displacement of the industry to regions with weaker environmental regulations or the ineffectiveness of the measures themselves.

To further explore the effectiveness of these coercive measures and address these limitations, a future research project could involve a comparative analysis of industries in different regions or countries. The study could examine the effectiveness of diverse types of coercive measures, such as economic incentives, fines and penalties, and regulatory requirements.

By analyzing and comparing the results of these strategies, the study could offer ideas on the most effective strategies for promoting sustainable practices within industries. Additionally, the study could explore possible unintended consequences and identify strategies to mitigate these risks. Ultimately, this research could help guide policymakers and industry leaders to make more informed decisions about sustainable production methods.

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