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The Impact of Digital Transformation on Environmental Performance in Manufacturing Companies: The Mediating Role of Green Manufacturing

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Abstract

This study investigates the mediating role of green manufacturing in the relationship between digital transformation and environmental performance in manufacturing firms. Data were collected through a survey and analyzed using structural equation modeling (SEM) to assess the direct effects of digital transformation and green manufacturing on environmental performance. The findings show that both digital transformation and green manufacturing have a significant positive impact on environmental performance. Moreover, digital transformation was found to significantly affect green manufacturing. In addition to SEM analysis, the Process Macro mediation test was used to assess the mediation effect of green manufacturing. The results reveal that green manufacturing plays an important mediating role and enhances the positive impact of digital transformation on environmental performance. This highlights the importance of integrating digital strategies with environmentally responsible production methods to improve sustainability outcomes. Overall, this study contributes to the growing body of research on sustainable manufacturing by demonstrating the important link between digital transformation, green manufacturing and environmental performance.

Keywords: *Digital Transformation, Green Manufacturing, Environmental Performance*

Jel Codes: *L60, O33, Q56*

İmalat Firmalarında Dijital Dönüşümün Çevresel Performansa Etkisi: Yeşil Üretimin Aracı Rolü

Öz

Bu çalışma, imalat firmalarında dijital dönüşüm ve çevresel performans arasındaki ilişkide yeşil üretimin aracılık rolünü araştırmaktadır. Veriler bir anket aracılığıyla toplanmış ve dijital dönüşüm ile yeşil üretimin çevresel performans üzerindeki doğrudan etkilerini değerlendirmek için yapısal eşitlik modeli (YEM) kullanılarak analiz edilmiştir. Bulgular, hem dijital dönüşümün hem de yeşil üretimin çevresel performans üzerinde önemli bir pozitif etkiye sahip olduğunu göstermektedir. Ayrıca, dijital dönüşümün yeşil üretimi önemli ölçüde etkilediği tespit edilmiştir. YEM analizine ek olarak, yeşil üretimin aracılık etkisini değerlendirmek için Süreç Makro aracılık testi kullanılmıştır. Sonuçlar, yeşil üretimin önemli bir aracılık rolü oynadığını ve dijital dönüşümün çevresel performans üzerindeki olumlu etkisini artırdığını ortaya koymaktadır. Bu durum, sürdürülebilirlik sonuçlarını geliştirmek için dijital stratejilerin çevreye duyarlı üretim yöntemleriyle entegre edilmesinin önemini vurgulamaktadır. Genel olarak bu çalışma, dijital dönüşüm, yeşil üretim ve çevresel performans arasındaki önemli bağlantıyı ortaya koyarak sürdürülebilir üretim konusunda giderek artan araştırmalara katkıda bulunmaktadır.

Anahtar Kelimeler: *Dijital Dönüşüm, Yeşil Üretim, Çevresel Performans*

Jel Kodu: *L60, O33, Q56*

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INTRODUCTION

One of the leading causes of environmental destruction is unsustainable production and consumption patterns, especially in industrialized countries. This leads to excessive and inefficient use of natural resources, significant waste generation and high levels of harmful emissions. To achieve sustainable development, fundamental changes in industrial processes are required. These changes include improving the type and quantity of raw materials used, waste management and recycling processes, strictly controlling emissions and developing environmentally friendly products and production models. Innovations by the industrial sector in these areas will reduce the environmental footprint and contribute to achieving a long-term economic and ecological balance (Krajnc & Glavič, 2003).

Future projections indicate that sustainability and environmental management will become increasingly critical in manufacturing. This trend can potentially drive the development of far-reaching strategies aimed not only at reducing environmental impacts but also at increasing economic efficiency and societal benefit. Sustainability principles will be decisive at every stage of manufacturing operations, from resource utilization and waste management to energy consumption and the product lifecycle. Therefore, it is becoming increasingly necessary to prioritize sustainable and environmentally friendly practices in developing future manufacturing technologies and operations. Integrating advanced technologies will minimize the negative environmental impacts of industrial processes while contributing to increased production efficiency and competitiveness. In this context, sustainability and environmental protection are not only an ethical and legal obligation but also fundamental elements at the core of long-term business strategies (Rosen & Kishawy, 2012).

In this context, the concept of green management or corporate environmentalism as a strategic approach started to be discussed in the 1990s and became a famous slogan in the international arena in the 2000s. According to Banerjee's (2001) definition, this concept refers to the process by which companies address environmental issues and develop ecological management strategies. The strategic importance of this concept is increasing, especially for multinational enterprises operating in global markets. By putting environmental sustainability at the center of their business strategies, these companies aim to improve their environmental and economic performance. This makes environmental management a compliance requirement and a critical element of competitive advantage. As a result, businesses are taking important steps toward a sustainable future by developing innovative and integrated management strategies to address environmental issues (Lee, 2009). One of these management strategies is green production.

Digital transformation is now necessary for any organization that wants to keep up with the ever-increasing demands and expectations of its global population. Companies in today's age of fast technological advancement rely heavily on digitalization to ensure their continued existence, expansion, and competitiveness. The procedures and methods that modify business as we know it are central to this process. Revenue generation, process improvement, and model reshaping are all aspects of digital transformation that necessitate digital technologies and digitized data (Kraus et al., 2022).

Recent advancements in digital technologies empower companies to develop and implement eco-innovative products and processes, effectively addressing the growing pressure for environmental protection. At this point, digital transformation has emerged as a critical pathway for manufacturers to improve sustainability and align their operations with environmental

objectives (Xu,Chen et al., 2023). According to Xue et al. (2022), digital transformation represents a process rather than merely a technical challenge, leaving a profound and enduring impact on businesses. Companies that integrate digital technologies with strategic foresight are better positioned to gain a competitive edge in the marketplace. Advanced data technologies, including artificial intelligence, cloud computing, and big data analytics, significantly influence innovative business practices by promoting green manufacturing, minimizing waste, and enhancing efficiency. These advancements compel enterprises to adopt green technologies and optimize resource utilization to mitigate environmental pollution. Nevertheless, businesses currently lack a comprehensive understanding of the interplay between digital transformation and green practices. As a result, the potential of digital transformation to support green technological advancements remains underutilized.

This study examines the impact of digital transformation on environmental performance in manufacturing firms and the mediating role of green manufacturing in this process. In this context, by revealing the synergy between environmental performance, digital transformation and green production, it aims to enable businesses to develop new strategies for achieving sustainable development goals, as well as to provide guiding empirical information for policymakers and business managers to produce academic knowledge that encourages both environmentally and economically sustainable business models, and contributes to the literature.

1. THEORETICAL FRAMEWORK

1.1. Digital Transformation

Digitalization and digital transformation are key concepts in the development of businesses and technology today. In order to fully grasp the concept of digital transformation, it is essential to first understand digitalization. Digitalization refers to the process of converting data into digital form, which initially began with the integration of software and automation systems into business processes. The advancement of the Internet and digital technologies has driven significant changes in business models and organizational structures, leading to the emergence of digital transformation. With the advent of Industry 4.0, this transformation has evolved beyond mere technological adaptation into a comprehensive restructuring that affects all aspects of business operations (Klein, 2020a; Vogelsang et al., 2018).

Digital transformation in businesses has a significant impact on various areas such as business models, organizational structure, corporate culture, work environment, and business ethics. According to sources, digital transformation encompasses products, services, customer experience, value chains, and business processes. New digital technologies enable businesses to not only digitize their products and business models but also their processes, thereby facilitating the adaptation to new business models. In this context, digital transformation in businesses is examined in three main areas: business models, business processes, and organization (Klein, 2020b). It is also stated by Demirkan et al. (2016) that digitalization is the key to transforming processes, activities, and models in today's dynamic business environment. Businesses which embrace digital transformation processes and create innovative techniques will define the future of the business world. While these wider dimensions of digital transformation are significant, this study narrows its focus specifically to the implications of digital transformation on production processes.

Digital transformation in manufacturing companies offers opportunities in areas that provide competitive advantages such

as customer-specific flexible product production, operational efficiency, organizational agility and process automation, thus enabling the reshaping of industrial activities. In this context, digital transformation is a strategic tool for increasing sectoral innovation and competitiveness rather than just a technological transition (Duraivelu, 2022). In innovative production models, the effects of digital transformation on manufacturing are encapsulated. Most notably, this shift will lead to shorter production cycle times, more personalized product designs, and lower overall costs. According to Wang et al. (2017), this process involves modifying both the physical and organizational structures to adjust to the evolving demands of customers and the dynamics of global marketplaces. This transition enhances both the production processes and the strategic flexibility of organizations.

As a result of digitalization, new possibilities are emerging in the workplace, and old ways of communicating and working together are becoming obsolete. This method can free up resources for other uses, such as creating new goods and services, by doing away with conventional supply chain intermediaries. The effects of this shift have been further expedited by direct consumer access and the widespread use of mobile devices (Nalbantoğlu, 2021). In the context of the idea of digital transformation, advanced digital technologies such as additive manufacturing, cloud computing systems, automation, big data, artificial intelligence, and digital twins all play an important part (Jones et al., 2021).

Despite all its advantages, there are many challenges and obstacles manufacturing companies are likely to face in the digital transformation process, such as resistance to change, loyalty to old business models, high investment requirements, lack of knowledge and skills, and cybersecurity concerns. For the successful integration of the transformation process, it is important to manage the process and identify the problems to be encountered (Albukhitan, 2020).

1.2. Green Production

Although green is defined as a color, in the context of this study, it is used as an adjective that emphasizes considering environmental concerns, being nature-friendly, and being sustainable. The term "green production" has been defined in various ways in the literature (Pang & Zhang, 2019; Orji & Wei, 2016; Shrivastava & Shrivastava, 2017). However, in general, it refers to a production process that reduces adverse environmental effects, conserves natural resources, ensures public safety, and is economically efficient.

The concept of green production covers the transformation needed to reduce the increasing environmental problems in a period when industrialization is inevitable. Global warming, one of the biggest environmental problems created by increasing industrial production, threatens the whole world. This problem has become so great that even if all factories, power plants, and transport vehicles are not operated, the atmospheric temperature is expected to increase by 0.6°C this century. For this reason, the use of green energy, green product development, and the use of green methods in business processes are now a necessity rather than a need (Bayraktar et al., 2021).

More and more businesses are making environmentally conscious manufacturing choices on their own accord, driven initially by compelling causes like government requirements and later by the desire to acquire a competitive edge (Yıldız & Çavdar, 2020). Germany really saw the rise of green production in the '80s and '90s (Rehman & Shrivastava, 2012). In an effort to create goods that meet the environmental standards set by the European Union, Germany set a worldwide standard for manufacturing output during this time (Bylinsky, 1995; as cited in Rehman & Shrivastava, 2012). By 1996,

ISO 14001 Environmental Management System Standards were established. Today, more than 500,000 companies in more than 180 countries meet these standards and apply them in their business processes (ISO, 2024). In this context, we can summarize the main motivations that lead businesses to green production under three main headings (Dornfeld et al., 2013);

- Restrictions, requirements and controls imposed by regulatory bodies,
- Government incentives, tax advantages,
- Potential to create competitive advantage.

Green production has a wide range of applications in all manufacturing sectors, including both SMEs and large-scale enterprises (Seth et al., 2018). However, the chemical, automotive, food, and pharmaceutical industries stand out as sectors with high performance in green production practices compared to other sectors, and it is observed that green production provides better performance as firm size increases (Sangwan & Choudhary, 2018).

From this point of view, it can be considered that the common feature of these sectors where green production is applied with high efficiency is the use of technology and high adaptation capabilities. When we look at green production from the sustainability perspective, it can be stated that the two terms are used interchangeably but do not mean the same thing. As a matter of fact, while green production is related to a product, practice or process, sustainability often refers to a broader framework that includes production (Seth et al., 2018).

1.3. Environmental Performance

The traditional management approach evaluates the performance of an organization according to four main areas: cost, quality, time and service, but as mentioned earlier, due to increasing environmental concerns, ensuring sustainability has entered the equation as another important performance measure because it affects both ecological consequences and competitiveness (de Burgos Jiménez & Céspedes Lorente, 2001).

With the acceleration of studies in the field of sustainable development, interested parties have started to adopt the concept of environmental performance to measure and manage environmental impact. Environmental performance measurement allows not only businesses but also individuals and even states to better understand the environmental impact of their activities and make improvements (Neagu et al., 2017). In addition to environmental sustainability, the term is also linked to economic and social sustainability, as the long-term success of businesses depends on a balanced consideration of these three areas.

It is necessary to make a multi-factor evaluation when measuring the environmental performance of enterprises. Some main methods are defined in the environmental performance measurement of organizations in ISO 14031:2021 Environmental Management - Environmental Performance Assessment Guideline, which brings an international approach to this issue. These methods are as follows (ISO, 2024):

- Environmental Performance Indicators (EPI): Measurable indicators used to monitor and measure the environmental performance of organizations. These indicators are used to determine environmental impacts such as energy use, waste generation and water consumption.

- Benchmarking: It helps the organization identify improvement opportunities by comparing its environmental performance with other organizations in similar industries.
- Life Cycle Assessment (LCA): An approach that considers the whole environmental effect of a service or product across its lifetime. Throughout a product's life cycle, LCA considers every step, from the initial gathering of raw materials through its eventual disposal or recycling.
- Risk Assessment and Risk Management: Organizations use this method to identify and manage environmental risks. This helps to improve environmental performance by identifying the potential impacts of environmental hazards and developing protective measures against them.
- Environmental Cost Analysis (EMA): It helps organizations evaluate the costs of investments they will make to reduce environmental impacts and to determine the long-term benefits of these costs.

While these indicators help an organization assess, monitor and improve its environmental performance effectively, ISO 14031 allows organizations to select and implement indicators to suit their specific circumstances and needs. The environmental performance indicators used in this research are discussed in chapter four.

In addition to these methods, carbon footprint measurement, which has become increasingly important today, especially within the framework of legal regulations of states, has started to be used frequently in environmental performance measurement. An individual's, household's, or business's yearly contribution to global warming is defined by the US Environmental Protection Agency (2024) as the sum of all greenhouse gas emissions. An individual's impact on the environment is measured by the amount of greenhouse gases released into the atmosphere due to their daily use of goods and services. The same measurement within enterprises is carried out with the level of greenhouse gas emissions resulting from the goods and services produced.

2. A REVIEW OF THE LITERATURE AND THE DEVELOPMENT OF RESEARCH HYPOTHESES

Digital transformation is emerging as a powerful element of green manufacturing, promoting sustainable practices through technological innovation and increased efficiency. Indeed, digital transformation's contributions to green production, as stated by Jia et al. (2023), offer technological and innovative solutions that benefit the environment and the economy.

An effect coefficient of 0.477 indicates that the digital economy has a substantial beneficial impact on the green, low-carbon transformation of the manufacturing industry, according to the findings of a study conducted by Zhang et al. (2022). Again, technological Innovations greatly aid the manufacturing sector's green transition, according to Zhao et al. (2021). On the other hand, Costa et al. (2017) argue that cleaner production contributes to environmental efforts, but the benefits to be gained will not be easy, especially in the context of industries dominated by old technologies.

In the study conducted by Wang and Shi (2024) on the data of 280 firms in China between 2007 and 2021, the effects of digital transformation on green total factor productivity (GTFP) were analyzed based on two main components of GTFP: the green economic efficiency index and the green technology progress index. According to the findings, it is evaluated that digital transformation increases resource efficiency while decreasing production efficiency and environmental pollution and that a digital transformation implemented at normal levels contributes to long-term strategies. In contrast, an excessive

level of digital transformation may negatively affect sustainability goals by providing short-term benefits. For this reason, it is recommended that businesses should not go to extremes in digital transformation for long-term environmental sustainability and implement an average level of digital transformation.

In another recent study (Liao et al., 2024), the impact of digital transformation on green supply chain efficiency is analyzed using data from Chinese manufacturing firms traded in public financial markets between 2011 and 2020. The results show that digital transformation encourages green technology innovation, reduces transaction costs and alleviates financing difficulties. It is also emphasized that the impact of digital transformation on green supply chains increases significantly, especially in state-owned companies and enterprises with low per capita production values, i.e. enterprises with productivity problems. In addition, it is pointed out that states should ensure the highest possible benefit from digital economic growth. For this purpose, it is underlined that it is necessary to move quickly in the implementation of strategic plans for digital development and to create an environment that facilitates the transition of enterprises to digitalization. It was emphasized that businesses need to understand that digital transformation is a catalyst that strengthens green supply chain management.

As can be seen, it is frequently emphasized in the literature that digital transformation has a significant and positive effect on green production philosophy. In this context, the following hypothesis was established;

- H1: Digital transformation significantly affects green production

Recently, researchers looked at the correlation between digital transformation and green production to see how it affects company performance. They discovered that companies that use digital transformation technologies are more likely to improve their performance because they boost sustainability by promoting innovation in producing eco-friendly products (Khakwani et al., 2024).

Industrial digital transformation has led to a marked improvement in the environmental performance of manufacturing enterprises, according to research by Wen et al. (2021). The study also found that digitalization boosts product innovation and green total factor productivity but has no discernible impact on total factor productivity.

Li, Dai et al. (2020) researched how the new era of Industry 4.0 interacts with digital technologies in terms of their impact on economic and environmental performance. It was discovered that digital supply chain platforms mediate digital technologies' effects on economic and environmental performance and that this mediation effect rises under high environmental dynamism. This was determined based on the findings of the study.

In a recent study prepared by Song et al. (2024), it was concluded that digital transformation significantly improved the environmental performance of enterprises using data obtained from publicly traded companies in China. It is emphasized that this improvement is achieved by integrating new green technology applications into processes, increasing media focus on the issue and strengthening internal control. The study also states that digital transformation reduces waste and emissions by optimizing resource allocation, encourages the adoption of environmentally friendly technologies using innovative tools, and makes companies' environmental management more efficient by increasing external control through the media and improving internal processes. As a result, the study confirmed the positive impact of digital transformation on the environmental performance of enterprises and observed that this impact varies according to manufacturing sectors and

regions of operation. In particular, it has been observed that technology-intensive sectors with high levels of environmental constraints benefit more from this transformation. At the same time, this effect is less observed in internet-based business models.

Gu et al. (2023) examined the effects of digital transformation in the industrial sector and regional cooperation innovation on urban green development efficiency. While regional cooperation innovation is the process of different actors (companies, universities, and public institutions) coming together to develop innovative solutions, urban green development efficiency refers to the efforts to balance economic growth and environmental protection. In the research, the hypotheses that digitalization in the industrial sector will increase urban green development efficiency, that regional cooperation innovation will have a direct positive effect on this efficiency and that the impact of digitalization will be strengthened with a moderating role are tested. The results support all these hypotheses. In other words, while digital transformation is encouraged, developing appropriate cooperation platforms is also emphasized.

From the vantage point of enterprise boards' demographics (including gender, age, nationality, ownership structure, education, and political affiliation), Chen and Hao (2022) investigated the connection between digital transformation and environmental performance. According to the study, which looked at publicly listed companies in China from 2010 to 2019, digital transformation significantly improves corporate environmental performance. However, boards with diverse ages and nationalities, ownership structures, and political affiliations are not very open to digital transformation. On the other hand, boards with more female directors and higher education levels are more likely to adopt digital transformation strategies.

By combining qualitative and quantitative methods, Chiarini (2021) interviewed 19 company managers and surveyed 260 managers online to learn how Industry 4.0 technologies are helping Italian manufacturing firms improve their environmental performance. Sensors, radio-frequency identification, and artificial intelligence are just a few examples of the technologies that were found to enhance significantly environmental performance in the research. The environmental performance of specific technologies, nevertheless, was determined to be negatively impacted. These technologies include additive manufacturing and robots.

Xu, Yu et al. (2023) examined the effects of corporate digital transformation on environmental performance, especially on publicly listed companies in China. The research found that digital transformation significantly improves environmental performance while decreasing pollutants. Particularly in state-owned enterprises, large-scale businesses, and polluting companies, the beneficial effects of digital transformation on the environment were more noticeable. Furthermore, it is highlighted that digital transformation and environmental performance have a complicated relationship, which is more parabolic than linear. In other words, digital transformation may have positive results up to a certain point, but adverse effects may ensue once this point is crossed. Businesses should reevaluate their organizational structures, prioritize environmental controls, speed up their digital transformation, and improve resource management using big data and information exchange. It is emphasized that East China should promote digital transformation initiatives, particularly by offering assistance and recommendations to polluting Chinese state-owned enterprises. According to the report, additional research is needed to comprehend the connection between digital transformation and environmental performance fully.

Examining the literature reveals that digital transformation strategies substantially impact businesses' environmental

performance overall; albeit, this impact may differ based on the industry, region, and even the composition of the board of directors. To comprehend the impact of these factors on the study sample and what kinds of changes, if any, they produce, the following hypothesis was developed in this context:

- H2: Digital transformation significantly affects environmental performance

Green manufacturing practices significantly improve environmental performance while providing economic and operational benefits (Ahmad et al., 2022). Moreover, green innovation and intellectual capital are critical in supporting sustainability and improving overall performance. Industries that adopt green manufacturing have been observed to significantly improve their environmental footprint and operational efficiency (Rehman et al., 2016). Costa et al. (2017) determined that cleaner production can be an effective environmental management tool for SMEs. It has been emphasized in the literature that green transformation in industry is vital in terms of promoting growth with lower carbon emissions, creating a healthy environment and supporting sustainable development (Mehmood et al., 2024).

On the other hand, according to the findings of a study (Baah et al., 2020), which examines the motivation of SMEs in developing countries while adapting green production practices to their processes and its effects on business performance, it is shown that the pressures created by regulatory institutions and organizations increase the green production practices of enterprises and positively affect firm reputation, financial and environmental performance. However, it is emphasized that the organizational pressures created by other stakeholders of enterprises on green production negatively affect the economic performance of firms.

Manufacturing is the most energy-intensive industry in many countries, and Shi et al. (2021) note that this helps the economy grow. However, they also note that manufacturing produces many greenhouse gases, so they think that manufacturing's current production model needs to be replaced with green production. One school of thought holds that low-carbon production technologies are the way for environmentally friendly manufacturing. Specifically, this study aimed to quantify the state of low-carbon production technology and examine its evolution across OECD nations using data collected from 1990 to 2014. While the chemical industry outperforms other sectors, the data show that innovation in low-carbon production technologies significantly affects environmental performance.

Analysis of research conducted in our country reveals that sustainable production methodologies positively influence sustainability performance within the manufacturing sector (Gürül, 2019), and it is also concluded that environmentally conscious production strategies implemented in this sector enhance environmental performance to elevated levels (Tatlı & Özer, 2022). A study investigating the impact of cleaner production on corporate performance indicated that implementing cleaner production methodologies in the production process enhances firm performance (Yazgan et al., 2017). Yıldız and Çavdar (2020) discovered that sustainable production substantially influences environmental and economic performance.

According to the reviewed literature, green production has a noticeable effect on numerous performance indicators manufacturing companies use. We set out to test the following hypothesis about how these factors influence the long-term sustainability of our nation's manufacturing companies' impact on the environment:

- H3: Green production significantly affects environmental performance

According to Frare and Beuren's (2021) analysis of 81 Brazilian agricultural technology businesses, green process innovations boost environmental performance by mediating the connection between green entrepreneurship and proactive sustainability. Based on our findings, green production—the focus of our study—may be a good illustration of the green process advances we've been looking at, which, in turn, might help businesses do better for the environment. Another study on the same topic (Xu, Chen et al., 2022) finds that green technology innovation mediates the relationships between corporate social responsibility, financial and environmental performance of Chinese manufacturing firms, and green technology.

Using panel data from Chinese manufacturing businesses from 2011 to 2019, Chen et al. (2023) examined how digital transformation affected environmentally friendly products, technologies, and investments. The findings demonstrated that digital transformation improves manufacturing companies' green development, achieved through technology advancements, investments, and green products. However, they also showed that environmental uncertainties can differentiate this benefit. Accelerating digitalization would aid the country's shared development process, and the effect of digital transformation on environmentally friendly production differs by area and industry.

A different study that looked at the connection between digital transformation and environmental performance (Li & Lin, 2023) found that digital transformation increases green capabilities, boosting environmental performance. This effect is even more substantial when green culture is high. Green culture also acts as a moderator between digital change and environmentally friendly skills. The ability to create and execute plans to lessen an organization's influence on the environment is now part of what is known as "green capabilities," which aim to guarantee environmental sustainability. A company's "green culture" reflects its commitment to sustainability and its members' shared values and ideas about the importance of protecting the environment.

In another empirical study conducted by Yousaf (2021), it was concluded that green practices, which include environmentally friendly business processes and operational activities, improve the green innovation mechanism, which refers to the ability of SMEs to develop new products, services and processes to achieve environmental sustainability goals.

Setyadi et al. (2023) conducted a quantitative analysis of 110 manufacturing firms adopting environmentally friendly practices in Indonesia. They evaluated that green logistics and human resource management positively affect sustainable development through sustainable production.

While it is frequently emphasized that digital transformation improves the environmental performance of manufacturing enterprises, the following hypothesis was established to test the assumption that green production practices can mediate this relationship.

- H4: Green production has a mediating role in the effect of digital transformation on environmental performance.

3. METHODS

This section provides an overview of the research model, the scales used in the questionnaire, the population and sample that made up the research, the demographic findings from the data analysis, and an explanation of the research model's validity and reliability findings, as well as the analysis results.

The theoretical model designed for the research is given in Figure 1.

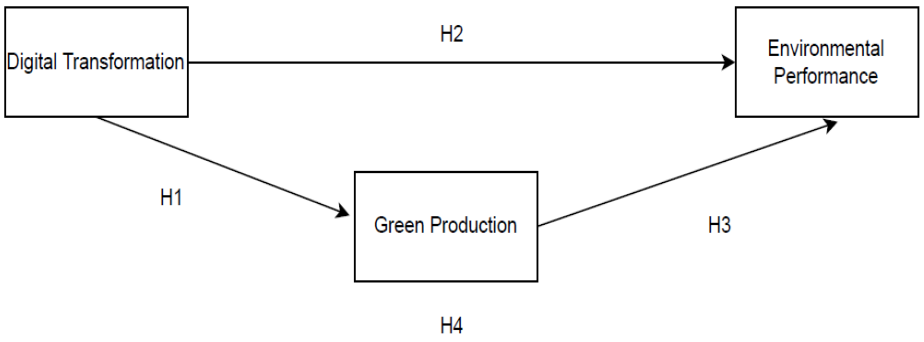

Figure 1. Research Model

The digital transformation scale used in the research is adapted from Nayal et al. (2022), and the green production scale and the green production behavior scale are adapted from Li, Dai et al. (2020). The environmental performance scale is adapted from Belhadi et al. (2022) and Zhu et al. (2008). Scale items are presented in Appendix 1. Permission was obtained from the authors by e-mail to use the questionnaire form in the research. In addition, permission was obtained for the study with the decision of the Kastamonu University Social and Human Sciences Scientific Research and Publication Ethics Board dated 04.10.2023 and numbered 11/15.

The research population consists of manufacturing companies registered with the Istanbul Chamber of Industry. The research sample consists of companies chosen from this pool of manufacturers using the convenience sampling method. Within the scope of the study, valid returns were obtained from 246 companies. Therefore, 246 manufacturing companies constitute the sample of the study. Research data were collected online and face-to-face over a period of 9 months between December 2023 and August 2024.

4. RESEARCH FINDINGS

The findings, including some demographic information of the manufacturing firms and managers included in the research, are presented in Table 1.

Table 1. Demographic Findings

Sector Information	**f**	**n**
Food (Food, beverages, additives)	55	22,4
Textile (Clothing, home textile products, apparel)	49	19,9
Pharmaceuticals / Chemistry / Paint	33	13,4
Machinery / White Goods / Durable Home Appliances	32	13,0
Electric - Electronics / Computer	28	11,4
Aluminum / Iron - Steel / Cable / Packaging	23	9,3
Automotive / Automotive Supply Industry	26	10,6
Activity Year	**f**	**n**
0-5	2	,8
6-15	69	28,0
16-30	74	30,1
31 and over	101	41,1

Number of Employees	**f**	**n**
0-50	49	19,9
51-150	62	25,2
151-250	50	20,3
251 and above	85	34,6
Responsible Department	**f**	**n**
Production	50	20,3
Purchasing	21	8,5
Sell - Marketing	33	13,4
Management	142	57,7

Of the manufacturing firms included in the survey, 55 are active in food, 49 in textiles, 33 in chemicals, pharmaceuticals and paint, 32 in machinery, white goods and durable household appliances, 28 in electricity, electronics and computers, 26 in automotive, 23 in aluminum, iron-steel, cable and packaging sectors.

Prior to the research hypotheses being confirmed, the study's scales were first assessed for composite reliability, construct validity, convergent validity, and reliability. Because the foreign language measures were translated into Turkish, exploratory factor analyses were carried out largely to assess the construct validity. Furthermore, an analysis was conducted on the skewness and kurtosis values of the descriptive statistics results to ascertain whether the scales satisfied the normal distribution criteria. Table 2 displays the descriptive statistics and exploratory factor analysis results.

Table 2. Exploratory Factor Analysis and Descriptive Statistics Findings

Digital Transformation	**Factor Load**	**Skewness**	**Kurtosis**	**Mean**	**Std. Deviation**
DT1	,757	-,391	-,303	3,35	,972
DT2	,821	-,316	-,304	3,24	,936
DT3	,877	-,538	-,268	3,40	,980
DT4	,873	-,266	-,679	3,40	,996
DT5	,886	-,134	-,495	3,19	1,018
DT6	,896	,103	-,545	3,15	,982
DT7	,920	-,268	-,398	3,33	,956
KMO: ,923 χ Square: 1510,506 df:21 sig.:,000 Top. Variance Explained: % 74,459					
Green Production	**Factor Load**	**Skewness**	**Kurtosis**	**Mean**	**Std. Deviation**
GP1	,619	-1,264	1,197	3,88	,842
GP2	,734	-,193	-,818	3,38	1,026
GP3	,593	-,715	,279	3,68	,929
GP4	,691	-,709	,364	3,78	,890
GP5	,624	-1,115	1,723	3,83	,898
GP6	,769	,090	-,992	3,12	1,100
GP7	,725	-,665	,211	3,68	,933
GP8	,821	-,660	,155	3,63	,928
GP9	,862	-,318	-,448	3,38	,998
KMO: ,874 χ Square: 1037,136 df:36 sig.:,000 Top. Variance Explained: % 51,952					
Environmental Performance	**Factor Load**	**Skewness**	**Kurtosis**	**Mean**	**Std. Deviation**
EP1	,746	-,336	-,465	3,29	,839
EP2	,789	-,643	,039	3,42	,921
EP3	,827	-,349	-,344	3,23	1,053
EP4	,826	-,556	,341	3,58	,899
EP5	,538	-,446	-,235	3,39	,957
KMO: ,830 χ Square: 382,522 df:101 sig.:,000 Top. Variance Explained: % 56,670					

As a result of the analysis, factor loading values for all scale items were above 0.50. Kaiser-Meyer Olkin Sampling Adequacy Test (KMO) value was determined as 0.923 for digital transformation, 0.874 for green production and 0.830 for environmental performance. Barlette's Sphericity test was found to be significant since the significance level obtained for chi-square values was less than 0.05. The fact that the KMO values are greater than 0.70 and Barlette's test is significant indicates that the sample size is sufficient and appropriate for factor analysis (Lloret et al., 2017). In addition, it was determined that the digital transformation scale explained 74.459% of the total variance, the green production scale explained 51.952%, and the environmental performance scale explained 56.670%. The scale items' skewness and kurtosis values were between -2 and +2. As a result, the data match the analysis's requirement for a normal distribution.

For the scales identified using confirmatory factor analysis, Table 3 shows the outcomes of the goodness-of-fit tests.

Table 3. Scales Goodness of Fit Values

Scale	**χ^2/df**	**GFI**	**CFI**	**TLI**	**SRMR**	**RMSEA**
Acceptable Criterion	≤5	≥.85	≥.90	≥.90	≤.08	≤.08
Digital Transformation	1,499	0,979	0,994	0,986	0,016	0,064
Green Production	2,231	0,951	0,969	0,953	0,041	0,074
Environmental Performance	0,582	0,995	1	1	0,015	0

Confirmatory factor analysis revealed that the goodness of fit criteria such as χ2/df, GFI, CFI, TLI, SRMR, and RMSEA met acceptable values (Boateng et al., 2018). Since the sample size was smaller than 250, the SRMR value was calculated. Since the SRMR value is also less than 0.08, the criterion is met.

Reliability analysis was performed after confirmatory factor analysis. In addition, mean-variance explained (AVE) and composite reliability (CR) values were calculated to test convergent validity. The findings of the validity and reliability analyzes are presented in Table 4.

Table 4. Validity and Reliability

Scale	**AVE**	**CR**	**Cronbach' Alpha**
Digital Transformation	0,69	0,94	0,942
Green Production	0,45	0,88	0,882
Environmental Performance	0,47	0,81	0,800

All scales had Cronbach's Alpha coefficients of 0.80 or higher after the reliability investigation. The reliability of the scales is demonstrated by this finding. Hair et al. (2019) state that AVE values should be above 0.50 and CR values should be above 0.70. Convergent validity is also given if the AVE value is less than 0.50 but around 0.50, provided the CR value criterion is satisfied (Aydın et al., 2021; Karaman, 2023). These results demonstrate that the scales meet the requirements for convergent validity, composite reliability, and reliability.

Following these steps, the structural equation model was developed and evaluated. Figure 2 displays the model that was derived from the study in the AMOS program.

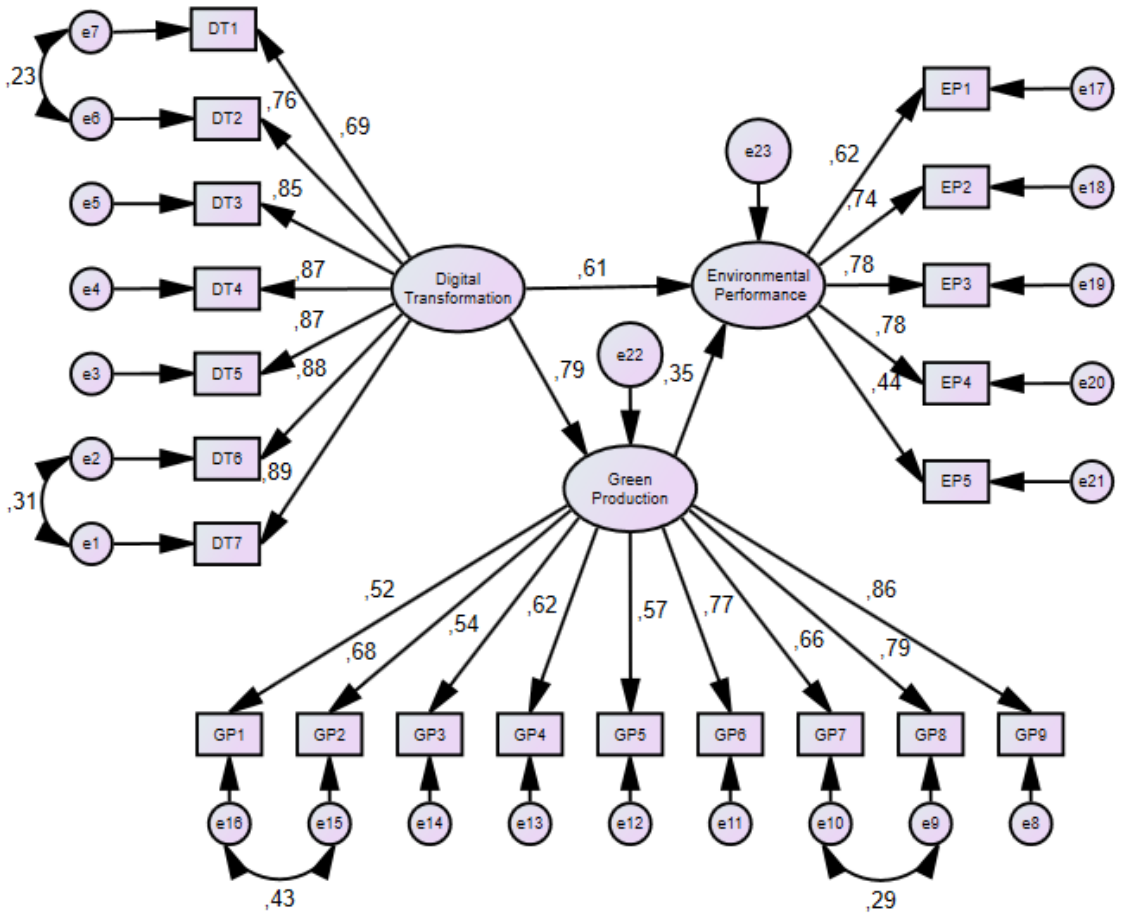

Figure 2. Structural Equation Model

Table 5 displays the goodness of fit indices, which came from the structural equation model analysis and include χ2/df, GFI, CFI, TLI, SRMR, and RMSEA.

Table 5. Model Goodness of Fit Values

	χ^2/df	GFI	CFI	TLI	SRMR	RMSEA
Acceptable Criterion	≤5	≥.85	≥.90	≥.90	≤.08	≤.08
Model	2,328	0,861	0,932	0,916	0,053	0,078

As a result of the model analysis, it was found that the goodness of fit criteria such as χ2/df, GFI, CFI, TLI, SRMR, and RMSEA met acceptable values. To see whether hypotheses H1, H2 and H3 were confirmed or not, the regression weight values determined as a result of the analysis were examined. The findings are given in Table 6.

Table 6. Model Regression Weights

			B	β	Std. Error	C.R.	p
Green Production	<---	Digital Transformation	0,791	0,791	0,059	13,359	***
Environmental Performance	<---	Digital Transformation	0,374	0,614	0,059	6,381	***
Environmental Performance	<---	Green Production	0,211	0,346	0,052	4,016	***

***:p<0,01

The structural equation model study showed that digital transformation significantly improves green manufacturing and environmental performance ($p<0.01$). The impact of digital transformation on environmentally conscious manufacturing was determined to have an unstandardized coefficient estimation value of 0.791. At the same time, its effect on environmental performance was found to have a value of 0.614. Green production and environmental performance are both significantly impacted by digital transformation, according to these findings. Additionally, a significant impact on environmental performance was observed from green production ($p<0.01$). A value of 0.346 was determined for the unstandardized coefficient estimate of the effect of green production on environmental performance. The results of the investigation provide support for hypotheses H1, H2, and H3.

Following the examination of the structural equation model, Process Macro analysis was performed in SPSS to evaluate the mediation hypothesis. The pertinent approach was formulated by Hayes (2018). The analysis findings are presented in Table 7. In Table 7, X represents the independent variable, Y is the dependent variable, and M is the mediating variable. The values presented for CI are the lower and upper bounds of the confidence interval, respectively. Both a significance level below 0.01 ($p<0.01$) and the absence of a zero value within the defined confidence range were considered for significance.

Table 7. Mediation Test Results

Outcome Variables						
		M (Green Production)			Y (Environmental Performance)	
Forecast Variables		**β**	**S.E.**		**β**	**S.E.**
X (Digital Transformation)	a	.6048***	.0346	c’	.4457**	.0461
M (Green Production)	-	-	-	b	.3402***	.0568
Constant		1.6040***	.1176		.6890***	.1387
		R^2=.5559			R^2=.6663	
F(1;244)=305.450; p<.001				F(2;243)=242.619; P<.001		
Total Impacts (path c): (β:.6515, %95 CI [.5868, .7162], t: 19.8320, p<.001)						
Indirect Impacts: (β:.2058, %95 BCA CI [.1191, .3020])						

First, the impact of digital transformation (route a), the independent variable, on green production (the mediating variable), was examined based on the Process Macro mediation test results. The study yielded a significant effect (β:.0.6048 95% CI [.5367,.6730], t: 17.4771, p<.001) and an R^2 value of 0.5559. Digital transformation accounts for 55.59 % of green output, according to this estimate. The impact of the mediating variable green production, denoted as path b, on the dependent variable environmental performance was examined. The analysis revealed that this effect was significant (β: 0.3402, 95% CI [.2282, .4522], t: 5.9845, p < .001). The analysis of the impact of the independent variable digital transformation on the dependent variable environmental performance revealed a significant effect (β: .4457, 95% CI [.3549, .5365], t: 9.6653, p

< .001). The R^2 value was determined to be 0.6663. This research indicates that digital transformation and green manufacturing account for 66.63% of environmental performance. To assess the significance of the overall effects, the impact of the independent variable digital transformation, represented as path c without the mediating variable green manufacturing, on the dependent variable environmental performance was analyzed. The effect was determined to be significant (β: .6515, 95% CI [.5868, .7162], t: 19.8320, p < .001). Subsequently, to ascertain the relevance of the indirect effects, the results of the indirect effects were analyzed with the inclusion of the mediator variable, green production, in the model. Significant indirect effects were seen (β: .2058, 95% BCA CI [.1191, .3020]). The effect size (K2) value was analyzed to assess the strength of the mediation effect. The value was determined to be 0.281. Given that this value approximates 0.25, it is inferred that a significant effect exists. Therefore, green production has a high mediation effect (Gürbüz, 2019). As a result of the mediation test, hypothesis H4 was supported.

CONCLUSION

This study investigates the mediating role of green production in the relationship between digital transformation and environmental performance in manufacturing firms. The research sample consists of 246 firms selected by convenience sampling among the manufacturing firms registered with the Istanbul Chamber of Industry. The research data were collected online and face-to-face through a questionnaire between December 2023 and August 2024 and analyzed using SEM to evaluate the direct effects of digital transformation and green manufacturing on environmental performance.

The results of the structural equation model analysis show that digital transformation has a significant positive effect on green production and environmental performance and has a significant effect on both. In addition, it was concluded that green production significantly influences environmental performance. The research findings show that digital transformation has a significant positive effect on green production. These findings confirm the studies in the literature by Jia et al. (2023), Zhang et al. (2022), Zhao et al. (2021), Costa et al. (2017), Wang and Shi (2024), Liao et al. (2024). Therefore, it has been proved that digital transformation in manufacturing enterprises significantly affects the essential elements that can realize practices that the embody green production philosophy, such as the green supply chain, green total factor productivity, resource efficiency, production efficiency, and green technology innovation. The structural equation model analysis observed that digital transformation significantly affects environmental performance, such as in green production. This result confirms the thesis of Khakwani et al. (2024) that firms using digital transformation technologies increase their sustainability through environmentally friendly product production and are prone to improve firm performance. This positive relationship has been frequently emphasized especially in Chinese academic studies (Song et al., 2024; Gu et al., 2023; Chen & Hao, 2022; Xu, Yu et al., 2023). Another study hypothesis, the significant effect of green production on environmental performance, was confirmed by the findings obtained. As can be seen from the literature, green production is not a type of production alone. Still, it is actually conceived as a philosophy created within the enterprise by combining different practices. Therefore, as stated by Rehman et al. (2016), concepts such as green innovation, intellectual capital, sustainability, and low-carbon production technologies emphasized by Shi et al. (2021) are considered green production practices. As a result of the mediation test conducted with the process macro method, the mediating role of green production in the effect of digital transformation on environmental performance was determined. This finding shows that some of the effects of digital transformation on environmental performance are through green production. While

examining this effect, many different factors, such as environmental dynamism (Li, Du et al., 2020), media impact, location (Song et al., 2024), regional cooperation mechanisms (Gu et al., 2023) and even the characteristics of the boards of directors of enterprises (Chen & Hao, 2022) have been examined. In parallel with the findings obtained in this study, the literature seems to prove the effect of digital transformation on the environmental performance of enterprises, mainly in a positive direction, but by looking at other examples, internal and external factors that have the potential to affect this relationship should also be considered in the digital transformation process. As stated in the study conducted by Wang and Shi (2024), the level of digitalization and what kind of contribution it will make to sustainability in the medium-long term is a factor that businesses should pay attention to and should also be investigated. In other words, the impact of digital transformation on environmental performance varies according to time and the severity of change. For this reason, businesses need to conduct their own internal and external analyses, considering sectoral practices, and adapt their digital transformation according to these variables.

As stated by Sangwan and Choudhary (2018), the impact of digital transformation on environmental performance varies according to sectors and the size of firms. Therefore, sector-specific digital transformation strategies should be developed. It is considered that digital technologies, especially in sectors where energy use is intensive, will significantly contribute to reducing the carbon footprint and increasing environmental performance. In parallel with the results obtained by Xu, Yu et al. (2023), the use of advanced digital technologies such as big data, artificial intelligence, cloud computing and digital twins should be expanded to improve environmental performance by increasing the efficiency of production processes. The effective use of these technologies in firms will contribute to the efficient use of resources and the reduction of operational costs by optimizing production processes. However, it should not be forgotten that the returns of the digital transformation process to the business are parabolic rather than linear; that is, acting with the logic of "we will digitalize all processes" may fail. As emphasized by Baah et al. (2020), the role of regulatory institutions in increasing green production practices, in addition to intrinsic motivations, is an undeniable factor. However, it is thought that the internalization of the motivation source of companies in green production practices by supporting it with green production culture will be more beneficial in the medium-long term. For this reason, having a high level of awareness in both the media and internal stakeholders about the contribution to the business, other than environmental performance, is very effective. In addition, as mentioned by Chen and Hao (2022), it should be taken into consideration that the characteristics of internal stakeholders may also be effective in this process. As emphasized in the study conducted by Li and Lin (2023), it is considered that firms can accelerate the transition to sustainable production methods by increasing the environmental awareness and motivation of employees. Thus, it will contribute to adopting a more effective and efficient production model by adapting green culture awareness to the corporate culture.

Finally, enhancing manufacturing's environmental performance is greatly aided by the complementary nature of digital transformation and green manufacturing. Incorporating digital technologies into manufacturing processes yields more efficient and eco-friendly outcomes; implementing green production techniques amplifies these benefits. To reach their environmental sustainability targets, businesses should enhance their investments in digital strategy integration with green production. Therefore, both public policies and the strategies of private sector actors should be oriented towards disseminating digitalization and green production practices.

The findings of this study, consistent with existing research in the literature, reveal the positive effects of digital transformation on environmental performance and green production, offering a unique contribution to the literature by addressing the mediating role of green production. However, future research could explore the relationship between digital transformation and green production in different sectors or regional contexts to evaluate the generalizability of the results. Additionally, the impact of variables such as regulatory policy effects or organizational culture factors that could enhance the effectiveness of green production may also be investigated. In this regard, a more comprehensive understanding of the complex relationships between digital transformation and sustainability can be achieved.

ETİK BEYAN VE AÇIKLAMALAR

Etik Kurul Onay Bilgileri Beyanı

Çalışma, etik kurul izni gerektirmeyen bir çalışmadır.

Yazar Katkı Oranı Beyanı

Yazarlar tüm çalışmaları birlikte yürütmüştür.

Çıkar Çatışması Beyanı

Çalışmada, çıkar çatışması bulunmamaktadır.

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ANNEX 1 - Scale Items

Digital Transformation
Every operational activity and process that can be digitalised in our company has been digitalised.
The digitised information technology system in our company collects large amounts of data from different sources.
Our company creates a more robust network of activities and processes in the supply chain through digital technologies.
We are developing an efficient consumer interface with the application of digital technologies in our company
Information sharing between our company and suppliers is carried out through digitalisation.
In our company, predictive analytical methods are used in the decision-making process.
In our company, supply chain activities and processes are automated as much as possible.
Environmental Performance
Waste water emissions from our company decreased.
Exhaust / greenhouse gas emissions produced by our company have decreased.
The amount of solid waste produced by our company has decreased.
The consumption of hazardous, toxic and harmful substances has decreased in our company.
Energy use has decreased in our company.
Water use has decreased in our company.
Green Production
The production process of our company strictly adheres to the requirements of green production.
Our company selects and develops environmentally friendly processes or equipment.
Our company purchases environmentally friendly processes and equipment.
Our company considers the need for cleaner production when designing products.
Our company is actively building a more environmentally friendly production brand.
Our company supports the image of green production.
Our company recycles water among the companies.
Our company is actively looking for partners to jointly achieve energy saving and emission reduction targets.
Our company actively recycles and disposes of waste products.