

Prioritizing Water Footprint Reduction in Gray Cardboard Manufacturing: An Integrated Quality Function Deployment and Pareto Approach

Aysenur Erdil^{1*} 

¹Istanbul Medeniyet University, Department of Business Administration, Türkiye

*Correspondence to: Aysenur Erdil, Istanbul Medeniyet University, Department of Business Administration, Türkiye.

E-mail: aysenur.erdil@medeniyet.edu.tr

Abstract: Water shortage poses a critical challenge to sustainable economic growth, particularly in water-intensive sectors such as paper and cardboard manufacturing. This study explores the importance of controlling water footprints in the production of gray cardboard and identifies the key technical factors affecting water consumption in a paper manufacturing company located in Türkiye's Marmara Region. Methodologically, empirical data gathered from production managers and technical staff through structured questionnaires and expert interviews were analyzed using an integrated decision-support framework combining Water Footprint Assessment (WFA), Quality Function Deployment (QFD), the House of Quality (HoQ), and Pareto analysis. The QFD and HoQ matrix evaluated the trade-offs between customer requirements and technical characteristics, while Pareto analysis prioritized high-impact variables. The findings reveal that a small set of high-priority technical factors accounts for the vast majority of water footprint impacts. To address these dominant issues, targeted practical recommendations are proposed, specifically focusing on mitigating high-weight technical bottlenecks identified in the HoQ matrix through closed-loop water recirculation, improved water-use efficiency, process-water treatment optimization, and automated consumption monitoring at critical production stages. Overall, the proposed methodology provides a systematic decision-support structure for improving industrial sustainability and water resource management in the paper industry.

Keywords: Gray cardboard manufacturing, house of quality, pareto analysis, quality function deployment, sustainable manufacturing, water footprint.

Article info: Received 16 July 2026 | revised 7 September 2026 | accepted 2 October 2026 | published 23 October 2026

Recommended citation: Erdil, A. (2026). Prioritizing Water Footprint Reduction in Gray Cardboard Manufacturing: An Integrated Quality Function Deployment and Pareto Approach. *Indonesian Journal of Sustainability Accounting and Management*, 10(2), 520–550. <https://doi.org/10.20448/ijSAM.v10i2.9584>

INTRODUCTION

Water is the most vital aspect of our existence and a fundamental requirement for life. Throughout history, water has been essential to all living creatures, ecosystems, habitats, and civilizations. It is difficult to fathom existence without water. Freshwater supplies are now under threat because of shifting consumption habits, global warming, and a growing population. Consequently, the water demand has become more critical than ever before (Akin & Akin, 2007; Çiftçi et al., 2013; EU Project Management, 2015; Hoekstra & Wiedmann, 2014; Hogeboom, 2020; Intergovernmental Panel on Climate Change, 2023; TEMA Foundation, 2022; United Nations Educational Scientific and Cultural Organization, 2024).



Copyright © 2026 by the author(s). This article is published under the Creative Commons Attribution (CC BY 4.0) license. Anyone may reproduce, distribute, translate and create derivative works of this article (for both commercial & non-commercial purposes), subject to full attribution to the original publication and author(s). The full terms of this license may be seen at <http://creativecommons.org/licenses/by/4.0/legalcode>

Due to increased manufacturing activity, technological advances, and growing consumer demand, the industrial sector has become a significant user of freshwater resources. Water has always been regarded as less expensive than energy. Nevertheless, freshwater's strategic importance in guaranteeing industrial sustainability has increased significantly because of shortages and growing threats associated with climate change.

Water surveillance and effective water resource management are now essential components of sustainable production. Corporations are under increasing pressure from investors, regulatory agencies, and international sustainability initiatives, such as the Carbon Disclosure Project (CDP) and corporate sustainability reporting standards, to evaluate, track, and reduce their water-related ecological effects. As a result, businesses are gradually implementing production techniques intended to reduce ecological impacts while improving resource efficiency and overall environmental performance (Fereres et al., 2017; Özsoy, 2018; Zarate, 2010; Zhao, Chen, & Yang, 2009).

New metrics that evaluate water use across production and consumption systems have been developed in response to growing concerns about freshwater sustainability. The water footprint, which offers a comprehensive evaluation of both immediate and indirect freshwater usage, has notably emerged as an important metric. The water footprint was developed to evaluate freshwater consumption and contamination over the whole life cycle of products and services (Chapagain & Hoekstra, 2004). It was based on the ecological footprint concept proposed by Wackernagel and Rees (1996). The water footprint quantifies the total amount of freshwater used and contaminated throughout supply chains, in contrast to conventional metrics that focus exclusively on water extraction. Both direct water consumption and the virtual water embedded in traded items, intermediate products, and raw materials fall under this category (Hoekstra, 2013; Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011; United Nations Environment Programme, 2022).

The structure considers the geographical and temporal aspects of freshwater use while differentiating between green, blue, and greywater constituents. Therefore, water footprint evaluation provides a comprehensive understanding of water-resource use that is not possible with volumetric water-use metrics alone (Mekonnen & Hoekstra, 2011). For example, the water footprint of a single cup of coffee can reach about 140 liters when the complete manufacturing process is taken into account (Hoekstra et al., 2011; Hoekstra & Wiedmann, 2014; Pegram, Conyngham, Aksoy, Divrak, & Öztok, 2014; Water Footprint Network, 2016). As a result, water footprint evaluation has emerged as a valuable tool for promoting sustainable water governance, optimizing resource allocation, and planning environmentally sound strategies.

The paper and cardboard industry is one of the most water-intensive industrial sectors, requiring a significant amount of freshwater at every step of the production process, including pulping, stock preparation, forming, pressing, drying, and finishing. To improve process efficiency, minimize ecological effects, lower operating costs, and comply with increasingly stringent environmental requirements, water management at these stages is essential. Although technical advancements have improved water recycling and process optimization, many opportunities remain to identify crucial areas for improvement through methodical analytical methods.

Novelty and Contributions of the Study

Several studies have examined industrial water footprints and suggested ways to improve water efficiency. To prioritize water-saving options at the process level, very few have combined Water Footprint Assessment (WFA) with Quality Function Deployment (QFD), the House of Quality (HoQ), and Pareto analysis. Prior studies have mostly focused on assessing water use, while overlooking the conversion of water footprint data into structured management decision-support systems capable of identifying the critical technical elements affecting water use.

This study evaluates water footprint performance in gray cardboard manufacturing using a variety of methodologies, including WFA, QFD, the HoQ, and Pareto analysis, combined with an integrated decision-assistance structure. Using actual data from a paper and cardboard manufacturing business in Türkiye, this technique reveals which production processes have the greatest influence on water usage and describes the

technical issues that should be addressed to improve water savings. Understanding water footprint management in emerging-economy contexts such as Türkiye provides insights transferable to other Global South countries experiencing similar industrialization and water-stress challenges.

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

Theoretical Framework

An integrated conceptual and theoretical framework informed by Systems Theory and Resource Dependence Theory (RDT) forms the basis of this study. RDT claims that industrial firms are open systems that rely on critical external resources, such as freshwater, to operate efficiently. Companies need to improve supply chain resilience and proactively manage their internal resources as water scarcity intensifies. Systems Theory provides a foundation for viewing the production of gray cardboard as an interconnected industrial system in which different resources, such as materials, water, and energy, move and interact with one another.

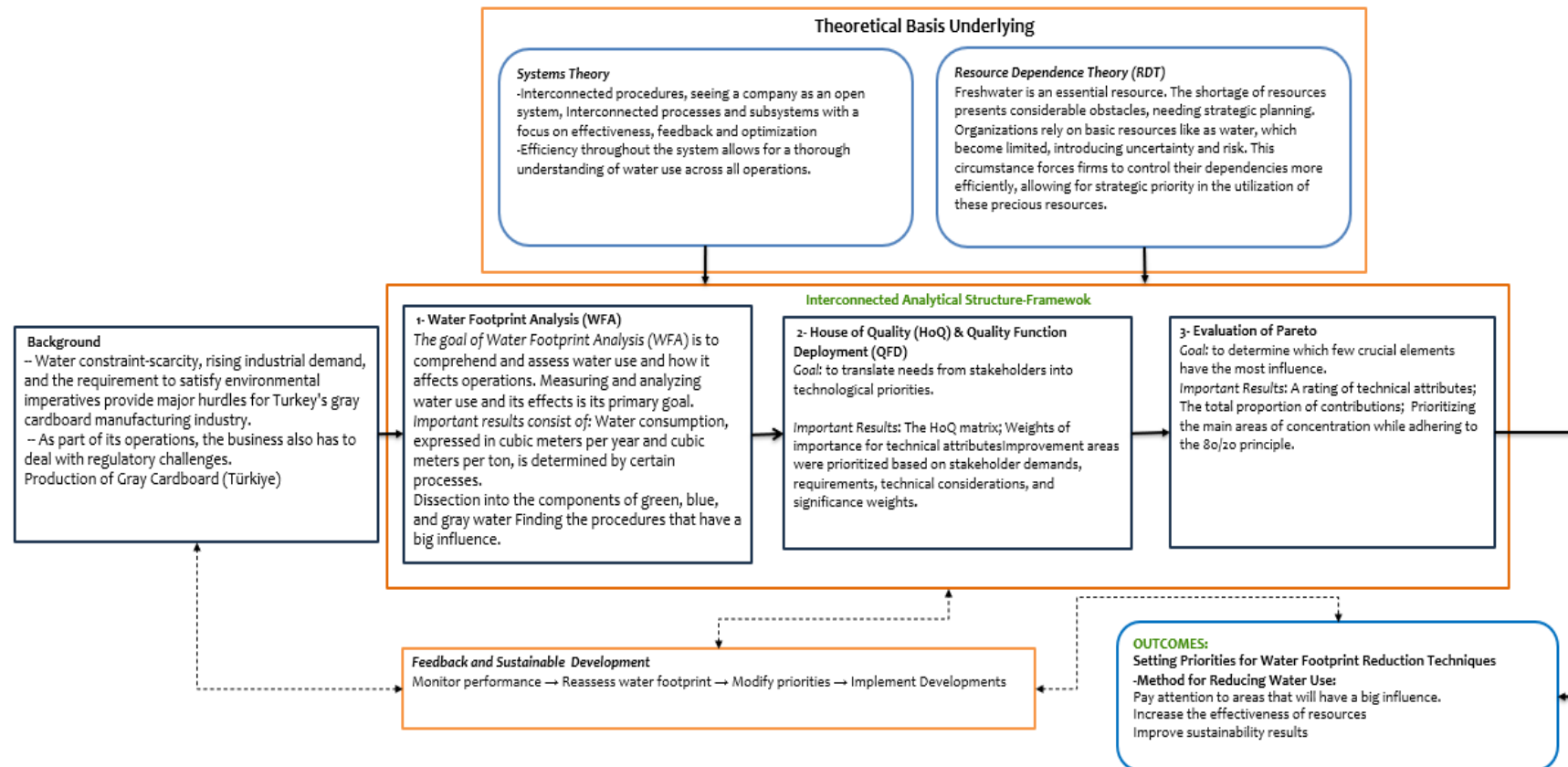


Figure 1: Conceptual and theoretical framework

Figure 1 depicts the study's conceptual structure, illustrating how Systems Theory and Resource Dependence Theory (RDT) provide the conceptual basis for combining WFA, QFD/HoQ, and Pareto analysis to prioritize solutions for minimizing the water footprint.

Environmental accounting and multifaceted decisions regarding operations are linked by the theoretical framework. The model uses Water Footprint Assessment (WFA) to convert environmental factors into numerical metrics, as illustrated by the study's strategy. These measurements are then assessed using Quality Function Deployment (QFD/House of Quality) to align internal engineering capabilities with external stakeholder and customer demands. Pareto Analysis subsequently employs a quantitative approach to identify important technological challenges. This sequential integration ensures a methodical transition from assessing ecological effects to making high-priority, useful technological decisions.

Justification for Using Pareto Assessment and QFD in Water Footprint Evaluation

When evaluating the amount of water used both directly and indirectly in blue, green, and grey forms, the traditional Water Footprint Assessment (WFA) works well. However, its primary purpose is to monitor water usage. Standard WFA lacks tools to assist in selecting which engineering tasks to prioritize or making decisions among various technical elements.

Notwithstanding its effective measurement of both direct and indirect quantitative water usage across blue, green, and grey elements, a conventional WFA is primarily utilized as an instrument for financial analysis. Nevertheless, integrated decision-support systems that rank technical solutions at the process stage or assess trade-offs between different technical components are rarely incorporated into WFA.

These methodological limitations are successfully addressed through the combination of Pareto analysis and Quality Function Deployment (QFD/House of Quality).

As a multi-criteria decision-making (MCDM) tool, Quality Function Deployment (QFD/HoQ) transforms qualitative stakeholder/customer needs and environmental factors into quantifiable technical requirements. HoQ meticulously illustrates the complex, multifaceted links between process water consumption and product quality standards in the context of water footprinting.

The House of Quality (HoQ) outcomes are prioritized using a statistical technique called Pareto analysis, also referred to as the 80/20 rule. In manufacturing plants, it is not feasible to address every technological area at once due to operational and financial constraints. Key, high-impact technical problems are identified using Pareto analysis, which concentrates attention on areas that provide the greatest optimization advantages.

Literature Review on Industrial Water Footprint

Increasing worldwide demand for freshwater supplies has pushed policymakers and scholars to develop comprehensive metrics to assess water use and its environmental implications. The water footprint concept has emerged as a valuable multidimensional instrument for evaluating the combination of direct and indirect freshwater consumption associated with products, services, enterprises, and human interactions. Unlike previous approaches to analyzing water consumption, the water footprint considers green, blue, and greywater aspects, thereby providing a more comprehensive understanding of water resource use and pollutant creation (Wang, Hubacek, Shan, Gerbens-Leenes, & Liu, 2021).

According to recent research, the notion of a water footprint has developed from a straightforward accounting measure into a crucial instrument for measuring sustainability. Such assessments are increasingly being utilized to identify water-intensive operations, analyze their consequences throughout supply chains, and help make informed resource-management decisions in businesses with high freshwater requirements (Olivos et al., 2024). This increasing focus highlights how effective water management must take into account the quantity and quality of water across all stages of production and consumption (Ansorge, Stejskalová, Vološinová, & Dlabal, 2022).

The existing literature indicates that the water footprint has become an important sustainability indicator for evaluating the relationship between freshwater resources and human activities. It is expected that water-footprint assessments will become more crucial in promoting sustainable resource management, creating environmental regulations, and developing comprehensive water security strategies, because global warming,

population growth, urbanization, and industrial expansion are progressively increasing pressure on water resources worldwide (Demir & Muratoglu, 2025; Olivos et al., 2024; Wang et al., 2021).

Freshwater resources are essential for ecological sustainability and human well-being. Physical water scarcity is no longer the primary issue, according to recent studies. Declining water quality, shifting hydrological processes, and escalating financial and social problems related to water scarcity are receiving increasing attention. These interconnected pressures have significantly increased concerns regarding the long-term sustainability of global freshwater resources (Hoekstra & Wiedmann, 2014; Intergovernmental Panel on Climate Change, 2023; United Nations Educational Scientific and Cultural Organization, 2024; Vörösmarty, Green, Salisbury, & Lammers, 2000).

Water shortage is also exacerbated by social factors in addition to natural factors. Regional water stress is greatly influenced by factors including population expansion, economic development, industrialization, and shifting consumption habits (Modi, Hanasaki, Yamazaki, Boulange, & Oki, 2022). At the same time, ecosystems are becoming less resilient and productive as a result of limited water availability rather than energy limitations brought about by climate change. Adopting comprehensive water governance solutions is necessary to address issues related to water security. Climate adaptation, ecological protection, technological advancements, effective resource management, and active stakeholder engagement should all be incorporated into these initiatives (Denissen et al., 2022; Mishra, Kumar, Saraswat, Chakraborty, & Gautam, 2021; Mohammed, Bolten, Souter, Shaad, & Vollmer, 2022).

Recent research has demonstrated that conventional assessments may underestimate global water scarcity when water quality degradation is considered together with water availability. Jones, Bierkens, and van Vliet (2024) reported that pollution substantially reduces the amount of usable freshwater, thereby intensifying water stress worldwide. Likewise, climate change has emerged as a major driver of freshwater quality deterioration through increasing temperatures, altered precipitation regimes, and more frequent hydrological extremes, all of which adversely affect aquatic ecosystems, drinking water supplies, and agricultural production (van Vliet et al., 2023).

The growing influence of anthropogenic activities has also exceeded critical planetary boundaries associated with freshwater systems. Porkka et al. (2024) demonstrated that streamflow and soil moisture conditions have already deviated beyond safe operating limits in many regions. Moreover, future climate projections indicate that between one-third and two-thirds of the global population may experience substantially wetter or drier climatic conditions during the coming decades, further increasing regional disparities in freshwater availability (Trancoso et al., 2024).

Because agriculture contributes significantly to the world's freshwater consumption, it is a major topic in water footprint studies. According to research, agricultural operations are large users of both blue and green water, and greywater generation increases greatly when fertilizers are used in conjunction with agricultural runoff (Deepa, Anandhi, & Alhashim, 2021; Demir & Muratoglu, 2025). Therefore, evaluating the water footprint is now essential for improving irrigation plans, selecting the best crops, and promoting sustainable farming methods (Demir & Muratoglu, 2025).

In the past several years, the use of water footprint methodologies has broadened significantly. These assessments are currently applied by researchers to consumer goods, aquaculture operations, industrial production systems, and agriculture. For instance, research has demonstrated how adding water footprint indicators to environmental labeling systems may raise consumer awareness and encourage sustainable purchasing habits (Nydrioti & Grigoropoulou, 2023). In order to improve resource efficiency and lessen the environmental effects of aquatic food production, there is also growing interest in evaluating water footprints in the aquaculture industry (Symeonidou & Mente, 2024).

One important tendency in recent research is the shift from volumetric assessments to impact-focused techniques. Modern research enables a more thorough assessment of sustainability performance by adding more factors about water shortages, ecosystem degradation, and environmental vulnerability (Deepa et al., 2021; Olivos et al., 2024). This change emphasizes the understanding that, depending on local hydrological

circumstances and ecosystem sensitivity, the same amounts of water use could have wildly disparate environmental effects (Olivos et al., 2024).

Researchers have highlighted challenges associated with data availability, regional variability, impact characterization, and the comparability of results across different studies and geographical contexts (Ansorge et al., 2022). These limitations have prompted calls for greater methodological standardization and the incorporation of local water scarcity conditions into water footprint calculations (Ansorge et al., 2022; Wang et al., 2021).

Although water footprint assessment has been widely applied across agricultural, industrial, and consumer sectors, several methodological challenges remain unresolved. Previous studies have further emphasized limitations related to methodological harmonization, regional variability, impact characterization, and the incorporation of local water scarcity conditions into footprint calculations (Ansorge et al., 2022; Wang et al., 2021). Furthermore, while volumetric accounting approaches dominate the literature, fewer studies have comprehensively addressed the spatial heterogeneity of water-related environmental impacts and their implications for sustainability assessment (Deepa et al., 2021; Olivos et al., 2024). These challenges indicate the need for further research aimed at improving the accuracy, comparability, and policy relevance of water footprint methodologies. Therefore, the continued development of context-specific assessment frameworks remains essential for supporting sustainable water resource management under increasing environmental and socioeconomic pressures (Ansorge et al., 2022; Olivos et al., 2024).

While earlier research effectively applied water footprint assessment across agriculture, industrial production, aquaculture, and consumer product evaluation, a noticeable gap remains in integrating Water Footprint Assessment with structured decision-support tools such as Quality Function Deployment, the House of Quality, and Pareto analysis. Existing research has mostly concentrated on measuring water usage and environmental implications, with little emphasis on prioritizing process-level improvement opportunities based on customer needs and technical specifications.

By presenting a thorough framework that integrates WFA, QFD, HoQ, and Pareto analysis, the investigation addresses this research gap. To achieve sustainable water management in gray cardboard manufacturing, this framework is intended to identify essential water-consuming operations and rank technological improvement alternatives.

The Concept of Water Footprint and Its Components: Blue, Green and Grey Water Footprint

One of the most commonly used metrics for evaluating freshwater use associated with the manufacture and consumption of products and services by individuals, industries, and national economies is the water footprint (WF). By distinguishing among three complementary elements, blue, green, and greywater footprints, the water footprint framework accounts for both the quantity of water used and the impacts of water contamination, in contrast to conventional indicators that quantify only water consumption (Hoekstra et al., 2011).

By taking into account both water usage and the deterioration of its quality over the course of the production cycle, this multifaceted method provides a comprehensive assessment of human impacts on freshwater resources. The excessive use of groundwater and surface water through supplies such as rivers, lakes, saline bodies, and reservoirs is referred to in this framework as the "blue water footprint." Particularly important for conventional irrigated agriculture, the green water footprint quantifies the amount of rainwater retained in soil and subsequently absorbed by plants through transpiration. In contrast, the greywater footprint measures the quantity of freshwater required to neutralize pollutants created during manufacturing operations while maintaining standard water-quality standards. These variables work together to provide a comprehensive understanding of freshwater utilization by including both the amount and quality of water used (Hoekstra, 2013; Hoekstra et al., 2011; Mekonnen & Hoekstra, 2011).

The amount of surface and groundwater utilized to produce goods and services of the highest quality is measured by the blue water footprint (BWF), which shows how much freshwater is not promptly returned to its native hydrological system. This indicator highlights the direct use of freshwater throughout the production process by including water drawn from rivers, lakes, bodies of water, and aquifers to support domestic

requirements, industrial operations, and agricultural irrigation. Excessive extraction of blue water can reduce environmental flow requirements, accelerate groundwater depletion, and increase rivalry among agricultural, industrial, and residential users, particularly in water-scarce locations. This is because blue water is extracted from limited clean-water reserves (Deepa et al., 2021; Demir & Muratoglu, 2025).

The quantity of rainwater retained in the soil and subsequently used by plants through transpiration throughout biomass development, on the other hand, is referred to as the "green water footprint." Green water, which is the primary source of water for rainfed farming, is essential for sustaining crop yields without requiring direct access to surface or subsurface water sources. Because the availability of this resource depends mostly on precipitation patterns, soil-moisture preservation, and evapotranspiration rates, it is extremely vulnerable to changes in atmospheric and hydrological parameters over time. Therefore, the green water footprint provides crucial information on climate-related vulnerabilities, agricultural dependence on water, and the environmentally friendly utilization of water resources in an evolving environment (Hoekstra et al., 2011).

The amount of rainfall that is efficiently captured by the soil and utilized by plants through evapotranspiration to produce goods and services is measured by the green water footprint (GWF). Green water originates from rainwater held in the root zone to promote plant development and biomass production, as opposed to blue water resources, which are obtained from rivers, lakes, or groundwater. In conventional agriculture, where crop growth mostly depends on soil water content rather than direct irrigation, this resource is essential. Thus, the green water footprint is an important metric for analyzing agricultural water use and the impact of natural rainfall on productivity. Its size is determined by a variety of elements, including weather patterns, soil water-retention capabilities, crop water demands, and evapotranspiration rates, which vary according to the climate and cultivation season. By incorporating the green water footprint into water-resource assessments, we gain greater knowledge of agriculture's dependence on natural water sources, as well as improved evaluations of sustainable water consumption under present and future climatic conditions (Deepa et al., 2021; Mekonnen & Hoekstra, 2011).

In order to ensure that water basins meet specified quality criteria, the Grey Water Footprint (GWF) measures the quantity of freshwater required to assimilate pollutants generated during the production of products and services. The greywater footprint highlights the environmental effects of water pollution and the capacity of freshwater systems to disperse pollutants, in contrast to blue and green water footprints, which focus on consumptive water use. Both the quantity of pollutants released and the maximum permissible concentrations established through environmental regulations affect its magnitude. Fertilizer runoff from agricultural operations, industrial waste discharges, and municipal wastewater are all major factors contributing to the greywater footprint, and they may have serious consequences for aquatic habitats. The grey water footprint tends to rise as population density, industrialization, and the intensification of farming practices increase, making it an important metric of pollution burden and water-quality resilience (Ansorge et al., 2022).

A water footprint evaluation is an efficient way to assess a nation's water use and dependence on outside supplies. The demand on a country's domestic water supply throughout the production of products and services is shown by the production water footprint. The water required to sustain a country's residents' consumption patterns and lifestyle choices, on the other hand, is shown by the consumption water footprint. A nation's reliance on foreign water supplies through the importation of products and services is also revealed by the consumption water footprint (Hoekstra, 2013; Hoekstra et al., 2011).

Identifying the differences among blue, green, and grey water footprints makes it possible to assess water use across different time periods and locales, thereby improving the examination of environmental effects associated with industrial systems. Consequently, the water footprint is becoming increasingly accepted as a useful instrument for developing standards, conducting environmental sustainability evaluations, and supporting water resource management decision-making. Its utilization aids in identifying regions with high water consumption, assessing resource efficiency, and developing sustainable production and consumption plans for a variety of sectors, including industrial, farming, aquaculture, and food distribution

systems (Olivos et al., 2024; Symeonidou & Mente, 2024; United Nations Environment Programme, 2022; Wang et al., 2021).

Water Footprint Characteristics of Türkiye

Due to factors including population expansion, rapid urbanization, industrial development, and climate change, Türkiye is increasingly recognized as a water-constrained country. In the past, the nation possessed sufficient freshwater resources to meet its needs. However, estimates indicate that Turkey may soon experience water scarcity because of declining per capita water supplies. To maintain long-term environmental and economic stability, improving the sustainable distribution and management of freshwater reserves has become a strategic priority. By analyzing both direct water consumption and the virtual water embedded in production, consumption, and international commerce, water footprint evaluation provides a comprehensive picture of national water use. This study considers both internal freshwater use and external water dependencies related to imported and exported commodities, in contrast to conventional water accounting approaches (Hoekstra et al., 2011). The water resources used to produce items manufactured abroad are referred to as virtual water imports, whereas the water used in domestic manufacturing of goods intended for export is referred to as virtual water exports (Chapagain & Hoekstra, 2004; Hoekstra, 2013).

According to recent assessments, Turkey's virtual water balance is relatively stable, with the amounts of virtual water exported and imported being approximately equal. This balance suggests that the country's total reliance on freshwater supplies is not greatly affected by foreign commerce. Approximately 89% of Turkey's production-based water footprint is derived from agricultural activities, which significantly influence the country's water footprint. This demonstrates how important water is to crop productivity. Green water makes up the largest portion of Turkey's production water footprint, since a large portion of this agricultural output depends on rainfall. Greywater is the freshwater required to neutralize pollutants created in the domestic, industrial, and agricultural sectors, whereas blue water, which includes conventional irrigation water from both surface and groundwater resources, is the second-most important component. According to current estimates, Turkey's yearly production-generated water footprint is around 139.6 billion cubic meters, of which approximately 64% is green water, 19% is blue water, and 17% is greywater (Akin & Akin, 2007; Çiftçi et al., 2013; Mekonnen & Hoekstra, 2011; Pegram et al., 2014).

The regional distribution of water footprint concentration in Turkey varies significantly, according to recent studies. Due to the needs of conventional farming and irrigation, agricultural regions in the west and south of the nation usually exhibit higher water production but also higher consumptive water usage. Concerns over aquifer depletion and long-term sustainable hydrology have been highlighted by excessive groundwater extraction in a number of irrigated basins (Akboştancı, Tunç, & Türot-Aşık, 2023; Hoekstra et al., 2011; Pegram et al., 2014; Pilevneli, Capar, & Sánchez-Cerdà, 2023).

Through the interchange of virtual water, international trade substantially influences Turkey's water-resource balance. Turkey essentially transfers a significant portion of its freshwater resources to foreign markets when it exports agricultural products. On the other hand, the nation imports agricultural products that contain water resources, which helps alleviate the country's water shortage (Akboştancı et al., 2023; Tur & Alkan, 2023). This virtual water flow establishes an essential link between global production networks and Turkey's water supplies.

From the perspective of consumption, the water footprint calculates the total amount of freshwater required throughout the entire supply chain of products and services used by a population, regardless of where the water is used (Hoekstra et al., 2011). With an estimated yearly consumption-based water footprint of 140.2 billion cubic meters, Turkey is heavily dependent on both purchased virtual water and native freshwater sources. Similar to the production viewpoint, green water accounts for around 66% of all water use in the consumption-based footprint. Meanwhile, blue and greywater each make up around 17% of the total, reflecting the impacts on water quality, industrial operations, and irrigation demand (Kayaer & Çiftçi, 2018).

According to sectoral analyses, agriculture accounts for about 89% of the country's consumption-related water footprint, making it the primary determinant of freshwater utilization. Domestic water use constitutes around 5% of overall freshwater use, while industrial output accounts for about 6% (Hoekstra, 2013). According

to these findings, improving agricultural water-use efficiency offers the greatest potential for reducing Turkey's total freshwater use.

With comparable amounts of combination-based and consumption-based water footprints, the data demonstrate that Turkey maintains a balanced connection between its domestic production and national consumption. Nevertheless, the difficulties brought about by increased irrigation requirements, growing urban and industrial water demand, and increasing climate unpredictability underscore the critical need for integrated water resource management. In this regard, evaluating water footprints constitutes a crucial instrument for developing long-term national water security, improving agricultural water efficiency, and establishing sustainable water-allocation plans.

Water Footprint of Consumption: A Literature Review

A key indicator for comprehending freshwater usage throughout increasingly connected international supply chains is the consumption-based water footprint. This approach, in contrast to conventional production-based assessments, links freshwater use to the ultimate demand for products and services, independent of where they are produced. This viewpoint successfully takes into account both the virtual water connected to international commerce and household water usage (Wang et al., 2021). International demand for clean water is mostly driven by consumption patterns, particularly in industrialized and rapidly developing countries, according to recent assessments. Significant amounts of virtual water may be moved through commodities used in farming and industry thanks to international commerce, which creates a geographical gap between the production and consumption of goods. Because of this, importing nations frequently depend on water supplies from supplying territories, a number of which are currently dealing with severe water stress (Chapagain & Hoekstra, 2004; Fang, Heijungs, & de Snoo, 2021; Hoekstra et al., 2011; Vanham, 2018).

A very limited number of processed agricultural commodities, including dairy, cereals, and animal products, contribute considerably to the world's water footprint through consumption, according to analyses of global supply chains (Chapagain & Hoekstra, 2004; Hoekstra et al., 2011; Mekonnen & Hoekstra, 2011; Wang et al., 2021). Average individual water footprints are also significantly influenced by socioeconomic factors such as urbanization, eating habits, and socioeconomic status. In contrast to plant-based diets, diets high in animal-based foods usually require much more freshwater, highlighting the need for demand-side tactics, in addition to technological advances, to increase water-use efficiency (Modi et al., 2022).

The body of research makes it abundantly evident that assessing water footprints according to consumption provides a comprehensive framework for understanding the relationship between consumer demand and the utilization of freshwater resources worldwide. By concentrating on both production efficiency and consumer preferences throughout global supply chains, this perspective may be integrated into sustainability strategies to improve resource management (Chapagain & Hoekstra, 2004; Hoekstra et al., 2011; Mekonnen & Hoekstra, 2011; Wang et al., 2021).

Türkiye's Water Footprint within the Global Water Footprint Framework: A Comparative Literature Review

An essential technique for determining the sustainability of freshwater resources is assessing the water footprint. This method links consumer behavior, international trade dynamics, manufacturing systems, and water use. The water footprint encompasses the virtual water incorporated into traded items, in addition to green, blue, and greywater components, in contrast to typical water-use measures that primarily take direct withdrawals into consideration. This provides a more thorough understanding of a country's use of water resources (Green Pen, 2014; Hoekstra et al., 2011). This strategy is particularly important for nations like Turkey, where freshwater supplies are being strained by growing water demand, climate change, and agricultural dependence.

The composition of Türkiye's water footprint differs significantly from worldwide trends. According to studies, green water makes up the majority of the water used in the nation for both production and consumption. This shows how important rain-fed agriculture is to Türkiye's freshwater needs. This dependence

highlights how vulnerable agriculture is to changes in water supply and climatic unpredictability (Çiftçi et al., 2013; Pegram et al., 2014). Furthermore, Türkiye's blue water footprint is very large compared with the global average, underscoring the importance of irrigation and the substantial use of groundwater and surface-water resources, particularly in maintaining its irrigation-intensive industries (Akin & Akin, 2007; Hoekstra, 2013).

Türkiye's national water footprint is still largely driven by agriculture, with irrigation-intensive crop production representing one of the largest users of freshwater resources. Water supplies are severely strained in semi-arid regions due to growing irrigation demand. Therefore, improving water management in agriculture and increasing irrigation efficiency have emerged as crucial objectives for the long-term sustainable use of water resources (Akboşancı et al., 2023; Hoekstra et al., 2011; Muratoglu, 2020; Pegram et al., 2014; Pilevneli et al., 2023).

According to international comparison analyses, Türkiye's per capita water footprint has been reported to exceed the global average and to show an increasing trend. It was once calculated to be approximately 1,642 m³ per person per year, but more recent estimates indicate that this amount has increased to over 1,977 m³ per capita. This pattern indicates that pressure on freshwater resources continues to increase. Population growth, changing dietary patterns, increased industrial and agricultural activity, and higher consumption rates are among the factors behind this increase. Several of these factors increase both the amount of water used domestically and the virtual transfer of water through international trade (Chapagain & Hoekstra, 2004).

Türkiye's engagement in the international virtual water market has a substantial influence on its national water footprint. Through exporting agricultural goods, the country successfully transports a significant quantity of embedded freshwater to global markets. Furthermore, imported goods and services serve to ease domestic water scarcity by drawing in external water resources for domestic purposes. This situation emphasizes the importance of international commerce in determining the sustainability of water supplies and guaranteeing national water sovereignty (Akboşancı et al., 2023; Green Pen, 2014; Tur & Alkan, 2023).

Global warming is expected to have a considerable impact on how potential water footprints evolve. As temperatures rise, precipitation patterns vary, and droughts become more prevalent, freshwater supplies are expected to decline, while demand for irrigation in critical agricultural regions increases. At the same time, continued urban growth and expanding industrial activity are likely to increase freshwater demand even further. This scenario highlights the urgent requirement for fully integrated water management policies that properly balance the demands of agricultural productivity, industrial expansion, and domestic use (Çiftçi et al., 2013; Yerli & Şahin, 2022).

According to the research, climate-affected agriculture, irrigation intensity, virtual water trade, geographical variations, and shifting consumption habits all affect Turkey's water footprint. These findings underscore the importance of integrating water footprint assessments into national water management programs. This integration would enable more effective irrigation systems, environmentally friendly farming practices, greater industrial water-use efficiency, and knowledge-based decision-making to ensure enduring water sovereignty and environmental sustainability (Demir & Muratoglu, 2025; Green Pen, 2014).

Research Contribution and Research Gap

There is a substantial research deficit in the paper and cardboard industry, despite the wealth of literature available on water footprints across industries and water reclamation technology. A gap remains between general water footprint data and specialized decision-making procedures, as previous research has mostly concentrated on overall water volume evaluations or particular wastewater treatment techniques. Previous research has rarely provided a quantitative method for matching internal technical criteria with consumer and stakeholder objectives to systematically identify operational objectives.

By presenting a thorough decision-making framework that incorporates Water Footprint Assessment (WFA), Quality Function Deployment (QFD), the House of Quality, and Pareto analysis within the real-world context of a gray cardboard manufacturing facility, this study seeks to close this gap. Compared with previous research, the study's main contributions may be summarized as follows:

(i) **Prioritization of Key Challenges:** Determining the crucial technological components that significantly impact the water-footprint efficiency of gray cardboard manufacturing, such as closed-loop recirculation, computerized tracking, and process-based improvements in water treatment.

(ii) **Application to Emerging Regions:** The study offers a flexible operating framework for paper mills in emerging nations facing comparable industrial expansion and water-shortage problems, based on actual data from Turkey.

(iii) **Methodological Collaboration:** A novel multicriteria decision-making (MCDM) framework is introduced, transforming conventional water-footprint computation into an active, ranked technological instrument supporting decision-making.

IDENTIFICATION OF WATER CONSUMPTION AND ENVIRONMENTAL IMPACTS IN THE PULP AND PAPER INDUSTRY

Globally, the burden on natural resources and the impacts on the environment have increased as industrial output grows as a result of urbanization, population growth, and economic development. The paper and paperboard industry is especially resource-constrained, as it uses substantial amounts of energy, water, and plant-based raw materials. Through a number of mechanical and chemical processes, virgin fibers, recycled paper, and cellulose pulp are transformed into final paper and gray cardboard products (Ali & Sreekrishnan, 2001; Central Anatolian Exporters' Associations, 2012).

Freshwater is an essential part of the paper-making process. It is used for pulping, conveying fibers, washing, bleaching, dilution, cooling, operating boilers, and cleaning equipment, among many other purposes. Water consumption may therefore vary depending on the type of raw materials used, the production process employed, and the intended quality of the final product. Only the chemical and metal sectors use more water per unit of output than the paper industry, making it one of the world's largest industrial water users (Eroğlu & Usta, 2004).

Substantial volumes of effluent containing suspended particles, biodegradable organic materials, and residual processing chemicals are produced by the pulp and paper sector, which is well known for using a lot of freshwater. The precise composition and pollutant levels of these effluents are determined by the properties of the raw materials and the production techniques employed. Inadequate treatment can damage biological processes in downstream water bodies and increase organic pollution. It is essential to improve internal water recycling, maximize process efficiency, and implement cutting-edge wastewater treatment techniques to lessen these environmental impacts and support sustainable business development (Thompson, Swain, Kay, & Forster, 2001; Wayland, Trudeau, Marchant, Parker, & Hobson, 1998).

In addition to consuming substantial amounts of freshwater, paper production generates considerable effluent. Suspended particles, organic debris, dissolved compounds, and various processing additives are all present in this effluent. The production techniques, the source of the fibers used, and the substances utilized throughout manufacturing all significantly affect the composition and contamination levels of these effluents. If not properly treated, industrial waste discharges can damage aquatic ecosystems, increase organic loads, and lower dissolved oxygen levels in the bodies of water they enter (Pokhrel & Viraraghavan, 2004; Thompson et al., 2001). As a result, using cutting-edge wastewater treatment technology in conjunction with water recycling and greener production techniques has become essential for sustainable paper manufacturing.

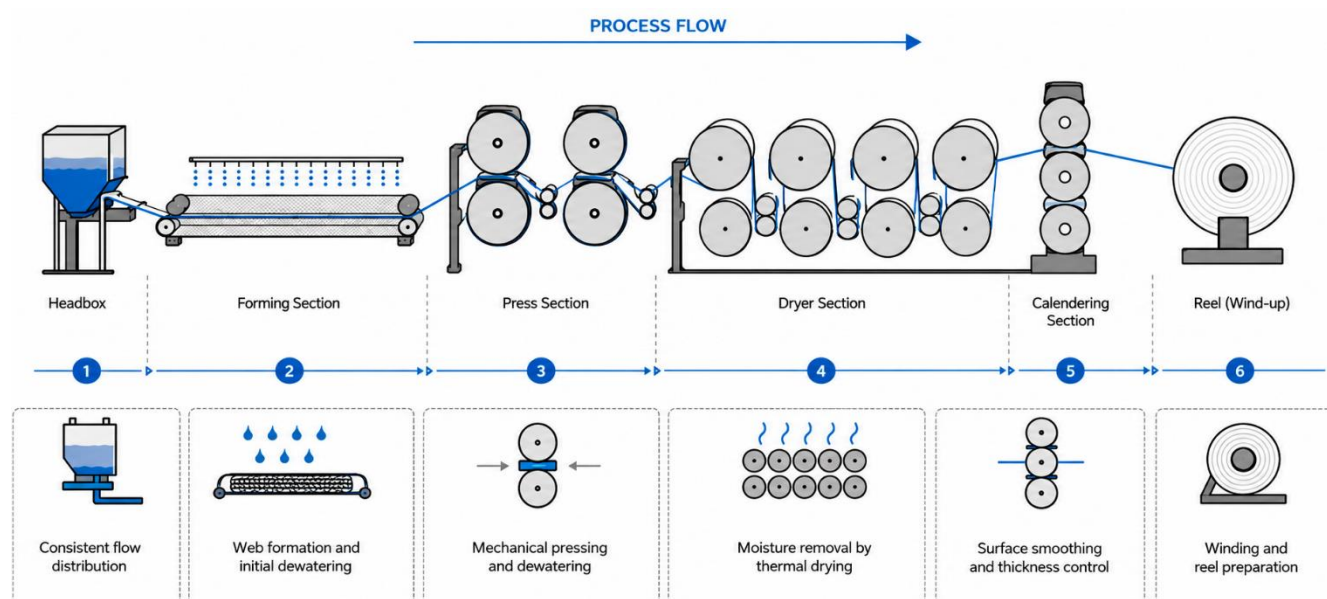
Technological advances have greatly improved the industry's water-use efficiency. To produce a tonne of paper, older manufacturing processes in traditional paper mills may require about 400 m³ of freshwater. In contrast, through process optimization and internal water recirculation, contemporary integrated plants have reduced this requirement to around 20–50 m³ per tonne (Yakut, 2012). Plants may additionally reduce freshwater consumption to about 5–10 m³ per tonne when recycled paper is used as the primary raw material. Nevertheless, actual consumption still varies depending on the industrial setup and product type (European Commission, 2001). Due to varying manufacturing methods and quality requirements, some paper and paperboard grades still require up to 60 m³ of freshwater per tonne (Thompson et al., 2001).

Including over 46 manufacturing establishments, the majority of which are medium-sized businesses, the Turkish paper and paperboard industry is an important component of the nation's industrial economy. These businesses often rank among Türkiye's leading industrial organizations, highlighting the industry's economic influence, as well as the urgent need to improve environmental performance. This industry is a strategic priority for implementing sustainable water management techniques, increasing process efficiency, and reducing the environmental effects of industrial operations because of its substantial water consumption and wastewater production.

The research emphasizes the necessity of environmentally friendly water resource management in the paper and gray cardboard industries, citing it as critical to ecological performance. Enhancing water-use efficiency, lowering wastewater generation, and implementing cleaner production technologies are viewed as critical initiatives. These strategies aim to reduce environmental consequences while maintaining the sector's competitiveness.

FOURDRINIER PAPERMAKING SYSTEM AND GRAY CARDBOARD MANUFACTURING PROCESS

The Fourdrinier papermaking system ranks as the main continuous manufacturing technique for producing paper and paperboard products. Utilizing a number of mechanical and thermal processes, pulpy cellulose fibers from recycled paper or raw wood pulp are transformed into a uniform sheet. Its prolonged dominance in the paper sector is credited to its high production efficiency, consistent product quality, and operational flexibility (Peng, 2011).



Source: (Modified by the authors from Peng (2011); Gullichsen and Fogelholm (2000); Holik (2013); Smook (2016) and Republic of Turkey Ministry of Environment and Urbanization (2017)).

Figure 2: Illustration-based visualization of the production of gray cardboard and the Fourdrinier papermaking process

The forming (wet-end) section, press section, dryer section, and calendar section are the four interconnected process units that comprise the manufacturing line. Each section contributes differently to surface finishing, sheet forming, moisture removal, and the development of the product's final mechanical and physical properties (see Figure 2; (Britt, 2020; Gullichsen & Fogelholm, 2000; Holik, 2013; Republic of Turkey Ministry of Environment and Urbanization, 2017; Smook, 2016)).

The first step is to make a diluted suspension of fibers, which is a uniform slurry made by dispersing cellulose fibers in water. Fillers, sizing agents, retention aids, and other process additives are introduced at this point to satisfy certain product requirements. To guarantee that the suspension is evenly distributed throughout the continuously moving forming fabric, the prepared fiber stock is then gradually delivered to the headbox. The effects of gravity and vacuum-assisted methods help eliminate a large amount of free water during the forming step, allowing the fibers to entangle and create a continuous paper network. After its creation, the emerging network is routed to the press area. Here, a series of press rolls and felts mechanically remove more water, increasing the sheet's density and strengthening the fiber connections. This mechanical dewatering improves overall process efficiency and substantially reduces the energy required for subsequent thermal drying.

After being pressed, the sheet moves on to the drying area, where it comes into contact with a series of steam-heated cylinders that progressively remove moisture. In addition to reducing the moisture content, this heat-drying method improves the paper's mechanical strength and dimensional stability. Different additives, such as starch, sizing agents, or surface-treatment chemicals, may be added during or immediately after the drying process, depending on the particular application requirements. These additives help enhance the paper's practical qualities, including printability, water resistance, and surface smoothness. The paper or paperboard is run through polished rollers in the calendering area, where regulated pressure is applied during the final step of the Fourdrinier process. While reducing the moisture content to around 5–6%, this calendering method improves surface uniformity, thickness consistency, density, and smoothness. The finished product is either cut into sheets or wound onto reels, ready for packing, storage, or further processing as required.

Although recycled paper is used as its principal raw material, gray cardboard manufacturing follows a similar basic processing sequence. The process begins with the repulping of used paper bales in water-filled pulpers, where cellulose fibers are dispersed and separated through mechanical agitation generated by rotor systems. To obtain a uniform fiber mixture, contaminants such as plastics, metals, sand, and other foreign materials are removed during the pulp preparation stage through a series of cleaning and screening operations. The purified pulp is then transferred to the headbox and processed using the conventional Fourdrinier configuration through the forming, pressing, drying, and calendering stages once the required consistency has been achieved (Gullichsen & Fogelholm, 2000; Smook, 2016).

The fundamental fiber mat is created during the initial formation phase, when moisture is removed using vacuum and gravity. Approximately 70% of the excess water is physically removed as this mat passes through press-felt devices. The moisture content is further reduced to around 5% by the subsequent heat-drying process, enabling the material to acquire the physical characteristics required for the production of gray cardboard. Following drying and weighing, the finished board is cut, turned, and shaped according to predetermined weights and dimensions before moving on to other conversion procedures, including sizing, laminating, gluing, or packing, depending on customer requirements (Holik, 2013; Smook, 2016).

According to Karayılmazlar and Aytekin (1999) and the European Commission (2001), freshwater plays a crucial role in a number of operations, including pulp preparation, fiber conveyance, washing, cooling systems, boiler feed, equipment sanitization, and the formulation of process chemicals. Consequently, the pulp and paper industry has been recognized as one of the world's biggest industrial users of freshwater. Large amounts of wastewater are unavoidably produced as a result of the manufacturing processes' heavy reliance on water. Suspended particles, dissolved organic materials, and residual process-related chemicals are frequently present in this effluent. The characteristics of raw materials, the kinds of additives used, and the production environment all have an impact on the particular composition and pollutant load of this effluent (Özçelep, 2009).

Important steps for reducing the environmental effects of gray cardboard manufacturing include increasing water-use efficiency, strengthening internal water-recirculation systems, and incorporating cutting-edge wastewater treatment technologies. These measures are critical for fostering sustainable production practices, lowering freshwater use, and limiting environmental problems associated with industrial wastewater generation.

BACKGROUND OF THE STUDY

Recycled paper, as well as packaging waste from various commercial and manufacturing industries, is carried to ABC Corporation (Inc.), a gray cardboard plant located in Turkey's Marmara Region, where these materials are transformed into gray cardboard products. Accordingly, this section of the study examines the importance of controlling water footprints in the manufacture of gray cardboard by evaluating water use during the manufacturing process and its relationship with production sustainability. In addition to identifying the main operational factors influencing water consumption, the research provides recommendations for improving sustainability, sustainable resource management, and water-use efficiency in the paper and cardboard industry.

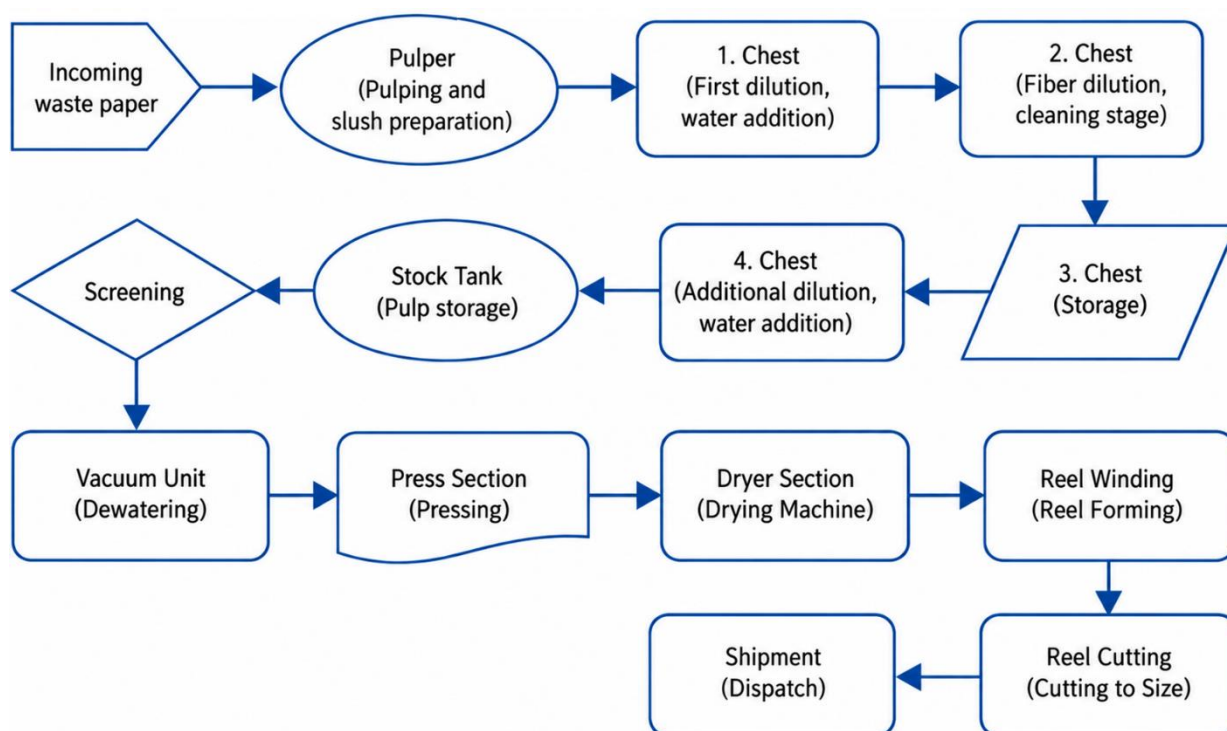


Figure 3: Process Flow Chart of Gray Cardboard Production- Process Flow Chart of the Plant at ABC Inc.

The screening, vacuum-assisted dewatering, and pressing operations generate wastewater, which is then returned to the pulp system. The wastewater treatment plant subsequently processes the remaining wastewater. The factory uses entirely mechanical manufacturing procedures to convert recycled waste paper into gray cardboard. Waste paper is the only raw material used in the production process; no chemical additives are used. The screening, vacuum-assisted dewatering, and pressing processes are the main sources of wastewater, which is subsequently treated and/or recirculated as appropriate (see Figure 3).

The following Table 1 displays the amount of water used at each stage of ABC Company's gray cardboard production process. By comparing the amount of water consumed at each production stage with the relevant production output and the designated water-use coefficient for each process, the process-associated water footprint (m^3 water/ton of gray cardboard) was determined.

According to operating statistics, the power plant can produce 26,000 tons of gray cardboard annually, and its system water intake is 39,328.75 m^3 . Approximately 9,832.19 m^3 of water is recovered each year through the operation of the online wastewater treatment and water restoration system, accounting for over 25% of the system's total water requirement. Consequently, the plant's annual freshwater intake is reduced to

29,496.56 m³, illustrating how water reuse techniques contribute to improved resource efficiency. The typical blue water footprint for gray cardboard production was determined to be approximately 1.134 m³ of water per ton of product (29,496.56 m³ ÷ 26,000 tons), using freshwater-intake data obtained online. The study determines that the blue water footprint component is particularly effective because it focuses solely on water extracted from conventional freshwater sources for commercial system use (see Table 1).

While the main industrial grades range from 270–450 g/m², the production line produces gray cardboard in basis weights ranging from 210 to 900 g/m². The production machine's combined system width of 2,200 mm enables the production of gray cardboard coils for subsequent processing operations and evolving applications (ABC Inc, 2024).

Table 1: Process-based water consumption and water footprint assessment for gray cardboard production at ABC Inc

Serial No.	Processes	Water Consumed (m ³ /year)	Percentage Share (%)	Water Footprint (m ³ water/ton of gray cardboard)
1	Pulper	13,371.775	34	0.514
2	1st Chest	4,719.450	12	0.182
3	2nd Chest	2,359.725	6	0.091
4	3rd Chest	1,573.150	4	0.061
5	4th Chest	786.575	2	0.030
6	Pulp Chest	786.575	2	0.030
7	Screen	4,719.450	12	0.182
8	Vacuuming	786.575	2	0.030
9	Press	5,506.025	14	0.212
10	Drying Machine (Water Evaporation)	3,932.875	10	0.151
11	Reel Winding	0	0	0.000
12	Reel Cutting	0	0	0.000
13	Shipment	0	0	0.000
14	Administrative Water Consumption	786.575	2	0.030
	Water Footprint Attributed to Production			1.513
15	Wastewater Treatment (Sedimentation Pond) (-)	9,832.188	25	0.378
	Total Water Footprint			1.134

DATA AND METHODOLOGY

This study examines ABC Company, a paper and cardboard manufacturer with operating networks in Turkey and other countries. The research, defined by the company's strategic integration of production and management, focuses particularly on crucial organizational elements to assess the substantial influence of the water footprint within manufacturing processes. Additionally, the House of Quality model was used to apply Pareto analysis and Quality Function Deployment (QFD) methodologies. These analytical techniques made it possible to conduct a systematic evaluation of the connections between various customer requirements and certain technological characteristics, particularly regarding environmental sustainability, manufacturer–consumer alignment, and the preservation of customer satisfaction.

Data Collection and Sampling

In this research, a purposive sampling strategy (a targeted sampling approach), classified as non-probability sampling, was used to gather opinions and perspectives from key personnel at ABC Company who were

selected specifically for their practical experience in industrial water management. The requirements that prospective participants had to meet included a minimum of a bachelor's degree, employment in a managerial, technical, or administrative capacity, and substantial professional experience, preferably ten years or more, in the field. All 40 qualified participants, comprising department heads, process engineers, and unit managers, successfully completed the requisite evaluation processes, achieving a 100% response rate. This full participation provides a robust foundation for the subsequent analysis.

Toward the end of 2025 and into the first few months of the following year, data were collected on-site at the manufacturing plant. Online questionnaires, interactive team brainstorming sessions, and in-person semi-structured interviews were all used in the data-gathering procedure. The evaluation methodology was developed using industry benchmarking studies, contemporary corporate sustainability literature, and qualitative feedback from senior plant employees to align it closely with the site's operating environment. After an internal assessment by subject-matter experts to guarantee content authenticity, a pilot test involving four division heads was conducted to verify the framework's relevance and clarity. In order to rank important water footprint metrics sequentially, a numerical scoring system was also incorporated into the discussion and workshop formats. Throughout, standard research integrity protocols were closely followed and maintained at all stages. Before participation, written or verbal informed consent was obtained, and participation was completely voluntary. All comments were anonymized and analyzed only in aggregate form to safeguard individual privacy and company confidentiality. Recognized research integrity and ethical norms were closely followed at every stage of the investigation. Participants provided written or verbal informed consent before participation and did so voluntarily. All answers and comments were anonymized and evaluated only collectively to protect privacy and maintain corporate confidentiality.

Identification of Customer Requirements and Technical Characteristics

A thorough qualitative method was used to determine technical characteristics and Customer requirements. To generate prospective variables, primary and secondary sources, such as literature studies, business activity reports, and internal papers, were first reviewed.

In-depth interviews with expert managers were conducted throughout the fieldwork phase, in addition to interactive workshops and focus-group brainstorming sessions. A cross-validation approach was used to bring together disparate expert opinions from different areas. The final variable collection contained only those technical attributes that matched organizational documents and were approved by the majority of experts.

The Water Footprint Network (WFN) methodology was used as the basis for determining the amount of water used in production processes (Hoekstra et al., 2011).

The water content (VWC, m³/ton; Equation 1) of a product or product group (c) is calculated by dividing the total water volume consumed per unit of production (CWU, m³/year; Equation 2) by the total annual production volume (Production, ton/year).

$$VWC_c = \frac{CWU_c}{\text{Production}_c} \quad (1)$$

The total water footprint volume is obtained by multiplying coefficients derived from national and international standards (TSE, FAO, WFN) by the relevant production quantities.

$$\text{Total Water Footprint} = \sum(\text{Production}_c \times VWC_c) \quad (2)$$

Methodological Limitations and Rationale for Focusing on Blue Water

In water footprint evaluation, choosing a study's scope is a strategic decision that affects the accuracy and usefulness of the findings. The methodological scope selected for this study is justified for several reasons. The study does not include the theoretical volume needed to dilute contaminants because the greywater footprint is excluded. Because any effects on water quality are not taken into consideration, this omission might result in an overestimation of the system's environmental performance. This is a methodological drawback that is

especially relevant to aquatic ecology. Nevertheless, there are several compelling reasons to concentrate on the Blue Water Footprint.

First, evaluating actual withdrawals from surface water and aquifers provides a clear picture of a watershed's physical water scarcity and drought pressures. Furthermore, unlike greywater characteristics, which are highly questionable owing to regional variations in environmental background concentrations, blue water data from field measurements and institutional records are consistently verifiable. Finally, net volumetric blue water statistics provide a useful foundation for emergency water allocation planning, on-site water conservation initiatives, and conventional agricultural irrigation management.

METHODOLOGY

Pareto Analysis

A crucial technique in quality management, Pareto analysis is used to classify and rank the underlying causes of a problem according to their relative importance. This approach aids strategic decision-making and improves procedures by identifying the crucial elements that have the greatest overall impact. Pareto analysis is a useful method for prioritizing remedies and optimizing resource efficiency in quality management situations by separating the most essential causes from the less important ones (Egermayer, 1988). Difficulties are identified using the 80/20 ratio in Pareto analysis, and suggestions for improving and addressing these difficulties are made. In Pareto analysis, this approach assists in identifying the most important technical features, thereby determining the high-priority class of technical characteristics.

Table 2: Pareto Analysis of water footprint contributions across gray cardboard production processes for ABC Inc

No.	Processes	Water Footprint (m ³ water/ton of Gray Cardboard)	Water Footprint (%)	Cumulative Water Footprint (%)
1	Pulper	0.514	34	34
2	Press	0.212	14	48
3	1st Chest	0.182	12	60
4	Screen	0.182	12	72
5	Drying Machine (Water Evaporation)	0.151	10	82
6	2nd Chest	0.091	6	88
7	3rd Chest	0.061	4	92
8	Administrative Water Consumption	0.030	2	94
9	4th Chest	0.030	2	96
10	Pulp Chest	0.030	2	98
11	Vacuuming	0.030	2	100
12	Reel Winding	0.000	0	100
13	Reel Cutting	0.000	0	100
14	Shipment	0.000	0	100
15	Wastewater Treatment	0.000	0	100
Total		1.513		

According to the evaluation of the production phases, the first four processes, Pulper, Press, 1st Chest, and Screen (sieve), account for approximately 72% of the water used in the production of gray cardboard. This implies that these phases have a significant impact on the process's total water usage (see Table 2 and Figure 3). Prioritizing these procedures is advised when seeking to reduce water use. Focusing on improving these crucial stages is expected to reduce water consumption and production costs, increase the efficiency of water use in subsequent production stages, and support a more environmentally friendly manufacturing process.

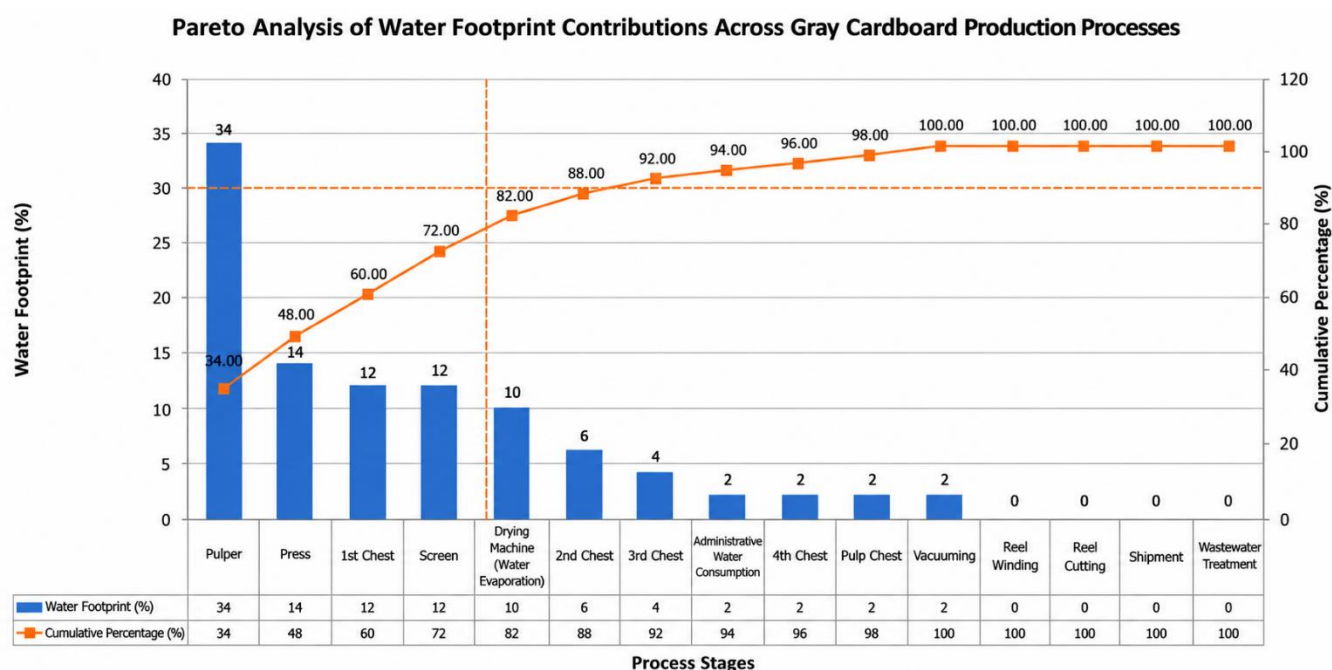


Figure 4: Applying Pareto to identify the main variables influencing ABC Inc.'s water footprint during the production of gray cardboard

To achieve the greatest decrease in the facility's overall water usage, the Pareto analysis clearly indicates which production activities should be prioritized. According to the Pareto principle, the Pulper, Press, First Chest, and Screen (Sieve) stages should receive the majority of attention, as they account for the largest portion of overall water consumption (see Table 2; Figure 4). It is anticipated that concentrating on improving these crucial processes would result in the greatest reductions in water use, along with increased operational effectiveness and reduced costs. Possible tactics include using more treated rainwater as a substitute source for operations; regularly maintaining and cleaning screening and filtration equipment to reduce water waste; and integrating cutting-edge membrane and ultraviolet (UV) filtration techniques into the wastewater treatment process to increase purification effectiveness and encourage internal water recycling. Taken as a whole, these programs are expected to support environmentally friendly water management practices and result in a significant reduction in the overall amount of water used during the manufacture of gray cardboard.

Quality Function Deployment

A strategic method called Quality Function Deployment (QFD) converts consumer preferences and needs into workable design and manufacturing procedures. This approach ensures that every phase, from initial product development through marketing and distribution, is guided by consumer requirements (Sher, 2006).

QFD aims to improve design quality in order to satisfy customers, convert their demands into the basic quality assurance systems required during production, and secure the system while the product is in the design stage (Gonzalez, Quesada, Mueller, & Mora-Monge, 2004). Successful companies prioritize new needs and criteria that are not taken into account or recognized in relation to customers' current and future needs. The most important characteristic of leading companies in the sector is that they can continuously respond to their customers' needs and expectations and strive to fulfill them (Compton, 1999; Prasad, Subbaiah, Rao, & Sastry, 2010).

Successful businesses are adept at recognizing and meeting customer demands that are not readily apparent or expressed in the marketplace. Their success depends on their capacity to quickly adjust to shifting consumer demands and guarantee ongoing satisfaction. QFD offers an organized method for converting the "Voice of the Customer" (VoC) into specific production requirements within this framework. Throughout the

product's entire lifespan, including development, production, and distribution networks, this methodical transformation guarantees that customer preferences are incorporated into comprehensive design requirements. Ultimately, QFD aims to optimize design quality by embedding customer satisfaction and requirements directly into core quality assurance frameworks, thereby safeguarding the operational system during the pre-production design phase. Nowadays, the QFD approach increases the importance and application area of the method universally, in line with the shortening of existing product development processes in companies, enabling the production of better-quality and more suitable products while providing a high level of customer satisfaction (Deros, Rahman, Rahman, Ismail, & Said, 2009; Lee, Wu, & Tzeng, 2008).

A central component of QFD is the Quality House, which consists of a set of matrices used to establish relationships between customer expectations and the technical criteria required to satisfy them. The Quality House is a set of matrices aimed at correlating customer expectations with the technical criteria determined to realize them, comparing quality characteristics and criteria based on objective rating criteria, and identifying positive or negative correlations between the technical criteria and customer expectations (Hauser & Clausing, 1988; Morris & Morris, 1999).

Methodological Rationale: Multi-Criteria Decision-Making (MCDM) Framework

In contrast to conventional statistical or economic methods, this study uses Pareto analysis and Quality Function Deployment (QFD), specifically the House of Quality (HoQ) matrix, as a means of performing Multi-Criteria Decision-Making (MCDM). Instead of testing hypotheses based on macro-level information sets, this research attempts to methodically optimize water footprint efficiency within a complex industrial production system, whereas statistical and economic techniques concentrate on large-sample parametric testing, regression analysis, or time-series data to determine probabilistic relationships and historical trends.

For these research goals, the combined QFD-Pareto MCDM approach is especially appropriate for several significant underlying reasons.

(i) Connecting Qualitative and Technical Criteria: QFD is an organized method for making decisions that converts qualitative, multifaceted requirements, such as consumer and environmental specifications, into quantifiable engineering dimensions or technical features.

(ii) Handling Complex System Connections: Instead of depending on restrictive econometric assumptions, such as linearity or normality, the House of Quality (HoQ) matrix enables evaluation of interrelationships, trade-offs, and the corresponding relevance of different criteria.

(iii) Objective Prioritization of Major Bottlenecks: The structure employs a mathematical method to separate the few crucial technical elements, those having the most influence, from the less crucial ones by integrating Pareto analysis with the HoQ results. This prioritization guarantees that engineering endeavors and funds are focused on resolving the technological barriers that may most successfully lower industrial water use.

RESULTS

Within the scope of the study, the Quality Function Deployment (QFD) table was developed based on evaluations of feedback from a structured questionnaire, semi-structured face-to-face interviews, activity reports from companies operating in the sector, a review of the literature, and discussions with experts and employees working in this sector (see Table 3; ABC Inc (2024), expert interviews).

Customer requirements (CR) were identified based on the objective of evaluating water footprint performance and improving sustainable water management throughout the paper and cardboard manufacturing process. These requirements reflect the environmental, operational, and customer-oriented expectations associated with efficient water use and sustainable production. The principal customer requirements include reducing water consumption throughout production, minimizing water losses, improving process efficiency, promoting environmentally responsible manufacturing practices, producing energy- and water-efficient products, complying with environmental regulations, and meeting customer expectations

regarding sustainable production. Collectively, these specifications serve as the primary drivers for improving the manufacturing system's resource efficiency and ecological performance.

In addition to expert assessments from managers, process engineers, and production workers at ABC Company, the technical characteristics were identified by examining responses to a standardized questionnaire. These characteristics reflect the operational and engineering approaches that may be used to improve water footprint efficiency while satisfying stakeholder and consumer requirements. Following their identification, the relationships between customer requirements and technical characteristics were evaluated using the QFD methodology through the House of Quality (HoQ) matrix. Subsequently, Absolute Importance Weights (AIWs) were calculated, and Pareto analysis was performed to identify and prioritize the technical characteristics with the greatest potential to improve water-use efficiency and environmental sustainability. The resulting relationship matrix is presented in Table 3, and the priority rankings of the technical characteristics are presented in Table 5.

The QFD connection matrix was developed through an organized expert consensus process that included 40 domain experts, including managers, process engineers, and production personnel. Using the conventional QFD relationship scale of 0, 1, 3, and 9, these experts worked together to evaluate the links between technical attributes and customer requirements. They discussed preliminary evaluations and reached a consensus score for every cell in the matrix through moderated panel meetings. Conventional inter-rater reliability statistics, such as Cohen's kappa, cannot be used because the assessment method produced a single, collectively agreed-upon QFD matrix instead of separate evaluations from different experts. The use of traditional reliability statistics was evaluated but found unsuitable. Cohen's kappa was not calculated because the assessment produced a single, consensual QFD matrix lacking independent ratings from separate experts. Since Cohen's kappa is designed to gauge agreement between independent raters, using it on a consensus-based matrix would misrepresent the data's structure. Similarly, Cronbach's alpha was considered inappropriate because QFD relationship scores, rather than evaluating several questionnaire components regarding a common concept, show the degree of connection between technical features and consumer needs. Likewise, Cronbach's alpha was deemed inappropriate because the QFD relationship scores do not constitute multiple questionnaire items measuring a shared underlying construct. A systematic consensus approach was employed to guarantee reliability in the QFD evaluation, whereby discrepancies in expert opinions were deliberated and settled prior to determining the relationship scores. These scores indicate the strength of specific relationships between customer requirements and technical characteristics.

The HoQ relationship matrix was used within the QFD framework to evaluate the connections between technical characteristics and customer requirements. Importance weights (IW) were used to rank customer requirements from 1 (least important) to 5 (most essential). Meanwhile, the traditional QFD scale, 0 for no relationship, 1 for weak, 3 for moderate, and 9 for strong, was used to gauge how strongly customer needs and technical attributes were related. According to Cohen (1995) and Morris and Morris (1999), the "What" in this situation is defined by customer requirements, while the "How" is defined by technical characteristics. A detailed perspective of the HoQ relationship matrix is shown in Table 3, which shows the relationship scores between eighteen technical characteristics (k1–k18) and five customer requirements (CR1–CR5).

Table 3: Quality function deployment (QFD) framework in the paper and paperboard industry: The case of ABC company

Customer Requirements (Importance) ("What")	Technical characteristics (How)* /Degree of importance of customer requirements**	Water footprint technical characteristics (How)*																		General Total
		k1	k2	k3	k4	k5	k6	k7	k8	k9	k10	k11	k12	k13	k14	k15	k16	k17	k18	
Compliance with production, environmental responsibility and management, and consumer expectations (CR1)	5	9	3	9	9	9	9	9	9	9	9	9	9	9	3	9	9	9	9	
Eliminating water losses and achieving water savings during water use (CR2)	5	9	9	0	0	9	9	9	3	3	3	9	9	9	1	3	9	9	9	
Production of energy- and water-efficient products (CR3)	4	9	3	9	3	9	9	9	9	9	3	9	9	9	0	9	3	9	9	
Preference for environmentally friendly production processes (CR4)	4	3	3	3	3	9	3	9	3	9	3	3	9	9	0	3	9	9	9	
Reducing excessive consumption (CR5)	5	9	9	3	9	9	9	9	9	9	3	3	1	9	3	9	3	9	9	
Absolute Importance Weight (AIW)		183	129	108	114	207	183	207	153	177	99	153	167	207	35	153	153	207	207	2842
Relative Importance Weight (%)		6.44	4.54	3.8	4.01	7.28	6.44	7.28	5.38	6.23	3.48	5.38	5.88	7.28	1.23	5.38	5.38	7.28	7.28	100
Rank-Priority		6	14	16	15	1	6	1	10	8	17	10	9	1	18	10	10	1	1	18

Note: Degree of Importance of Customer Requirements **: 1–5 (1 = Not Important; 2 = Slightly Important; 3 = Moderately Important; 4 = Important; 5 = Very Important). Technical Characteristics relationship scale *: 0 = No Relationship; 1 = Weak Relationship; 3 = Moderate Relationship; 9 = Strong Relationship.

Source: Adapted from Yilmaz (2009).

The Absolute Importance Weight (AIW) for each technical characteristic was calculated by combining the customer importance weights with the corresponding relationship scores. The AIW values were subsequently used to rank the technical characteristics according to their contribution to improving water-use efficiency and reducing the water footprint. The calculation procedure is presented in Equation 3 and 4 (Mukherjee, 2014; Talebi, 2014; Yilmaz, 2009), which were applied consistently throughout the analysis.

$$\text{Absolute Importance Weight (AIW)} = \sum \text{Degrees of Customer Requirements (IW)}_i \times \text{Technical Characteristics}_{ij} \quad (3)$$

AIW: Row absolute weight vector for the degree of technical complexity of specific criteria-absolute importance weight.

Wherever;

IW: Importance weight of customer's requirement with respect to technical characteristics $_{ij}$.

Technical characteristics: Improvement Ratio - weight appointed to the relationship matrix, weight dedicated to the relationship matrix by row i and column j ($i = 1, 2, \dots, m$ $m = 18$; $j = 1, 2, \dots, n$ $n = 5$).

m = Number of technical requirements.

n = Number of customer requirements.

$$\text{Relative Importance Weights (\%)} = \frac{\text{AIW}_j}{\text{AIW}_i} \quad (4)$$

Relative Importance Weight in the first column = (The first total Absolute Importance Weight in the first column / General Total of Absolute Importance Weight) $\times 100$.

Within the scope of the study, the technical characteristics determined for companies operating in the paper and cardboard sector, using ABC company as an example (see Table 4), were established to meet customer needs, ensure environmental sustainability, and improve product quality and company performance. The Relative Importance Weight percentages presented in Table 5 were calculated from the QFD relationship matrix shown in Table 3. The technical characteristics were ranked according to their Absolute Importance Weight (AIW) values to identify priority areas for improving water footprint performance in the paper and cardboard manufacturing process.

The relevance of each technological characteristic in satisfying consumer requirements for reducing the water footprint and encouraging environmentally friendly production in the paper and cardboard manufacturing industry was evaluated using the Relative Importance Weight (RIW) percentages displayed in Table 3 and 5. These technical characteristics were ranked from highest to lowest according to their RIW values using the Quality Function Deployment (QFD) approach. This prioritization identified the most significant technical characteristics affecting ABC Company's overall process performance, production efficiency, and environmental sustainability. Recommendations for improving water resource management and reducing the overall water footprint were developed based on the top-ranked attributes, which were identified as critical areas for improvement.

The ranking findings indicated that five technical features (k_5 , k_7 , k_{13} , k_{17} , and k_{18}) topped the list with the greatest Relative Importance Weight (RIW), each contributing 7.28% to the total value. These were followed by k_1 and k_6 , both with RIWs of 6.44%, while k_9 ranked third with an RIW of 6.23%. The other technical features were arranged in descending order based on their RIW values, as shown in Table 5. This ranking implies that improvement efforts in the paper and cardboard manufacturing business should focus primarily on the highest-ranked technical qualities to improve water footprint performance, increase resource efficiency, and promote sustainable production.

Table 4: Technical characteristics identified for the paper manufacturing industry with a focus on environmental sustainability and customer requirement fulfillment (Oriented water footprint)

Code	Criteria (Characteristics)	Code	Criteria (Characteristics)
k1	Collaborating with decision-makers, companies, non-governmental organizations, and researchers to promote the sustainable management of water resources	k10	Supporting international agreements that ensure secure access to water resources, which are indispensable for both society and the environment
k2	Establishing a periodic water consumption monitoring plan for production/service operations (focused on water input)	k11	Assessing potential risks associated with future water use
k3	Conducting regular machine inspections and maintenance	k12	Identifying methods to mitigate the environmental impacts of water use
k4	Improving the monitoring and tracking of water use throughout production processes	k13	Identifying water-related occupational risks in production and service operations
k5	Ensuring sustainable water use and efficient water resource management	k14	Machine maintenance system
k6	Reducing water withdrawal during production	k15	Integrating water-related strategies into the company's overall strategic management framework
k7	Reducing water intensity in production processes	k16	Establishing performance standards for direct operations and supply chain activities
k8	Promoting sustainable agriculture	k17	ISO 14046 Water Footprint Assessment
k9	Strengthening relationships with local communities and customers	k18	Achieving cost savings by reducing water consumption throughout the production process

Table 5: Water footprint technical characteristics prioritization using Pareto analysis, absolute importance weights, and relative importance weights (%)

Priority (Rank)	Relative importance weights (%)	Technical characteristics –requirements
1 (Rank 1)	7.28	k5; k7; k13; k17; k18
2 (Rank 6)	6.44	k1; k6
3 (Rank 8)	6.23	k9
4 (Rank 9)	5.88	k12
5 (Rank 10)	5.38	k8; k11; k15; k16
6 (Rank 14)	4.54	k2
7 (Rank 15)	4.01	k4
8 (Rank 16)	3.80	k3
9 (Rank 17)	3.48	k10
10 (Rank 18)	1.23	k14

A Pareto analysis was used to prioritize the technical characteristics revealed through the QFD study according to their relative relevance. This technique identifies the most important aspects by ranking technical qualities based on their contribution and calculating their cumulative percentages. As highlighted by Egermayer (1988) and the Australian National Audit Office (2010), such prioritization helps target improvement efforts toward those features with the greatest potential for lowering water footprint and improving sustainable production performance.

To improve the prioritization of technical attributes based on their cumulative influence, Pareto analysis was integrated with the QFD findings. While Pareto analysis identifies the traits that together account for the majority of overall technical relevance, QFD assesses the relative value of these traits by analyzing their connections to customer needs. Combining QFD with Pareto analysis creates a methodical basis for concentrating improvement efforts on the most significant technical features.

The results in Table 6 illustrate that technical features vary in relevance within the QFD framework. Five technical aspects, k5 (Ensuring sustainable water usage), k7 (Reducing water intensity), k13 (Identifying water-related occupational risks), k17 (ISO 14046 evaluation), and k18 (Achieving cost savings), have the highest AIW values (207), accounting for 7.28% of the total technical importance. As a result, these areas are prioritized for improvement.

The next most important qualities are k1 and k6, both with AIW values of 183 and each bearing a relative relevance of 6.44%. They are followed by k9, with an AIW of 177 and an importance of 6.23%, and k12, with an AIW of 167 and an importance of 5.88%. These attributes represent additional high-priority areas within the QFD framework. In contrast, k14, which refers to the Machine Maintenance System, has the lowest AIW value, 35, accounting for just 1.23% of the overall technical importance and categorizing it as a secondary priority.

Table 6: Pareto analysis of technical characteristics based on absolute importance weights

Technical characteristic	Absolute importance weight (AIW)	Relative importance (%)	Cumulative percentage (%)	Priority group
k5	207	7.28	7.28	High Priority
k7	207	7.28	14.56	High Priority
k13	207	7.28	21.85	High Priority
k17	207	7.28	29.13	High Priority
k18	207	7.28	36.41	High Priority
k1	183	6.44	42.85	High Priority
k6	183	6.44	49.29	High Priority
k9	177	6.23	55.52	High Priority
k12	167	5.88	61.40	High Priority
k8	153	5.38	66.78	High Priority
k11	153	5.38	72.16	High Priority
k15	153	5.38	77.55	High Priority
k16	153	5.38	82.93	Secondary Priority
k2	129	4.54	87.47	Secondary Priority
k4	114	4.01	91.48	Secondary Priority
k3	108	3.80	95.28	Secondary Priority
k10	99	3.48	98.76	Secondary Priority
k14	35	1.23	100.00	Secondary Priority

The first 12 technical attributes, k5, k7, k13, k17, k18, k1, k6, k9, k12, k8, k11, and k15, represent 77.55% of the total technical significance, according to the cumulative distribution. This shows that, according to QFD, there is a considerable concentration of technical priorities within a small number of features. ABC Company may successfully improve the areas that contribute most to QFD priorities by concentrating managerial responsibilities and improvement resources on these high-priority traits.

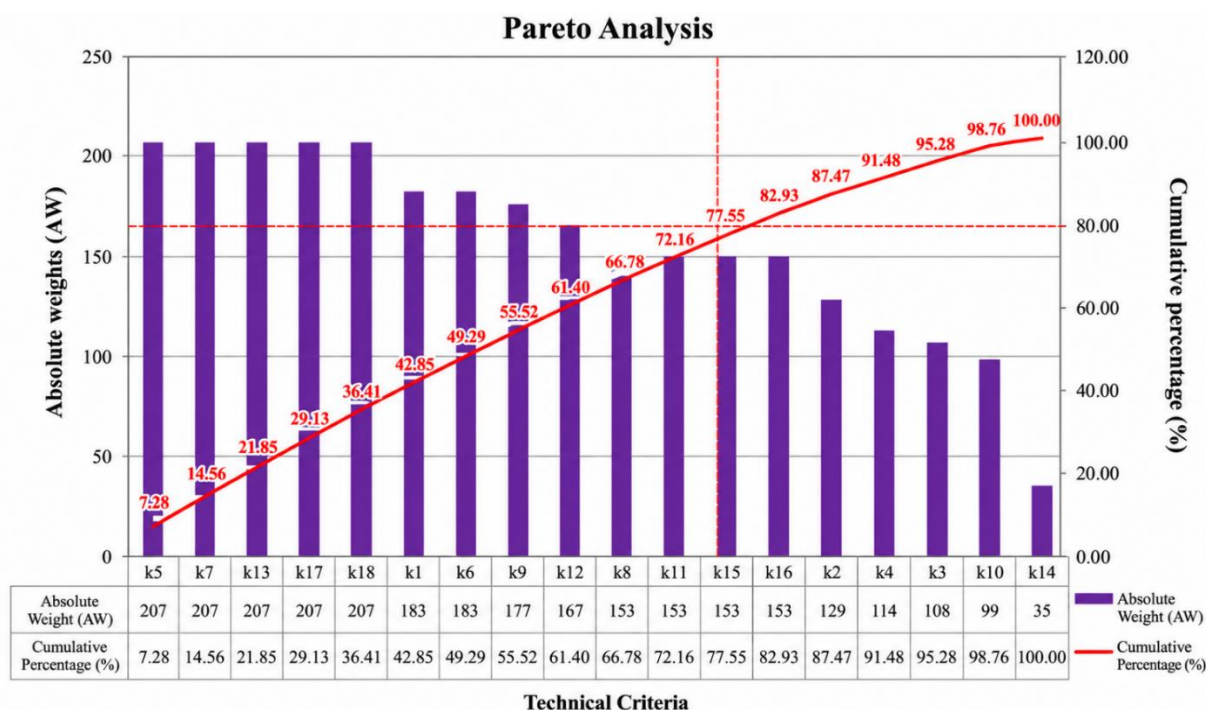


Figure 5: Pareto Analysis of Water Footprint Technical Criteria for ABC Company

The cumulative distribution of technical attributes according to their Absolute Importance Weights is shown in Figure 5. With the cumulative contribution peaking at 77.55% after the first 12 qualities, the Pareto curve confirms that technical relevance is heavily concentrated among the top-ranked features. As a result, this figure provides a visual basis for setting priorities for improvement initiatives and allocating resources to the technical attributes that have the most influence on the QFD goals.

CONCLUSION

The study presents a complete decision-support system that incorporates Water Footprint Assessment (WFA), Quality Function Deployment (QFD), the House of Quality (HoQ), and Pareto analysis. This method is intended to evaluate and prioritize alternatives for reducing the water footprint in gray cardboard manufacturing. The findings show that a tiny fraction of technical parameters has a substantial environmental influence due to water use. According to the Pareto analysis, the initial 12 technical features accounted for 77.55% of the total effect, implying that focusing on improvements in these areas can significantly increase water-use efficiency and encourage more sustainable industrial practices.

The important technical qualities were identified through Pareto analysis. In this investigation, high-priority characteristics represent a total of 77.55%. According to Table 6 and Figure 5, the top 12 technical characteristics comprising this proportion are considered critical for the industry.

The results demonstrate that a useful way to identify critical improvement objectives in manufacturing processes is to combine water footprint evaluation with quality management methods. The proposed methodology helps decision-makers transform analytical findings into practical actions that improve resource efficiency, environmental performance, and cost savings, rather than focusing only on quantifying water usage. Understanding related risks and effects requires evaluating the water footprint, which is the amount of water used during manufacturing. Regardless of whether watersheds are currently experiencing water scarcity, it is crucial to assess these footprints in order to reduce their impact. This investigation contributes to the current literature by demonstrating the efficacy of combining Water Footprint Assessment (WFA), Quality Function

Deployment (QFD), and Pareto analysis into a single decision-support framework designed for industrial water management. The technique described provides a systematic way to prioritize technical improvement possibilities, providing industrial organizations with a practical instrument for fostering sustainable production and continuous process improvement. From a management perspective, the findings suggest that industrial enterprises should routinely monitor water use in relation to output. This entails identifying operations with the highest water consumption and directing upgrade efforts toward these priorities. Implementing globally accepted requirements, such as ISO 14046-based water footprint evaluations, might improve environmental management systems and promote more effective water resource consumption throughout the production cycle. Global requirements must be taken into account and supported to ensure that water use benefits society, the environment, and the industrial sector. The ISO 14046 international standard should be followed by enterprises, operations, and products in the sector. This standard emphasizes life cycle assessment techniques while outlining the components and procedures for assessing and disclosing water footprints. Manufacturers may monitor and assess water usage throughout their operations by using the ISO 14046 standard for water footprint assessment. This helps reduce the high expenses associated with wasteful and unproductive water consumption.

The results of the investigation have important ramifications for sustainable accounting. The approach suggested here can help create measurable environmental performance indicators by identifying manufacturing activities that use the most water. This development might improve the overall quality and openness of sustainability reporting. Additionally, it makes it easier to track environmental expenses and gives management more reliable information for allocating resources and making strategic choices. Collecting water footprint data through sustainability accounting systems is expected to increase corporate environmental responsibility and promote more effective ecological performance monitoring. Enhancing sustainability requires the development and use of techniques to reduce the environmental effects of water use in manufacturing and related operations. Even if the suggested approach worked well in the case-study firm, further research is needed to increase its applicability. The approach should be tested in different paper and cardboard production facilities, as well as in other water-intensive sectors, in future research. A more comprehensive assessment of environmental sustainability would be possible by including components such as the greywater footprint, life-cycle evaluation, economic performance measurements, and more varied multicriteria decision-making techniques. Additionally, longer-term longitudinal studies would enable researchers to evaluate the lasting effects of water-management programs on environmental and operational effectiveness. By methodically ranking the potential for technical improvement, the suggested framework provides academics and practitioners with a structured method for improving industrial water management. This study contributes practically to sustainable manufacturing and supports more informed environmental sustainability decisions by combining water footprint evaluation with quality management methodologies.

Limitations

This investigation has a number of limitations that should be considered when evaluating the results, as with any other empirical study. The breadth of the case study is the main limitation. The proposed framework was implemented at a single gray cardboard manufacturing company located in Türkiye's Marmara Region. Although this enabled a thorough evaluation in a real-world production setting, different businesses may produce different outcomes because of differences in production technology, operational procedures, and resource management. Therefore, without further validation in other manufacturing environments, these results should not be generalized to the entire paper and cardboard sector. The water footprint evaluation itself has another drawback. The greywater footprint associated with wastewater contamination was not included in the investigation, which focused on water usage during manufacturing. As a result, the study primarily addresses the quantitative component of water usage without thoroughly evaluating the effects of pollution discharge on the ecosystem. Incorporating greywater footprint evaluation would provide a more thorough assessment of environmental sustainability. Expert perspectives are crucial to the Quality Function Deployment (QFD) analysis. Experts helped identify the relationships between technical features and consumer demands by relying on their manufacturing expertise. Despite their firsthand experience with

industrial processes, these experts' evaluations are inherently subjective. Different industrial settings or expert perspectives might result in different connection weightings, which could affect the prioritization results.

Additionally, the study uses data from interviews with professionals and structured surveys. Individual perspectives, personal experiences, or biases regarding responses might nevertheless affect the data obtained through surveys, even with efforts to obtain trustworthy answers from informed people. It is difficult to completely exclude these factors in research requiring subjective opinions. Finally, the study documents the circumstances observed throughout a specific data-collection period. The results represent the state of affairs at the time of the research because production methods, water usage, and operational priorities may change. Future research involving more businesses and longer-term measurements would support the suggested framework's resilience and provide further evidence of its wider applicability.

Managerial and Policy Implications

By meeting customer demands, conserving water, saving expenses, and encouraging eco-friendly behaviors through sustainability programs centered on environmental challenges, the company enhanced its products and services. It provided advice on improving these important areas.

Global standards must be taken into account and upheld in order to guarantee that water use benefits society and the environment while remaining aligned with the industrial sector. The international standard ISO 14046, which describes standards for assessing and disclosing water footprints with a focus on life cycle assessment techniques, should be adhered to by businesses, processes, and products in the sector.

Improving sustainability involves minimizing the environmental impact of water use during production and related activities. Corrective and preventive measures must be balanced for regulations to be effectively enforced. Employing environmentally focused practices could assist industrial organizations in achieving their strategic objectives and improving their reputation. Customers should also support companies in obtaining ISO 14046 and ISO 14000 environmental management certifications, since these certifications are crucial for attaining customer satisfaction, cost-effectiveness, performance enhancements, and improved standing. Emphasizing state-approved, environmentally focused sustainability evaluations based on competitive evaluation ought to be crucial for companies in the associated industry. Businesses in the sector should prioritize state-approved, ecologically focused sustainability evaluations through competitive evaluation. Incorporating water footprint information into sustainability assessments may improve environmental performance transparency and provide stakeholders with a better understanding of water-related sustainability initiatives. By creating a straightforward structure for determining which water-related enhancements should be prioritized and receive additional funding, focusing on technical features aids managers in making decisions.

FUNDING: This study received no specific financial support.

INSTITUTIONAL REVIEW BOARD STATEMENT: This study was approved by the Social and Humanities Scientific Research and Publication Ethics Committee of Istanbul Medeniyet University, Türkiye [Decision No. 2026/7]. Informed verbal consent was obtained from all participants, and all data were anonymized to protect participants' confidentiality.

TRANSPARENCY: The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

COMPETING INTERESTS: The author declares that there are no conflicts of interest regarding the publication of this paper.

DISCLOSURE OF AI USE: During the preparation of this work, the author used OpenAI's ChatGPT to review the wording of the Introduction and Discussion sections in terms of academic language, grammar, and clarity, and Grammarly to perform grammar, punctuation, and stylistic checks. All outputs generated by these AI-assisted tools were thoroughly reviewed, edited, and verified by the author. The author assume full responsibility for the final content of the publication.

REFERENCES

- ABC Inc. (2024). *Company technical specifications*. Internal Technical Report, India: ABC Inc.
- Akbostancı, E., Tunç, G. İ., & Türüt-Aşık, S. (2023). Virtual water flows of Turkey's agricultural products: A gravity approach. *Journal of Cleaner Production*, 420, 138453. <https://doi.org/10.1016/j.jclepro.2023.138453>
- Akın, M., & Akin, G. (2007). The importance of water, water potential in Turkey, water basins and water pollution. *Ankara University Journal of Language and History-Geography*, 47(2), 105–118.
- Ali, M., & Sreekrishnan, T. (2001). Aquatic toxicity from pulp and paper mill effluents: A review. *Advances in Environmental Research*, 5(2), 175–196. [https://doi.org/10.1016/S1093-0191\(00\)00055-1](https://doi.org/10.1016/S1093-0191(00)00055-1)
- Ansorge, L., Stejskalová, L., Vološinová, D., & Dlabal, J. (2022). Limitation of water footprint sustainability assessment: A review. *European Journal of Sustainable Development*, 11(2), 1–14. <https://doi.org/10.14207/ejsd.2022.v11n2p1>
- Australian National Audit Office. (2010). *Better practice guide on the strategic and operational management of assets by public sector entities: Delivering agreed outcomes through an efficient and optimal asset base*. Canberra, Australia: Australian National Audit Office.
- Britt, K. W. (2020). *Papermaking*. Encyclopedia Britannica. Retrieved from <https://www.britannica.com/technology/papermaking>,
- Central Anatolian Exporters' Associations. (2012). *Paper and cardboard sector report*. Ankara, Turkey: Central Anatolian Exporters' Associations.
- Chapagain, A. K., & Hoekstra, A. Y. (2004). *Water footprints of nations*. Value of Water Research Report Series No. 16. Delft, the Netherlands: UNESCO-IHE Institute for Water Education.
- Çiftçi, B. M., Kurt, B., Turak, A., Türker, A., Çalışkan, M. A., Balkız, Ö., . . . Zeydanlı, U. (2013). *The state of water in Türkiye and new approaches to water management: An environmental perspective*. Business World and Sustainable Development Association–Turkey, Food and Agriculture Organization of the United Nations, Nature Conservation Center, and Foundation for Life.
- Cohen, L. (1995). *Quality function deployment: How to make QFD work for you*. Reading, MA: Addison-Wesley Publishing Company.
- Compton, W. D. (1999). *Engineering and technology management* (E. Okudan Gül, Trans.) (1st ed.). İstanbul, Türkiye: Beta Publications.
- Deepa, R., Anandhi, A., & Alhashim, R. (2021). Volumetric and impact-oriented water footprint of agricultural crops: A review. *Ecological Indicators*, 130, 108093. <https://doi.org/10.1016/j.ecolind.2021.108093>
- Demir, M. S., & Muratoglu, A. (2025). Water footprint concept, approaches, and applications: A comprehensive review for the agricultural sector. *Water and Environment Journal*, 39(2), 128–142. <https://doi.org/10.1111/wej.12968>
- Denissen, J. M. C., Teuling, A. J., Pitman, A. J., Koirala, S., Migliavacca, M., Li, W., . . . Orth, R. (2022). Widespread shift from ecosystem energy to water limitation with climate change. *Nature Climate Change*, 12(7), 677–684. <https://doi.org/10.1038/s41558-022-01403-8>
- Deros, B. M., Rahman, N., Rahman, M. N. A., Ismail, A. R., & Said, A. H. (2009). Application of quality function deployment to study critical service quality characteristics and performance measures. *European Journal of Scientific Research*, 33(3), 398–410.
- Egermayer, F. (1988). *Pareto analysis in incoming inspection at Verdor*. Netherlands: European Organization for Quality Control.
- Eroğlu, H., & Usta, M. (2004). *Paper and cardboard production technology* (Vol. 1). Trabzon, Türkiye: Pulp and Paper Industry Foundation.
- EU Project Management. (2015). *What is a water footprint and its application areas*. Retrieved from <https://www.abprojeyonetimi.com/su-ayak-izi-nedir-ve-uygulama-alanlari/>
- European Commission. (2001). *Integrated pollution prevention and control (IPPC): Reference document on best available techniques in the pulp and paper industry*. Belgium: European Commission.
- Fang, K., Heijungs, R., & de Snoo, G. R. (2021). Theoretical exploration of consumption-based water footprint allocation in global trade systems. *Journal of Cleaner Production*, 280, 124414.
- Fereres, E., Villalobos, F. J., Orgaz, F., Mínguez, M. I., van Halsema, G., & Perry, C. J. (2017). Commentary: On the water footprint as an indicator of water use in food production. *Irrigation Science*, 35(2), 83–85. <https://doi.org/10.1007/s00271-017-0535-y>
- Gonzalez, M. E., Quesada, G., Mueller, R., & Mora-Monge, C. A. (2004). QFD strategy house: An innovative tool for linking marketing and manufacturing strategies. *Marketing Intelligence & Planning*, 22(3), 335–348. <https://doi.org/10.1108/02634500410536911>
- Green Pen. (2014). *We are consuming water*. Retrieved from <https://www.yesilaski.com/suyu-tuketiyoruz.html>
- Gullichsen, J., & Fogelholm, C.-J. (2000). *Papermaking science and technology: Book 6A. Chemical pulping*. Helsinki, Finland: Fapet Oy.
- Hauser, J. R., & Clausing, D. (1988). The house of quality. *Harvard Business Review*, 66(3), 63–73.
- Hoekstra, A. Y. (2013). *The water footprint of modern consumer society* (1st ed.). London, England: Routledge.
- Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., & Mekonnen, M. M. (2011). *The water footprint assessment manual: Setting the global standard*. London, England: Earthscan.
- Hoekstra, A. Y., & Wiedmann, T. O. (2014). Humanity's unsustainable environmental footprint. *Science*, 344(6188), 1114–1117. <https://doi.org/10.1126/science.1248365>
- Hogeboom, R. J. (2020). The water footprint concept and water's grand environmental challenges. *One Earth*, 2(3), 218–222. <https://doi.org/10.1016/j.oneear.2020.02.010>
- Holik, H. (2013). *Handbook of paper and board* (2nd ed. Vol. 1–2). Weinheim, Germany: Wiley-VCH.
- Intergovernmental Panel on Climate Change. (2023). *Climate change 2023: Synthesis report*. Geneva, Switzerland: Intergovernmental Panel on Climate Change.
- Jones, E. R., Bierkens, M. F. P., & van Vliet, M. T. H. (2024). Current and future global water scarcity intensifies when accounting for surface water quality. *Nature Climate Change*, 14(6), 629–635. <https://doi.org/10.1038/s41558-024-02007-0>

- Karayılmazlar, S., & Aytekin, A. (1999). Investigation of water preparation and wastewater treatment in paper mills and their relationship with the environment (SEKA Afyon-Çay Establishment example). Paper presented at the 1st International Symposium on Protection of Natural Environment and Ehlami Karaçam, 23–25 September, Kütahya, Türkiye.
- Kayaer, M., & Çiftçi, S. (2018). An assessment of the strategic, ethical, and legal dimensions of Turkey's transboundary waters within the framework of the "water problem" and Turkey's freshwater potential. *Pesa International Journal of Social Research*, 4(3), 386–404.
- Lee, Y.-T., Wu, W.-W., & Tzeng, G.-H. (2008). An effective decision-making method using a combined QFD and ANP approach. *WSEAS Transactions on Business and Economics*, 5(12), 541–551.
- Mekonnen, M. M., & Hoekstra, A. Y. (2011). *National water footprint accounts: The green, blue and grey water footprint of production and consumption*. Value of Water Research Report Series No. 50. Delft, the Netherlands: UNESCO-IHE Institute for Water Education.
- Mishra, B. K., Kumar, P., Saraswat, C., Chakraborty, S., & Gautam, A. (2021). Water security in a changing environment: Concept, challenges and solutions. *Water*, 13(4), 490. <https://doi.org/10.3390/w13040490>
- Modi, P., Hanasaki, N., Yamazaki, D., Boulange, J. E. S., & Oki, T. (2022). Sensitivity of subregional distribution of socioeconomic conditions to the global assessment of water scarcity. *Communications Earth & Environment*, 3(1), 144. <https://doi.org/10.1038/s43247-022-00475-w>
- Mohammed, I. N., Bolten, J. D., Souter, N. J., Shaad, K., & Vollmer, D. (2022). Diagnosing challenges and setting priorities for sustainable water resource management under climate change. *Scientific Reports*, 12(1), 796. <https://doi.org/10.1038/s41598-022-04766-2>
- Morris, L. J., & Morris, J. S. (1999). Introducing quality function deployment in the marketing classroom. *Journal of Marketing Education*, 21(2), 131–137. <https://doi.org/10.1177/0273475399212006>
- Mukherjee, I. (2014). Module III: Product quality improvement (Lecture 1: How QFD helps in product quality improvement?). Indian Institute of Technology Bombay, NPTEL. Retrieved from <https://archive.nptel.ac.in/content/storage2/courses/110101010/modules/module3/lec1/1.2.html>
- Muratoglu, A. (2020). Assessment of wheat's water footprint and virtual water trade: A case study for Turkey. *Ecological Processes*, 9(1), 13. <https://doi.org/10.1186/s13717-020-0217-1>
- Nydrioti, I., & Grigoropoulou, H. (2023). Using the water footprint concept for water use efficiency labelling of consumer products: The Greek experience. *Environmental Science and Pollution Research*, 30(8), 19918–19930. <https://doi.org/10.1007/s11356-022-23573-w>
- Olivos, G. S. M., Ramos, J. A. M., Chavez, L. P. V., Salvador, R. Y. V., Sanchez, A. J. N., & Bonifacio, A. E. B. (2024). Water footprint as a sustainability indicator: A systematic literature review. *Revista de Gestão Social e Ambiental*, 18(5), e06325. <https://doi.org/10.24857/rgsa.v18n5-116>
- Özçelep, Z. B. (2009). Advanced treatment of paper industry wastewater using membrane processes. Unpublished Doctoral Dissertation. Istanbul University, Istanbul, Türkiye.
- Özsoy, Ş. (2018). Your water footprint on your sustainability journey. *Water and Environmental Technologies*(118), 42–43.
- Pegram, G., Conyngham, S., Aksoy, A., Divrak, B. B., & Öztok, D. (2014). Türkiye's water footprint report: The relationship between water, production, and international trade. Istanbul, Turkey: WWF-Türkiye. Retrieved from https://wwftr.awsassets.panda.org/downloads/su_ayak_izi_raporweb.pdf
- Peng, H. (2011). PIV measurements of flow through forming fabrics. Master's Thesis, University of British Columbia, Vancouver, Canada.
- Pilevneli, T., Capar, G., & Sánchez-Cerdà, C. (2023). Investigation of climate change impacts on agricultural production in Turkey using volumetric water footprint approach. *Sustainable Production and Consumption*, 35, 605–623. <https://doi.org/10.1016/j.spc.2022.12.013>
- Pokhrel, D., & Viraraghavan, T. (2004). Treatment of pulp and paper mill wastewater—a review. *Science of the Total Environment*, 333(1–3), 37–58. <https://doi.org/10.1016/j.scitotenv.2004.05.017>
- Porkka, M., Virkki, V., Wang-Erlandsson, L., Gerten, D., Gleeson, T., Mohan, C., . . . Kumm, M. (2024). Notable shifts beyond pre-industrial streamflow and soil moisture conditions transgress the planetary boundary for freshwater change. *Nature Water*, 2(3), 262–273. <https://doi.org/10.1038/s44221-024-00208-7>
- Prasad, K. G. D., Subbaiah, K. V., Rao, K. N., & Sastry, C. V. R. S. (2010). Prioritization of customer needs in house of quality using conjoint analysis. *International Journal for Quality Research*, 4(2), 145–154.
- Republic of Turkey Ministry of Environment and Urbanization. (2017). *Technical assistance project for strengthening the capacity of the Ministry of Environment and Urbanization in the field of EIA: Forest products and pulp and pulp facilities (paper and cardboard) sector* (Contract No. 2007TR16IPO001.3.06/SER/42). Ankara, Turkey: Republic of Turkey Ministry of Environment and Urbanization.
- Sher, S. S. (2006). The application of quality function deployment (QFD) in product development—the case study of Taiwan hypermarket building. *The Journal of American Academy of Business*, 8(2), 292–295.
- Smook, G. A. (2016). *Handbook for pulp and paper technologists* (4th ed.). United States: TAPPI Press.
- Symeonidou, S., & Mente, E. (2024). Water consumption and the water footprint in aquaculture: A review. *Water*, 16(23), 3376. <https://doi.org/10.3390/w16233376>
- Talebi, H. (2014). A fuzzy AHP weighted QFD for service quality improvement in a fitness center. Unpublished Master's Thesis. Bahçeşehir University, Istanbul, Türkiye.
- TEMA Foundation. (2022). Water footprint. Retrieved from <https://sutema.org/su-ayak-izi>

- Thompson, G., Swain, J., Kay, M., & Forster, C. F. (2001). The treatment of pulp and paper mill effluent: A review. *Bioresource Technology*, 77(3), 275-286. [https://doi.org/10.1016/S0960-8524\(00\)00060-2](https://doi.org/10.1016/S0960-8524(00)00060-2)
- Trancoso, R., Syktus, J., Allan, R. P., Croke, J., Hoegh-Guldberg, O., & Chadwick, R. (2024). Significantly wetter or drier future conditions for one to two thirds of the world's population. *Nature Communications*, 15(1), 483. <https://doi.org/10.1038/s41467-023-44513-3>
- Tur, F., & Alkan, B. (2023). *Virtual water trade: Rethinking the trade with risks of climate change*. Paper presented at the 30th TEA Conference on Economics, Kemer, Antalya, Türkiye.
- United Nations Educational Scientific and Cultural Organization. (2024). *The United Nations world water development report 2024: Water for prosperity and peace*. Paris, France: UNESCO Publishing.
- United Nations Environment Programme. (2022). *Freshwater strategic priorities 2022–2025*. Nairobi, Kenya: United Nations Environment Programme.
- van Vliet, M. T. H., Thorslund, J., Stokal, M., Hofstra, N., Flörke, M., Ehalt Macedo, H., . . . Mosley, L. M. (2023). Global river water quality under climate change and hydroclimatic extremes. *Nature Reviews Earth & Environment*, 4(10), 687-702. <https://doi.org/10.1038/s43017-023-00472-3>
- Vanham, D. (2018). The water footprint of the EU: Quantification, sustainability and relevance. *Water International*, 43(6), 731-745. <https://doi.org/10.1080/02508060.2018.1516097>
- Vörösmarty, C. J., Green, P., Salisbury, J., & Lammers, R. B. (2000). Global water resources: Vulnerability from climate change and population growth. *Science*, 289(5477), 284-288. <https://doi.org/10.1126/science.289.5477.284>
- Wackernagel, M., & Rees, W. E. (1996). *Our ecological footprint: Reducing human impact on the earth*. Gabriola Island, BC, Canada: New Society Publishers.
- Wang, D., Hubacek, K., Shan, Y., Gerbens-Leenes, W., & Liu, J. (2021). A review of water stress and water footprint accounting. *Water*, 13(2), 201. <https://doi.org/10.3390/w13020201>
- Water Footprint Network. (2016). *Water footprint network*. Climate-ADAPT Retrieved from <https://climate-adapt.eea.europa.eu/en/metadata/organisations/water-footprint-network>
- Wayland, M., Trudeau, S., Marchant, T., Parker, D., & Hobson, K. A. (1998). The effect of pulp and paper mill effluent on an insectivorous bird, the tree swallow. *Ecotoxicology*, 7(4), 237-251. <https://doi.org/10.1023/A:1008942929560>
- Yakut, A. (2012). Examining the production of new paper from recyclable used paper. *Tesisat Mühendisliği*, 127, 68-75.
- Yerli, C., & Şahin, U. (2022). An assessment of the urban water footprint and blue water scarcity: A case study for Van, Türkiye. *Brazilian Journal of Biology*, 82, e249745. <https://doi.org/10.1590/1519-6984.249745>
- Yılmaz, H. (2009). Optimization of the product design through quality function deployment (QFD) and analytical hierarchy process (AHP): A case study in a ceramic washbasin. Unpublished Master's Thesis. İzmir Institute of Technology, İzmir, Türkiye.
- Zarate, E. (2010). *WFN water footprint sustainability assessment working group final report: A joint study developed by WFN partners*. Enschede, Netherlands: Water Footprint Network.
- Zhao, X., Chen, B., & Yang, Z. F. (2009). National water footprint in an input–output framework—a case study of China 2002. *Ecological Modelling*, 220(2), 245-253. <https://doi.org/10.1016/j.ecolmodel.2008.09.016>