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RESEARCH ARTICLE **Open Access**

Identifying Factors Affecting Energy Waste in the Production Industry and Providing a Suitable Model for Energy Efficiency and Development of Renewable Energy in the Production Sector

Aman Allah Rahpeyma[1*], Mohammad Bahrami Seifabad[2], Yaghoub Ansari[3] , Roohalah Negahdari Nia[4]

Abstract
The energy sector is a vital pillar of economic development of any country. The government and the private sector are exploring efficient energy sources, and for this purpose, various governments have specified carbon-related targets considering the existing realities. In such circumstances, manufacturing companies are under pressure to improve their energy performance. In these circumstances, reducing energy loss from production systems is very important. The aim of the present study is to identify the factors affecting energy loss in the manufacturing industry and to provide a suitable model for energy efficiency and the development of renewable energies in the manufacturing sector. The research method is mixed. The study sample consisted of 148 experts in manufacturing industries affiliated with the Electronic Industries Company in Shiraz. Data analysis was performed using pls software. The results show that reforming the infrastructure related to renewable energies, paying the initial costs of technology adoption, supporting policies, technological innovations, and inter-sectoral cooperation in technology can be solutions for the development of renewable energies in the manufacturing sector.
Keywords: Energy waste, manufacturing industries, energy efficiency, renewable energies

Introduction

Over the past 30 years, the world's GDP has grown dramatically, rising 136.03% in 2019 compared to 1990, which has caused total energy use to increase by 65.79% in the same timeframe (World Bank 2022). The share of developing economies in global energy consumption as well as energy waste, especially in the production sector, is significant. Energy losses occur during the generation, transmission and transportation of energy. These losses can have an immense impact on environmental quality. Developing economies are more susceptible to these losses due to their lack of technology in the energy sector. Furthermore, energy losses are a waste of resources, as they do not generate any output and only increase costs. Additionally, a higher share of fossil fuels in developing economies' energy resources leads to increased environmental degradation due to increased energy losses. This, in turn, leads to an increased demand for fossil fuels, energy demand, foreign dependency on energy, foreign exchange needs, and current account deficits (Naimoglu 2021; Naimoglu and Ozel 2022; Naimoglu and Akal 2022). Therefore, it is important to reduce energy losses to have a sustainable energy supply and maintain high environmental quality.

On the other hand, the integration of renewable energy solutions into the manufacturing industry is increasingly recognized as a pivotal strategy for enhancing sustainability and reducing the global carbon footprint. This transition is not only a response to the growing environmental concerns but also a strategic move to ensure

1. Assistant Professor, Department of management, Zarghan Branch, Islamic Azad University, Zarghan, Iran. (Corresponding Author: rahpeyma20@yahoo.comMohammad)
2,3,4. Assistant Professor of Management Department, Yasouj Branch, Islamic Azad University, Yasouj, Iran.

long-term economic viability and energy security within the sector. The importance of renewable energy in manufacturing stems from the sector's substantial energy consumption and its significant impact on environmental degradation, making it a critical area for interventions aimed at mitigating climate change and promoting sustainable industrial practices (Usman et al., 2024).

Renewable energy technologies, such as solar photovoltaics, wind turbines, and biomass energy systems, offer the manufacturing industry an opportunity to decouple energy consumption from carbon emissions. Taboada et al. (2012) explored a solar photovoltaic-based energy solution for green manufacturing, highlighting the potential for renewable energy to accommodate the electricity needs of large manufacturing facilities while minimizing system costs and reducing the carbon footprint. Similarly, Xin et al. (2022) investigated the impact of renewable energy technology innovation on manufacturing carbon intensity in China, revealing significant inhibitory effects on local and neighboring carbon intensity, thereby underscoring the role of innovation in facilitating the green transformation of the manufacturing sector. Furthermore, the adoption of renewable energy in manufacturing is not without challenges. Issues such as power volatility, high initial investment costs, and the need for technological adaptation pose significant barriers to widespread adoption. However, these challenges are increasingly being addressed through policy support, technological advancements, and financial incentives aimed at enhancing the economic competitiveness of renewable energy solutions.

The transition towards renewable energy in manufacturing also presents numerous opportunities, including cost savings, improved energy efficiency, and enhanced corporate reputation. This study emphasized the strategic function of sustainability in manufacturing, advocating for optimization of resource utilization and recovery of wastages through renewable energy use. Moreover, Kılçı (2022) examined the relationship between renewable energy use and carbon emissions in Germany and Finland, providing insights into how renewable energy policies can contribute to a more environmentally friendly future by significantly reducing carbon emissions. The integration of renewable energy solutions into the manufacturing industry is of paramount importance for achieving sustainability and reducing the carbon footprint.

The issue of energy efficiency in the manufacturing industry in Iran is considered a major challenge, and its root solution will undoubtedly be possible only through a national action with the coherence, participation, and synergy of all relevant sectors, including producers, consumers, government officials, and policymakers. In the meantime, the emergence of widespread imbalances that have gradually trapped Iran in a serious crisis in sustainable energy supply, especially in the manufacturing industry, has made increasing productivity and preventing energy waste as a national asset an unavoidable necessity (Alam Tabriz et al.,2024). However, to confront imbalances on the path to increasing productivity, there are two important points, of which the acceptance of the principle of energy waste is undoubtedly the most important. In the first stage, this will require identifying the factors affecting energy waste in the manufacturing industry. In the second step, a review of infrastructure should be put on the agenda. On the other hand, given that challenges in the areas of energy efficiency in the Iranian manufacturing industry still remain, the opportunities for innovation, cost savings, and environmental benefits are a compelling case for the transition to renewable energies. To this end, the present study, by supporting policy frameworks, technological advances, and financial mechanisms, addresses the obstacles and realizes the full potential of renewable energies in the manufacturing sector in Iran. The present study will first identify the factors affecting energy waste in the manufacturing industry and then, based on the identified issues, will present an appropriate model of energy efficiency and renewable energy development in the manufacturing sector in order to face the problems and challenges of this sector.

Literature Review

Energy waste

"Energy waste" is not a common phrase, and there is no clear definition in manufacturing literature, while evidence identifies the important and massive potential for improving energy performance by reducing energy waste (Mardani et al., 2022). One possible reason why "energy waste" has not become a common term is that energy is physically invisible. Therefore, it is difficult to observe the energy loss. In such a situation, it is necessary to have a more accurate definition of unnecessary energy consumption, i.e. energy waste, and to understand the characteristics of energy waste more so that all stakeholders can have a comprehensive understanding of energy consumption in production.

The narrow definition of energy waste

The results of the literature review show that there are two main causes of energy waste – waste heat and the inefficient utilization of the production system.

Fig. 1. provides a simple illustration of the relationships between energy inputs, production systems, and two main causes of energy waste. Energy enters a production system as one type of resource and is consumed by machines, devices, hardware, etc. Part of the energy will be converted into heat and dissipated, normally into the air. Some measures were developed to reduce dissipated energy such as using new material to prevent heat dissipation (Pontik, 1976) or developing a new approach to detect such energy losses (Czopek et al., 2022). However, it is still impossible to avoid all the waste heat from a production system.

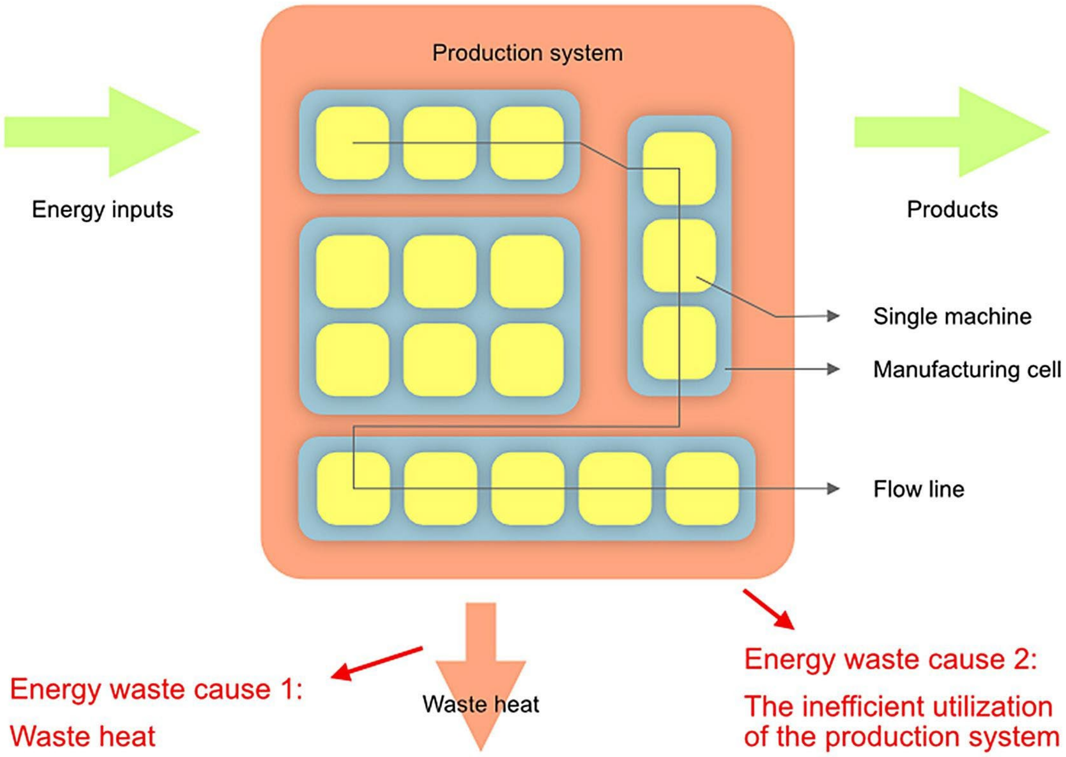

Figure1. *The relationship among two main causes of energy inputs, production systems, and two main causes of energy wastes (Geng, Evans, 2022).*

The second cause of energy waste – the inefficient utilization in the production system – is equally essential for factories to pay attention to. Based on Hon's research (2005), a production system in a factory normally has four levels (from low to high):

1) the single machine, 2) the manufacturing cell, 3) the flow line, and 4) the whole factory. Issues of wasting energy may occur at each level, covering problems like energy consumed by idle machines, inappropriate scheduling, inefficient use of production machines, etc. Previous studies revealed that different efforts have been made to solve different issues so that energy efficiency of the whole factory can be enhanced. These approaches are mainly management-based, while technologies, especially digital technologies, are essential for facilitating effective management. These technologies enable practitioners to visualise energy in the production systems so that they can apply their knowledge to removing or avoiding other types of resource wastes, i.e. material, water, etc., to energy (Yin et al., 2022).

However, few studies provide a holistic view of all the potential opportunities to save energy. However, it is important to create a concept that covers all possibilities of improving energy performance, in which energy waste is suitable in all cases. All the energy wastes should be eliminated. Based on these observations, we give a definition of energy waste as:

"Energy waste is the energy consumed above the minimum energy consumption that one production system can achieve based on the current configuration of this production system."

This definition is mainly aimed at the unnecessary operation energy consumption, which is more associated with the second cause of energy waste.

Considering that in the present study, the prevention of energy wastage in the industry has been discussed by using the development of renewable energy and solutions related to this type of energy, in the following, the literature related to renewable energy has been reviewed.

A brief history of how renewable energy has been increasingly adopted by the manufacturing industry

The adoption of renewable energy within the manufacturing industry marks a significant shift towards sustainable industrial practices, driven by the dual imperatives of environmental responsibility and economic viability. This transition has been characterized by gradual but steady progress, influenced by technological innovation, policy frameworks, and changing market dynamics. The initial foray into renewable energy by the manufacturing sector can be traced back to the energy crises of the 1970s, which underscored the vulnerabilities associated with dependence on fossil fuels. Early adopters began to explore alternative energy sources, such as solar and wind power, albeit on a small scale due to technological and economic constraints. These pioneering efforts laid the groundwork for subsequent advancements in renewable energy technologies (Breyer et al, 2022).

The turn of the century marked a pivotal moment in the integration of renewable energy into manufacturing, propelled by heightened awareness of climate change and its impacts. Governments and international bodies began to introduce policies and incentives aimed at reducing carbon emissions, which, in turn, encouraged manufacturers to reassess their energy strategies. The Kyoto Protocol, for instance, played a crucial role in promoting the adoption of renewable energy by establishing legally binding emission reduction targets for participating countries (Penna, 2019).

Technological advancements have been instrumental in accelerating the adoption of renewable energy in the manufacturing sector. Improvements in the efficiency and cost-effectiveness of solar photovoltaic (PV) panels, wind turbines, and biomass energy systems have made renewable energy a more attractive option for manufacturers. The scalability of these technologies has enabled their integration into a wide range of manufacturing processes, from small-scale operations to large industrial complexes (Kılçı, 2022).

Economic factors have also played a significant role in the adoption of renewable energy. The decreasing cost of renewable energy technologies, coupled with the increasing volatility of fossil fuel prices, has improved the business case for renewables. Moreover, the potential for energy cost savings over the long term has made renewable energy investments more appealing to manufacturers seeking to enhance their competitiveness and resilience. Policy support has been critical in facilitating the adoption of renewable energy in the manufacturing sector. Incentives such as tax credits, subsidies, and feed-in tariffs have lowered the barriers to entry for renewable energy projects. Additionally, regulatory measures, including carbon pricing and emission trading schemes, have incentivized manufacturers to reduce their carbon footprint through renewable energy adoption (Razeghi et al, 2023). Despite the progress made, challenges remain in fully integrating renewable energy into manufacturing operations. Issues such as energy storage, grid integration, and the intermittent nature of some renewable sources continue to pose obstacles (Altin and Akay; 2024). However, ongoing research and development efforts are focused on addressing these challenges, promising to further enhance the viability of renewable energy for manufacturing.

The adoption of renewable energy by the manufacturing industry has evolved from tentative exploration to strategic implementation. This transition reflects a broader shift towards sustainability, driven by technological innovation, economic considerations, and policy support. As the industry continues to navigate the challenges and opportunities associated with renewable energy, the commitment to sustainable manufacturing practices is expected to deepen, contributing to global efforts to combat climate change (Usman et al, 2024).

Current State of Renewable Energy in Manufacturing

The integration of renewable energy into the manufacturing sector represents a critical frontier in the pursuit of sustainable industrial development. The focus on renewable energy technologies—such as solar, wind, biomass, and hydroelectric power—reflects their growing importance in reducing carbon emissions, enhancing energy security, and improving economic competitiveness within the manufacturing industry. Recent studies have underscored the increasing adoption of renewable energy sources in manufacturing due to their potential to mitigate environmental impacts and reduce dependence on fossil fuels (Dey et al, 2022; Tutak & Brodny, 2022). Solar photovoltaic (PV) systems and wind energy, in particular, have seen significant implementation across various manufacturing sectors, driven by technological advancements, decreasing costs, and supportive policy frameworks. These technologies not only contribute to the decarbonization of industrial operations but also offer resilience against energy price volatility (Fraser et al, 2023).

However, the transition to renewable energy in manufacturing is not without challenges. High initial investment costs, technological complexity, and the need for skilled workforce for installation and maintenance are among the primary barriers to wider adoption. Additionally, the intermittent nature of some renewable energy sources, such as solar and wind, poses challenges for continuous manufacturing processes, necessitating innovative solutions for energy storage and management. Policy and regulatory support play a crucial role in facilitating the integration of renewable energy into manufacturing. Incentives such as tax credits, subsidies, and feed-in tariffs have been effective in lowering the barriers to entry for renewable energy projects (Dey et al, 2022). Moreover, international agreements and national policies aimed at reducing carbon emissions have prompted manufacturers to adopt cleaner energy sources to comply with regulatory standards and meet sustainability goals.

The literature also highlights the importance of technological innovation in overcoming the challenges associated with renewable energy adoption in manufacturing. Advances in energy storage technologies, smart grids, and energy management systems are critical for ensuring the reliability and efficiency of renewable energy sources in industrial applications. Furthermore, the integration of renewable energy with Industry 4.0 technologies, such as the Internet of Things (IoT) and artificial intelligence (AI), offers new opportunities for optimizing energy use and production processes (Hamdan et al, 2024).

The current state of renewable energy in manufacturing is characterized by rapid advancements and growing adoption, driven by the imperative for sustainability and supported by technological innovation and policy measures. Despite the challenges, the potential benefits of renewable energy for the manufacturing sector—ranging from environmental and economic to strategic—are compelling. Continued research and development, alongside supportive policies and industry engagement, are essential for realizing the full potential of renewable energy in manufacturing.

Main barriers faced by manufacturers in adopting renewable energy solutions.

The transition towards renewable energy in the manufacturing sector is pivotal for achieving sustainability and reducing global carbon emissions. Despite the clear benefits, manufacturers encounter several barriers in adopting renewable energy solutions. Technological challenges are at the forefront (Barman et al, 2023), with the variability and intermittency of renewable sources like solar and wind posing significant issues for continuous manufacturing processes that demand stable and reliable energy supplies. The current state of energy storage technology, although advancing, still falls short in terms of cost-effectiveness and efficiency for large-scale industrial use (Elahi et al, 2022).

Economic and financial constraints further complicate the picture. The initial capital investment required for renewable energy systems is substantially higher compared to conventional energy sources. This is particularly challenging for small and medium-sized enterprises (SMEs) that may have limited access to capital. The absence of clear financial incentives and supportive policies from governments exacerbates this barrier, rendering the return on investment uncertain and less attractive (Al-Emran, Griffy-Brown, 2023). Regulatory and policy frameworks also present hurdles. Inconsistent and unclear policies, along with cumbersome permitting and approval processes, can deter manufacturers from pursuing renewable energy projects. The lack of standardized regulations across different jurisdictions adds another layer of complexity, increasing the risk associated with renewable energy investments (Hassan et al, 2023).

Knowledge and information gaps about renewable energy technologies among manufacturers constitute another significant barrier. Many in the industry are not fully aware of the potential benefits and applications of renewable energy within their operations, nor do they understand the technical, economic, and regulatory nuances involved in making the transition (Igbinenikaro et al, 2024).

Cultural and social factors play a role as well. Resistance to change and skepticism about the reliability and effectiveness of renewable energy solutions can hinder their acceptance and implementation. The manufacturing sector's traditional reliance on fossil fuels is deeply ingrained, making the shift to renewable energy not just a technological challenge but a cultural one (Ali et al, 2023). Finally, the existing energy infrastructure in many regions is ill equipped to accommodate the decentralized nature of renewable energy generation. Integrating renewable sources into the grid requires significant modifications to existing networks and the development of new transmission and distribution systems, which can be both complex and costly.

Integrating renewable resources into the production network to prevent energy waste in this sector and make it more efficient requires significant changes to existing networks and the development of new transmission and distribution systems, which can be complex and costly. Overcoming these obstacles requires a coordinated effort from all stakeholders. Researchers, governments, industry leaders, and financial institutions must work together to create an enabling environment for research and development, create clear policies, and foster a culture of innovation and sustainability. The present study was conducted to provide solutions to address the problems of energy waste in the manufacturing sector in Iran. Since the renewable energy approach to preventing energy waste in the manufacturing industry has attracted much attention from researchers outside Iran, but no comprehensive study has been conducted in Iran so far, the contribution of the present study will be to identify sources of energy waste in the manufacturing sector and provide opportunities for innovation, cost savings, and environmental benefits through renewable energies. This study proposes a new approach to preventing energy waste in the manufacturing industry.

Hypotheses

In this part of the study, the research hypotheses will be developed according to the existing literature.

The integration of renewable energy solutions into existing infrastructures presents both technical and infrastructural challenges that must be addressed to ensure a smooth transition towards sustainable energy systems. Kataray et al (2023) discuss the integration of smart grids with renewable energy sources, emphasizing the opportunities and challenges presented by this combination. The review identifies communication networks and appropriate demand-side management with suitable algorithms as crucial for the successful integration of smart grids with renewable energy. The study also addresses the evolution of Indian energy legislation and regulations, highlighting the main barriers to smart grid integration and offering policy recommendations based on the assessment (Kataray et al., 2023). Vries and Verzijlbergh (2018) present a systematic review of the challenges to the regulation of electricity markets posed by the integration of variable renewable energy sources. The study develops a framework for analysing the need for coordination between aspects of power sector regulation to achieve economic efficiency. It identifies institutional fragmentation as a significant challenge in Europe, where variable renewable energy requires closer coordination between countries, different levels of the electricity system, and markets serving different time scales (Vries & Verzijlbergh, 2018). Yıldızbaşı (2021) explores the integration challenges of blockchain technology with renewable energy systems within the circular economy perspective. The study discusses how blockchain can address issues in energy grid management, such as efficient distribution, illegal energy use, and the entry of individual energy producers into the market. However, it also highlights the challenges faced during integration, including the complexity of energy distribution networks and the need for a novel integration process to ensure sustainability (Yıldızbaşı, 2021). The integration of renewable energy solutions into existing infrastructures faces several technical and infrastructural challenges, including power quality issues, the need for effective demand-side management, regulatory fragmentation, and the integration of innovative technologies like blockchain. Addressing these challenges requires coordinated efforts between policymakers, industry stakeholders, and technology developers to develop and implement effective mitigation strategies, ensuring the successful transition towards sustainable energy systems (Alamshahi et al, 2024). Considering the above, the first hypothesis of the research is presented as follows:

1- Improving the infrastructure related to renewable energy in the production sector can be a solution for the use of renewable energy in the production sector.

In today's world, the volatility of fossil fuel prices and the potential for regulatory changes that favor sustainability have created additional motivation to adopt renewable energy solutions (Xin et al., 2022). the opportunities afforded by renewable energy for the manufacturing sector are substantial. Beyond the environmental benefits, renewable energy can confer economic advantages through operational cost savings, enhanced energy security, and improved compliance with regulatory standards. Furthermore, companies that proactively embrace renewable energy can bolster their corporate reputation, aligning with consumer and stakeholder expectations for sustainable practices. The body of research on renewable energy in manufacturing underscores the importance of policy support, technological innovation, and cross-sector collaboration in overcoming barriers to adoption. Incentives such as tax breaks, subsidies, and grants play a crucial role in enhancing the economic viability of renewable energy projects. Meanwhile, ongoing advancements in technology are progressively addressing the challenges of cost, efficiency, and integration, paving the way for broader implementation across the manufacturing industry (Xin et al., 2022; Kılçı, 2022). The transition to renewable energy in the manufacturing sector is not merely a response to environmental imperatives but a strategic investment in the future. The path forward requires concerted efforts from industry stakeholders, policymakers, and the research community to navigate the complexities of this transition. By fostering an environment conducive to renewable energy adoption, the manufacturing sector can significantly contribute to global sustainability goals, ensuring a cleaner, more resilient future. Considering the above, hypotheses 2 and 3 of the research are presented as follows:

2- Paying the initial costs of adopting renewable energy technology in the production sector can be a solution for the use of renewable energy in the production sector.
3- Policy support, technological innovation and inter-sectoral cooperation in renewable energy technology in the production sector can be a solution for the use of renewable energy in the production sector.

Globally, renewable energy sources such as solar, wind, biomass and geothermal are considered the most effective solutions to energy optimization and environmental problems (Osman et al. 2022). The transition to renewable energy sources creates new jobs and reduces carbon dioxide emissions. Since renewable energy sources produce natural fuels, they can provide a sustainable energy source with minimal operating costs and regular energy supply. On the other hand, renewable energy sources do not have any harmful impact on the environment and, in addition, renewable energies such as solar, wind and tidal energy require minimal amounts of water for production, which can contribute to saving water resources (Tanaka et al. 2022).

However, the unstable availability of renewable energy sources, which depends on weather conditions, such as the availability of wind and solar radiation, is a major limitation. Energy storage systems can partially overcome this gap, but the overall cost and energy conversion efficiency are low (Elkadeem et al. 2019). In general, renewable energy sources may prevent energy waste. Considering these issues, Hypothesis 4 is presented as follows:

4- The use of renewable energies in the production sector (such as the sun, wind, and biomass) can prevent energy wastage.

Today, countries around the world are actively increasing their efforts in energy innovation to decarbonize the global energy grid and achieve energy waste prevention goals. The new wave of the Industrial Revolution 4.0 has contributed to this as investors and manufacturers have kicked off the trend by turning their attention to energy-related technological innovations that can help design smart energy grids for today's and tomorrow's needs. This development, among other things, has already led to the implementation of a number of technological innovations that can increase the use of renewable energy sources, such as the deployment of AI-based robots to monitor the efficiency of hydroelectric power plants and reduce maintenance costs. Hydroelectric battery hybrids to improve grid services, and the adoption of a "Hyperloop for Fish" to safely transport fish from dams (International Hydropower Association, 2021). Despite the advent of the Fourth Industrial Revolution (4IR) and its advancements, the development of these innovations requires significant investment and thus, there is a need to assess their effectiveness in terms of real contribution to achieving the decarbonization agenda through promotion. Despite the need to investigate the real end result of the impact of technological innovations on the advancement of renewable energy sources, empirical exercises in this area have been relatively inactive, as most research efforts have mainly focused on the development of these innovations without measurement. Therefore, the present study formulated the following research hypothesis number 5:

5- The use of new technologies related to renewable energies in the production sector can play a mediating role in preventing energy waste in the production sector.

Achieving energy efficiency is a process that requires technological changes in facilities and conscious choice of energy type (Chebotareva et al, 2020). In today's world, with the current state of technological progress, most facilities and technologies are now specifically built to provide energy efficiency and prevent its waste (Mohatdi et al, 2022). Saving energy can also help the manufacturing sector save money, and conscious daily actions can also reduce energy costs (Didekhani et al, 2019). Considering this, Hypothesis No. 6 of the research is formulated as follows:

6- Preventing energy waste in the production sector can provide economic benefits in the production sector.

According to the formulated assumptions, the conceptual model of the current research is as follows:

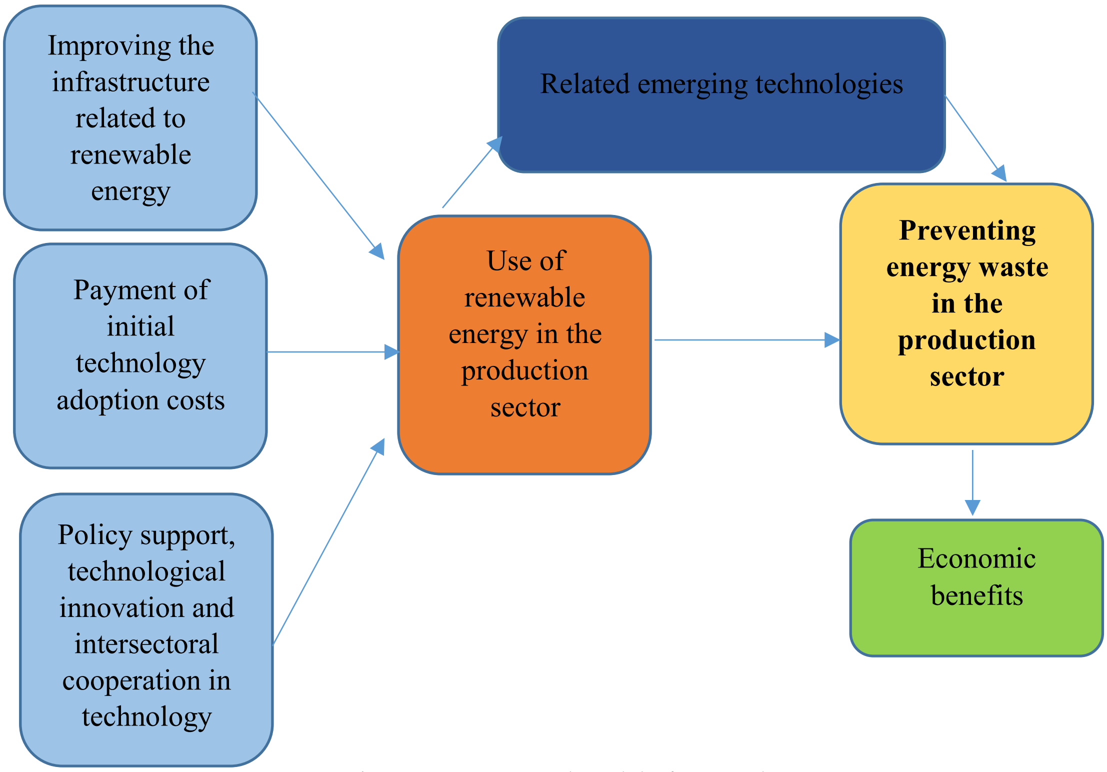

Figure 2. *Conceptual model of research*

Methodology

The present study was conducted in the field of mixed research and based on quantitative and qualitative data. Also, this study was applied in terms of purpose and library-survey in terms of data collection. The statistical population is all energy specialists in the manufacturing industries of companies affiliated with the Iranian electronics industry located in Shiraz. The sampling method was snowball. Based on this method, the number of samples for the study has reached 148 people. In order to collect data related to each of the research variables, a questionnaire with a total of 21 questions was used. Also, Smart-PLS software was used to analyze the data and test the hypotheses.

Findings

In this research, Smart-PLS software was used to investigate the relationships between variables using inferential statistics and depending on the type of data distribution. Also, the hypothesis of this research has been tested using confirmatory factor analysis. The most important goal of confirmatory factor analysis is to determine the power of the predefined factor model with a set of observed data. In other words, confirmatory factor analysis seeks to determine whether the number of factors and the variable loadings measured on these factors are consistent with what was expected based on the theory and theoretical model. In order to achieve the final results of the hypothesis test, various steps were carried out to check the preparations and prerequisites of the test, which include checking the fit of the model, which includes the following sub-structures: 1. measurement models, 2. structural model, and 3. general model, and testing the hypotheses through Examining the standardized coefficients of the paths related to the hypotheses and examining the significance coefficients of Z related to each of the hypotheses. Also, to check the fit of the measurement model, three reliability criteria of the index, convergent validity and divergent validity are used. As can be seen, in all model structures, factor loads have values above 0.4; Therefore, the reliability of the measurement models is acceptable, which indicates the appropriate fit of the measurement model. According to the algorithm of data analysis in the method of partial least squares (PLS), now it is the turn to examine Cronbach's alpha coefficients and composite reliability. Cronbach's alpha coefficients and composite reliability of constructs express the ratio of variance between each construct and its indicators to the variance of the whole construct. Cronbach's alpha and reliability coefficient higher than 0.7 are considered acceptable. According to the results, all the factors have an acceptable combined reliability coefficient. Also, Cronbach's reliability coefficient is acceptable; Therefore, it can be concluded that the research questionnaire has good reliability. As a result, the appropriateness of the measurement model is also confirmed. Divergent and convergent validity were also confirmed.

Examining the fit of the research model

The examination of the fit of the model is done in three parts: measurement model, structural model and general model to check to what extent the research model fits the data collected from the statistical sample. After confirming the fit of the model, the researcher is allowed to examine and test the research hypotheses. Smart PLS software, after obtaining the data related to the variables, presents the final model of the research, which includes most of the analysis, in the form of Figure 3. In the mode of estimating the standardized coefficients and Figure 4. The model in the mode of significant coefficients t, which all Analysis and fitting of measurement, structural and general models and hypothesis testing are done based on these outputs.

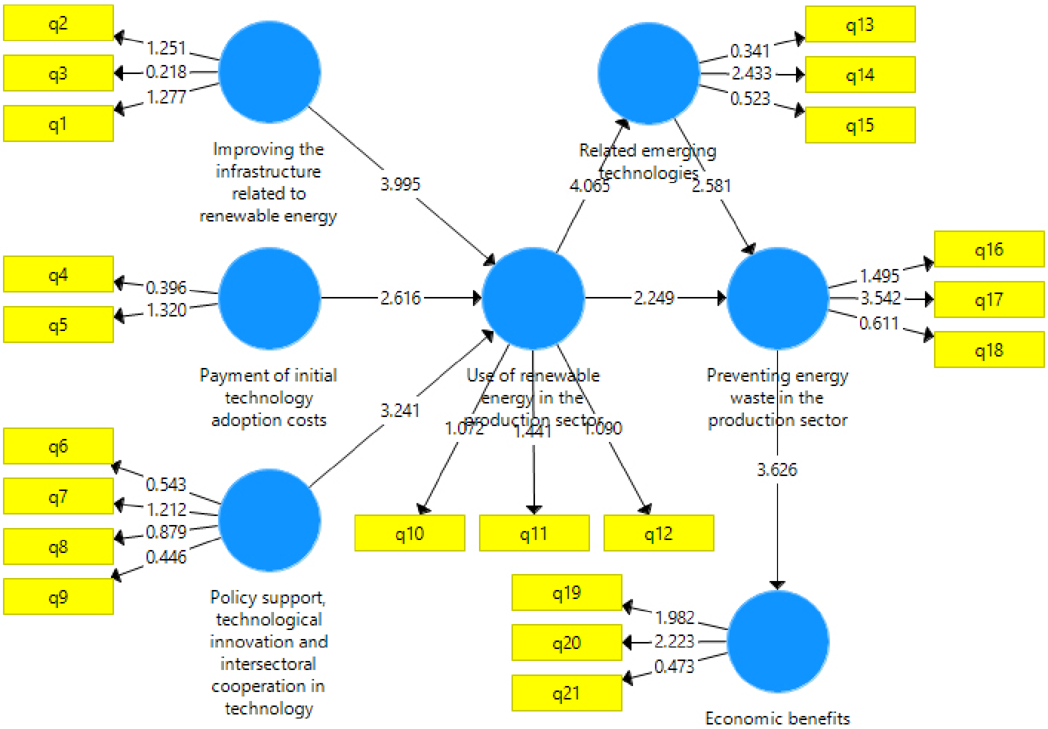

Figure 3. *The final model of the research in the mode of estimation of standardized coefficients*

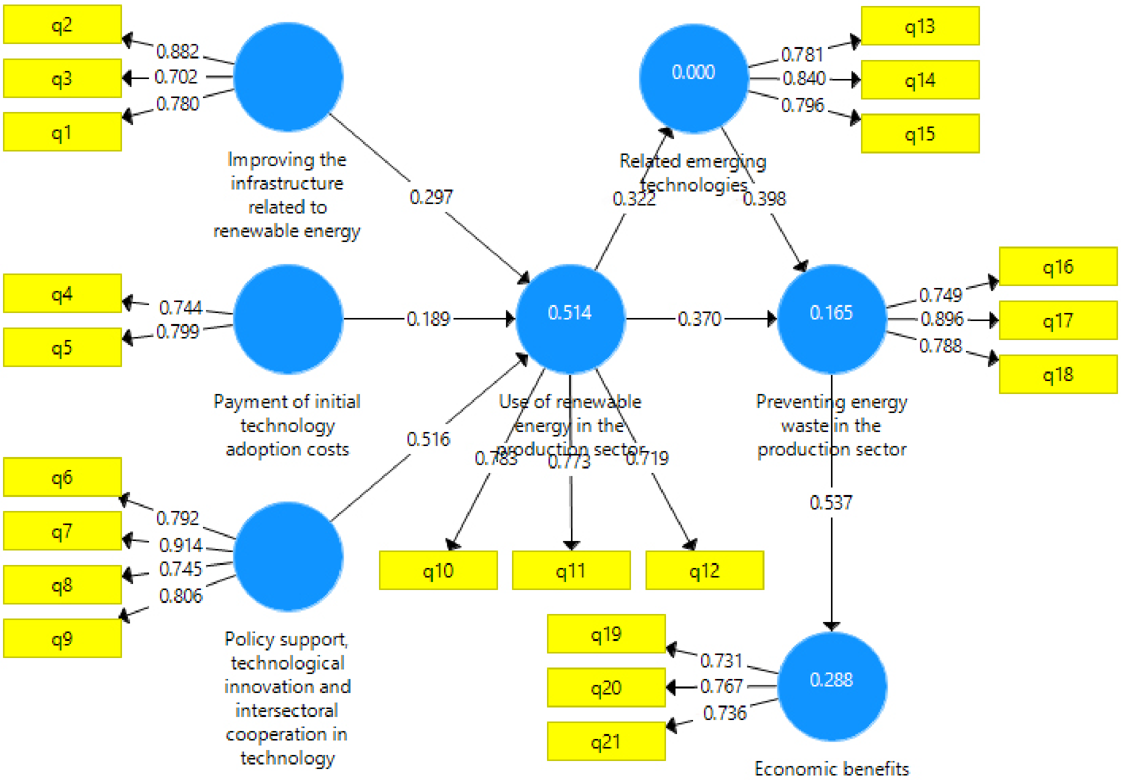

Figure 4. *The final research model in the case of significant coefficients*

Overall model fit

In this section, the fit of the overall model is examined based on the GOF criterion. According to the average shared values of the constructs (shared values of the first order constructs) and the average R2 of all the endogenous constructs of the model, the GOF value for the overall fit of the current research model is equal to:

$$GOF = \sqrt{\overline{AVE} \times \overline{R^2}} = \sqrt{0.807 \times 0.351} = 0.532$$

According to the three introduced criteria values of 0.01, 0.25 and 0.36 as weak, medium and strong values, obtaining a value of 0.532 for GOF shows the strong overall fit of the research model.

Hypothesis testing

According to the strong overall fit of the presented model, in Table No. 1. The results of the hypothesis test are presented. According to the structural model of the research in the case of significant coefficients, if it is observed that the t-statistics between two variables in each hypothesis is not in the range (1.96 & -1.96), then the hypothesis is accepted, otherwise the hypothesis is not accepted.

Table 1.
Results

Hypothesis	Description	T Statistics
OK	Improving the infrastructure related to renewable energy -> Use of renewable energy in the production sector	3.995
OK	Payment of initial technology adoption costs -> Use of renewable energy in the production sector	2.616
OK	Policy support, technological innovation and intersectoral cooperation in technology -> Use of renewable energy in the production sector	3.241
OK	Preventing energy waste in the production sector -> Economic benefits	3.626
OK	Use of renewable energy in the production sector -> Preventing energy waste in the production sector	2.249
OK	Use of renewable energy in the production sector -> Preventing energy waste in the production sector -> Preventing energy waste in the production sector	2.249

Discussion and Conclusion

The present study examines the energy waste in the production industry and the strategies for the development of renewable energy in the production sector. Based on the results of the analysis of research hypotheses, the modification of the infrastructure related to renewable energy, the payment of the initial costs of technology adoption, policy support, technological innovation and inter-sectoral cooperation in technology can be among the solutions for the development of renewable energy in the production sector. be It has also been shown in this research that the use of new technologies related to renewable energy in the production sector can play a mediating role in preventing energy wastage in the production sector and preventing energy wastage in the production sector can have economic benefits. have in front These results are in line with Yin et al.'s (2022) results, which state that to reduce energy waste, companies tend to use new digital technologies or update their technologies. Also, this finding shows that the reduction of energy waste is only related to the development of technology, which ultimately leads to the narrowing of experts' views on the reduction of production energy consumption.

As the global community grapples with the escalating challenges of climate change and environmental degradation, the manufacturing industry emerges as a pivotal arena for transformative action. This sector, traditionally energy-intensive and reliant on fossil fuels, is under increasing pressure to reduce its carbon footprint and embrace sustainability. The transition to renewable energy sources represents a critical pathway towards achieving these objectives, offering the dual benefits of mitigating environmental impact and ensuring long term economic resilience.

The rationale for this shift is multifaceted, rooted in both environmental necessity and strategic advantage. The manufacturing industry is a significant contributor to global greenhouse gas emissions, underscoring the urgent need for cleaner energy practices. Renewable energy technologies, such as solar, wind, and biomass, provide viable alternatives that can substantially lower emissions and reduce reliance on non-renewable resources.

Moreover, the volatility of fossil fuel prices and the potential for regulatory changes favoring sustainability further incentivize the adoption of renewable energy solutions (Taboada et al., 2012; Xin et al., 2022). Despite the clear benefits, the integration of renewable energy into manufacturing processes presents a complex array of challenges. These include the initial costs of technology adoption, the need for infrastructure modification, and the requirement for skilled personnel to manage and maintain new energy systems. Additionally, the intermittent nature of some renewable energy sources, such as solar and wind, necessitates innovative approaches to energy storage and demand management (Taboada et al., 2012).

Nevertheless, the opportunities afforded by renewable energy for the manufacturing sector are

substantial. Beyond the environmental benefits, renewable energy can confer economic advantages through operational cost savings, enhanced energy security, and improved

compliance with regulatory standards. Furthermore, companies that proactively embrace renewable energy can bolster their corporate reputation, aligning with consumer and stakeholder expectations for sustainable practices.

The body of research on renewable energy in manufacturing underscores the importance of policy support, technological innovation, and cross-sector collaboration in overcoming barriers to adoption. Incentives such as tax breaks, subsidies, and grants play a crucial role in enhancing the economic viability of renewable energy projects. Meanwhile, ongoing advancements in technology are progressively addressing the challenges of cost, efficiency, and integration, paving the way for broader implementation across the manufacturing industry (Xin et al., 2022; Kılçı, 2022).

The transition to renewable energy in the manufacturing sector is not merely a response to environmental imperatives but a strategic investment in the future. The path forward requires concerted efforts from industry stakeholders, policymakers, and the research community to navigate the complexities of this transition. By fostering an environment conducive to renewable energy adoption, the manufacturing sector can significantly contribute to global sustainability goals, ensuring a cleaner, more resilient future.

Management Suggestions

Conducting an energy audit is a critical first step in any comprehensive energy management strategy. It provides an overview of how energy is being used in a facility, pinpointing inefficiencies and identifying energy saving opportunities for businesses. It is therefore recommended that each manufacturing unit initially have a plan to audit its various departments. Each manufacturing unit should also initially identify the sources of energy consumption. All major energy consuming systems in the facility, such as HVAC, lighting, machinery and compressed air systems, should be mapped so that managers and professionals know where energy is being consumed. On the other hand, it is essential to identify energy wastage points in each manufacturing unit. For example, leaks in compressed air systems, inefficient lighting, or outdated equipment that consumes more energy than necessary can be the target points.

Energy-efficient manufacturing processes and energy systems should be continuously evaluated. Any operating practices that lead to unnecessary energy use should be identified.

Plant managers should use the collected data to establish an energy baseline, which serves as a reference point for measuring the impact of future energy efficiency measures and improvements.

Energy analysis in the audit leads to advanced diagnostics and insights that can identify more subtle opportunities for energy optimization and efficiency improvements. This ensures that plants are implementing the most effective energy efficiency measures, driven by data-driven insights and supported by BECIS' comprehensive range of energy solutions.

Ultimately, plant managers should look to renewable energy and related infrastructure improvements to achieve specific, cost-effective energy efficiency goals.

Suggestions for Future Research

More research could be done to study energy waste in real factories with case studies of renewable energy and leading solutions, which could lead to a more precise framework for categorizing different types of energy waste and linking them to solutions. Existing renewable energies help.

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