Implementation of the Cleaner Production Programme

On the Example of the Cemex Poland Group

WOJCIECH LUTEK
MYROSLAV MALOVANY
AGNIESZKA SITKO-LUTEK

ToKnowPress

Implementation of the Cleaner Production Programme

On the Example of the Cemex Poland Group

Wojciech Lutek
Myroslav Malovany
Agnieszka Sitko-Lutek

ToKnowPress
www.toknowpress.net

Implementation of the Cleaner Production Programme on the Example of the Cemex Poland Group
Dr. Wojciech Lutek
Dr. Myroslav Malovany
Dr. Agnieszka Sitko-Lutek

Reviewers
Dr. Sviatoslav Kniaz
Dr. Živilė Stankevičiūtė

Published by ToKnowPress
Bangkok · Celje · Lublin · Malta
2026

ToKnowPress is a Joint Imprint of
Kasetsart University, Bangkok, Thailand
International School for Social and Business Studies, Celje, Slovenia
Maria Curie-Sklodowska University, Lublin, Poland
MED.E.A. – Higher Education Institution for Mediterranean, Europe and Africa, Malta

www.toknowpress.net

https://doi.org/10.53615/978-961-6914-32-1

Distributed free of charge

Kataložni zapis o publikaciji (CIP) pripravili
v Narodni in univerzitetni knjižnici v Ljubljani
COBISS.SI-ID 265251075
ISBN 978-961-6914-32-1

Contents

List of Tables · 7
Introduction · 9
Acknowledgements · 13

1 The Concept of Cleaner Production · 15
Genesis and Definition of the Cleaner Production Programme · 15
Assumptions and Principles of Cleaner Production · 20
Practices of the Cleaner Production Programme · 23
CP Application Options and Implementation Phases · 27

2 Cleaner Production Activities · 45
Eco-Design · 45
Eco-Materials · 49
Eco-Efficiency in the Context of Cleaner Production · 63

3 Ecological, Economic and Social Aspects of CP Implementation on the Example of CEMEX Poland · 71
General Characteristics of the Cement Industry · 71
Brief Description of the Technological Process · 76
History and Development of the CEMEX Company · 79
Overview of the CP Activities · 81

Conclusions · 97
References · 99
Reviews · 143

List of Tables

1.1 Selected Definitions of the Cleaner Production Concept · 18
1.2 Application Practices under the Cleaner Production Concept · 24
2.1 Selected Definitions of the Term Eco-Design · 47
2.2 Eco-Design Strategies and Their General Principles · 49
2.3 Selected Definitions of the Term Green Technology · 58
2.4 Action areas and objectives of green technologies · 59
2.5 Preventive Practices of Cleaner Production
versus Eco-Efficiency Goals · 69

Introduction

The process of greening global industry began in the 1960s. Activities related to environmental protection through the cleanup of end-of-pipe emissions and the reduction of pollutant concentrations date back to the 1970s. In the 1980s, interest in academia and business shifted toward pollution prevention and an increased focus on cleaner technologies. The concept of environmental management, as well as the term *cleaner products*, originated in the 1990s (Glavič, 2021).

The concept of Cleaner Production (CP) was formulated in the early 1990s as a response by academic and business circles to the increasingly destructive environmental impact of the global economy. It is a strategy aimed at reducing negative environmental impacts by minimizing waste and emissions at the source throughout the production process, while simultaneously enabling companies to become more competitive. Cleaner Production is a proactive environmental strategy that goes beyond waste treatment and management and is based on a cradle-to-cradle approach.

According to De Oliveira Neto et al. (2019), the Cleaner Production Programme can be understood as the application of preventive environmental strategies to processes, products, and services, with the aim of jointly respecting energy, water, and raw materials, while eliminating or reducing toxic materials, emissions, and residues in production processes or throughout the life cycle of products and services.

This concept is considered by many in the scientific and business communities to be one of the most effective tools for achieving sustainable development through the continuous application of an integrated preventive strategy in production processes, products, and services aimed at reducing risks to humans and the environment (Gavrilescu, 2004). The implementation of CP practices is strongly driven by improvements in economic, environmental, social, and production performance.

Chinese official factors have played an important role in the development and implementation of Cleaner Production. Since the government of the People's Republic of China set the goal of quadrupling gross domestic product between 2000 and 2020, while improving environmental performance and maintaining social stability, the CP concept has played an increasingly important role in the country's development plans (Hicks & Dietmar, 2007).

In this context, it is significant that China is the world's largest cement producer (Liu et al., 2024), with 1.9 billion metric tonnes produced in 2024 (2.1 billion metric tonnes in 2023 and 2.4 billion metric tonnes in 2021), accounting for more than half of global production (Chen et al., 2025). The increase in cement production in China since 1990 has accounted for as much as 74% of the global increase in this product (Bourke, 2024).

It should be noted that the global cement industry is a significant source of environmental pollution and anthropogenic climate change, emitting a broad spectrum of atmospheric pollutants, including $PM_{2.5}$, PM_{10}, chlorine gas, nitrogen oxides (NO_x), sulphur dioxide (SO_2), ammonia (NH_3), and a wide range of greenhouse gases. Among these emissions, carbon dioxide (CO_2) is the dominant greenhouse gas contributing to global warming (Liao et al., 2022).

According to a forecast by the International Energy Agency (IEA), cement production is on a steadily increasing trend, and the cement industry produces approximately 1.4 Gt of CO_2 emissions per year, representing about 8% of global greenhouse gas emissions (Carbone et al., 2022). The energy consumption of the cement industry is estimated at about 2% of global primary energy consumption, or nearly 5% of total global industrial energy consumption (Kim et al., 2018).

In this context, the cement industry has a particular interest in implementing a Cleaner Production strategy, which represents one of the most recent developments in environmental thinking over the past two decades (Louafi & Boutora, 2020). This involves a shift toward more sustainable production practices, including improved energy efficiency, waste heat recovery, and the use of alternative raw materials and fuels (Tamta et al., 2025). These actions aim to minimize waste generation, reduce carbon emissions, and promote the conservation of natural resources.

The main objective of this monograph is to identify and assess the implementation and application of the Cleaner Production concept across environmental, economic, and social dimensions by presenting good practices implemented by the CEMEX Poland Group. The research methods used to achieve this objective include a literature review and a case study illustrating good management practices based on the Cleaner Production concept.

The work is structured in line with the substantive perspective of the discussion and consists of a theoretical part comprising Chapters 1 and 2, as well as Chapter 3, which presents selected good practices implemented by CEMEX Poland. In the first chapter, the authors introduce the Cleaner Production Programme, its genesis, objectives, principles, and practices. The applicability of CP and the phases of its implementation are presented, along with a discussion of the drivers, barriers, and benefits of the implementation process.

The second chapter details and presents activities carried out within the framework of the CP concept, including eco-design, eco-materials, green technologies, environmental labels and declarations, and eco-efficiency in the context of the discussed idea. The final chapter presents good practices in CP implementation based on the achievements of the CEMEX Poland Group.

The case study presented in this publication fully confirms the thesis that industry and the environment are not mutually exclusive but, in many dimensions, complement each other in achieving the objectives of sustainable development. The book serves as a compendium of knowledge on the implementation and realization of the Cleaner Production concept, indicating both the key issues in the field and its practical application.

Acknowledgements

The authors would like to thank all those without whose participation this monograph could not have been written. We express our gratitude to Dr. Michał Cichy, President of the Management Board, and Marian Stani, Member of the Management Board, of the Polish Cleaner Production Movement Association for their inspiration, support, and kindness during the process of selecting the company presented.

We also thank Ms. Iwona Wojtasik, Member of the Management Board of CEMEX Poland; Mr. Piotr Bąbelewski, Director of the Rudniki Cement Works; and Mr. Jarosław Sawecki, Regional Manager for CO_2 Reduction in Central Europe at CEMEX, for their assistance in presenting the pro-environmental activities carried out at both cement plants.

Special thanks are extended to Mr. Tadeusz Radzięciak, Member of the Management Board, Director of the Cement Production and Technology Division, and Director of the Chełm Cement Plant, who for many years has supported the relationship between Maria Curie-Skłodowska University and the CEMEX Poland Group.

Chapter One

The Concept of Cleaner Production

Genesis and Definition of the Cleaner Production Programme

The process of 'greening industry' began in the 1960s. Environmental protection through the cleanup of end-of-pipe emissions and the reduction of pollutant concentrations was introduced in the 1970s (Remmen, 2001). In the 1980s, the focus shifted toward pollution prevention and cleaner technologies. Environmental management and cleaner products became established in the early 1990s.

Due to the high global level of consumption, the continuous expansion of industrial production to meet the needs of the world's population, and the growing problems of environmental degradation, the United Nations Environment Programme (UNEP), a United Nations agency, was established in 1972 (United Nations Environment Programme, 2022). Its core objective was defined as organising international initiatives to protect the environment and promote sustainable development (Duflou & Kellens, 2019). In 1989, UNEP first proposed the term *cleaner production* while formulating the blueprint for the concept. Less than a year later, the CP concept was officially presented by UNEP as an essential tool for environmental protection (de Guimaraes et al., 2017). The first widely cited definition of the concept stated that it is an environmental strategy consisting of a continuous, integrated, preventive action with regard to processes, products, and services, aimed at increasing the efficiency of production and services while reducing risks to people and the natural environment (Chia & Hadibarata, 2021).

Since the inception of the Cleaner Production Programme, researchers have conducted continuous and detailed studies on the mechanisms of this strategy. Baas (1995) highlighted the need for a change in thinking about production, emphasising pollution prevention rather than merely eliminating its effects. In turn, Fresner (1998) pointed out in 1998 that company activities in the area of Cleaner Production fit well within the scope of the ISO 14001 standard. Chinese researchers Chen et al. (1999) advocated incorporating Cleaner Production Programme analyses into environmental impact assessments. Cleaner Production is considered the main production strategy for preventing environmental impacts during manufacturing processes (de Oliveira et al., 2019).

Cleaner Production was conceived as a new concept for pollution prevention in general and was first introduced in the chemical industry (Eder, 2003). Over many years of increasing popularity, it has been implemented in other industrial sectors, including agriculture and manufacturing. In practice, CP is regarded as playing an important role in saving resources, improving productivity, and reducing emissions (Scheverin et al., 2020). Cleaner Production also contributes to achieving the Sustainable Development Goals (Cardoso et al., 2019).

In the most general terms, the concept of Cleaner Production can be described as a set of principles aimed at protecting the environment and minimising waste, starting not only with production or service processes but extending across the entire life cycle of a product. The concept can also be applied at the personal level, referring to the lifestyles and daily choices of individual citizens (Sikva & Gouveia, 2020).

Cleaner Production is at the forefront of green practices that support sustainable production while harmonising the use of natural resources and production activities (Tayyab et al., 2020). It is one of several green practices that go beyond a sole focus on recycling raw materials and reducing industrial waste generation.

Cleaner Production can be understood as the application of preventive environmental strategies to services, products, and processes in order to respect energy, water, and raw materials, while eliminating or reducing toxic materials, emissions, and residues in the production process (De Oliveira Neto, da Silva et al., 2021) or throughout the life cycle of a service or product (Baas, 1995). It aims to mitigate risks to the environment and to people, increase productivity, and deliver environmental and economic benefits (De Oliveira Neto, Correia et al., 2021).

Cleaner Production refers to production strategies and practices aimed at reducing or eliminating waste generation and harmful emissions directly within the production process. This strategy seeks to achieve resource efficiency and minimise environmental impacts (De Oliveira Neto, 2020). Its scope encompasses several key dimensions:

- *Zero pollution*, considered the fundamental dimension of Cleaner Production, focuses on minimising pollution as much as possible, including solid waste, gas emissions, and water pollution. Cleaner Production seeks to achieve this by designing processes and products to minimise waste and emissions from the outset (García-Ávila et al., 2023). Achieving zero pollution increases productivity, reduces costs associated with waste treatment and environmental compliance, and improves a company's public reputation.

- *Cleaner technologies*, which encompass methods and equipment that reduce the environmental impact of production, including advanced cleaning technologies, automation that increases productivity, and innovations that support more efficient material use (García-Ávila et al., 2023). The application of cleaner technologies directly supports Cleaner Production goals by reducing waste, improving energy efficiency, and lowering costs, thereby promoting sustainability and operational efficiency (Giannetti et al., 2020).
- *Renewable energy sources*, such as solar, wind, and hydropower, play a key role in Cleaner Production. Their use reduces reliance on non-renewable and highly polluting resources such as coal and oil. Transitioning to renewable energy sources lowers long-term costs and enhances sustainability by making production processes cleaner and less harmful to the environment (Neha & Rambeer, 2021).

The integration of these three dimensions reinforces the principles of Cleaner Production and supports business entities in making significant progress toward environmental sustainability, while simultaneously improving economic performance and contributing to society (Giannetti et al., 2020). Small and medium-sized enterprises (SMEs) can not only improve their environmental performance but also strengthen their market position, enabling them to achieve a sustainable competitive advantage in today's business environment (Vargas et al., 2019). These practices lead to an increased share of green market components. Green markets depend heavily on the outcomes of Cleaner Production, allowing companies to gain a competitive advantage by demonstrating commitment to sustainability, reducing environmental damage, and attracting environmentally conscious consumers.

Implemented, continuous, and therefore systemic activities within the CP concept concern the following areas (Nowosielski et al., 2010):

TABLE 1.1 Selected Definitions of the Cleaner Production Concept

Source	Definition
Altham and Guerin (2005)	A preventive (precautionary) strategy that should be linked to a company's core business. It consists of improving production processes, management activities from the beginning to the end of the process, including product redesign with a focus on pollution reduction.
Fore and Mbohwa (2010)	The continuous application of an integrated preventive environmental strategy to processes, products and services to increase overall productivity and reduce risks to people and the environment.
Demirer (2009)	The reduction of the amount and toxicity of waste and emissions from production and handling processes, raw material and energy consumption, consumption of toxic materials, while for production, as: the prevention/reduction of its negative impact on environmental effects during its life cycle from raw material acquisition to its final disposal.
Hens et al. (2018)	A precautionary effort to reduce the environmental impact of production and product.
Rosak-Szyrocka et al. (2017)	The prevention or reduction of waste generation at source, i.e. directly during the production process through the use of energy-efficient, low-waste and waste-free production systems.
Hájek et al. (2019)	A preventive strategy to minimise the environmental impact of production and products.

Continued on the next page

- *Production processes* – saving raw materials and energy, minimising toxic materials, and reducing the quantity and toxicity of all generated waste.
- *Products* – reducing their negative environmental impact throughout the product life cycle.
- *Services* – incorporating an environmental dimension at the design stage and during subsequent consumption.

Cleaner Production can also be defined using the acronym CLEANER, as outlined by Dunn and Bush (2001): Combining Lower Emissions and Networked Energy Recovery.

Currently, there is no single, uniform definition of Cleaner Production in the literature. Most researchers classify it as a system encompassing pollution prevention, clean technologies, energy conservation, and emission reduction (Gunarathne & Sankalpani, 2021).

Table 1.1 presents selected definitions of the Cleaner Production concept proposed by both domestic and foreign researchers.

TABLE 1.1 *Continued from the previous page*

Source	Definition
Jabbour (2010)	A set of principles and preventive actions that enable the continuous application of a system aimed at achieving financial and environmental performance through the rational use of raw materials and the reuse of natural or industrialised residual resources.
Adamczyk and Nitkiewicz (2007)	The process of improving management and control systems for the production of products and services aimed at reducing their negative impacts at each stage of production. A preventive environmental protection strategy that, when applied in a systemic manner, becomes a voluntary, non-formalised environmental management system, allowing each organisation, regardless of size and profile of its activities, to achieve measurable environmental and economic benefits in a short time and to strengthen its position on the market.
Satish and Nagesha (2018)	A preventive way to reduce the negative environmental impact of products and production.
Fresner (2004)	the continuous application of an integrated preventive strategy to processes, products and services to increase environmental performance and reduce risks to people and the environment.

The Cleaner Production (CP) concept represents a new management and engineering paradigm that prioritises pollution prevention over pollution clean-up within a sustainability framework (Khorshidi et al., 2021). Cleaner Production is closely linked to the idea of sustainable development and is founded on the two pillars of sustainable production and sustainable consumption (Popek & Popek, 2020). At its core lies the theory of innovation, whereby a Cleaner Production Programme implemented within an enterprise enables the reduction or elimination of waste and emissions, resulting in tangible financial savings (Maama et al., 2021).

It should be emphasised that the CP strategy analyses production processes from technical, economic, and environmental perspectives, treating enterprises as macro-systems that transform inputs into outputs in ways that do not harm the environment. Moreover, the concept enables the identification and implementation of continuous improvements in production and environmental performance without increasing costs, based on a systemic perspective that allows all elements to interact (da Silva & de Medeiros, 2006).

It is also worth noting that the Cleaner Production Programme is increasingly driven by institutional pressures and stakeholder expectations that promote environmental responsibility. Regulatory requirements, growing investor interest in sustainability, and consumer demand for environmentally friendly products collectively motivate companies to adopt Cleaner Production strategies (de Oliveira et al., 2019). This approach not only reduces environmental damage but also enhances corporate reputation and facilitates access to emerging green markets (Habib et al., 2022).

The importance of Cleaner Production can be summarised in three fundamental aspects. First, it emphasises pollution prevention and control at the source. CP is concerned not only with the production process itself but with all stages of product manufacture, aiming to reduce pollution at the source and improve resource efficiency rather than relying on traditional end-of-pipe treatment methods (Wang et al., 2021). Second, it seeks to transform the mode of economic development by promoting a more intensive production model, in contrast to the traditional extensive development model (Jiang et al., 2021). Third, Cleaner Production contributes to the achievement of sustainable development goals, as the adoption of clean production processes enhances production and management standards, leading to increased economic and environmental benefits (Nasrin et al., 2015).

Assumptions and Principles of Cleaner Production

The scope of the Cleaner Production concept encompasses seven areas of activity comprising partially overlapping preventive practices. Nowosielski (2008) proposes the following approaches and identifies the scope of CP activities:

- *Service approach* – aimed at improving service efficiency through material savings and the rational use of energy in purchased products, while taking into account the ecological dimension.
- *Chain approach* – involving the synchronisation of activities along the production chain, taking into account material exchanges between manufacturers at different production stages, as well as the exchange of experience in implementing ecological solutions at each stage of the process.
- *Product approach* – covering all stages of product design and use, with the objective of reducing environmental impacts throughout the product life cycle.

- *Material approach* – addressing the selection of materials, their components, and the equipment and machinery used in production and consumption, in order to minimise negative environmental impacts as much as possible.
- *Technological approach* – considering the selection and environmental impact of technologies used in production, distribution, and service provision, while maintaining economic viability.
- *Operational approach* – encompassing planning, management, and production activities aimed at reducing waste streams.
- *Recirculation approach* – focusing on minimising waste generation and energy losses by closing material cycles and recovering energy within defined material and energy boundaries.

Based on a review of definitions developed over recent decades, it can be concluded that the Cleaner Production Programme is founded on four main principles (Sygut, 2016):

- *Precautionary principle* – when an activity poses risks to the environment or human health, all necessary precautions should be taken, even if some causal relationships have not been fully established. According to this principle, the burden of proof that no safer alternative exists lies with the proponents of the activity rather than with actual or potential victims.
- *Prevention principle* – preventing environmental damage is more cost-effective and efficient than managing or remedying it after it occurs. This principle requires life cycle analysis of products, from raw material extraction to final disposal, encouraging the development of safer alternatives and cleaner products and technologies.
- *Democratic principle* – Cleaner Production involves all stakeholders affected by industrial activities, including workers, consumers, and local communities. Access to information and participation in decision-making processes, supported by central and local authorities, ensure democratic oversight of production and service processes. Effective implementation of CP requires the full involvement of all actors in the product chain.
- *Holistic principle* – society should adopt an integrated, systemic approach to resource use and consumption. Information on the materials, energy, and human involvement in product manufac-

turing should be accessible, enabling informed choices and alliances for sustainable production and consumption. Life Cycle Assessment (LCA) is one of the tools supporting this holistic perspective.

To further promote and clarify the concept of Cleaner Production among economic organisations, Veleva and Ellenbecker (2001) formulated nine guiding principles:

- Products and packaging are designed to be safe and environmentally friendly throughout their life cycle; services are designed to be safe and environmentally friendly.
- Waste and environmentally incompatible by-products are continuously reduced, eliminated, or recycled.
- Energy and materials are conserved, and the forms of energy and materials used are the most appropriate for their intended purposes.
- Chemicals, physical agents, technologies, and working practices that pose risks to human health or the environment are progressively reduced or eliminated.
- Workplaces are designed to minimise or eliminate physical, chemical, biological, and ergonomic hazards.
- Management engages in an open and participatory process of continuous evaluation and improvement, focused on the long-term economic performance of the enterprise.
- Work is organised to protect and enhance employee productivity and creativity.
- The safety and well-being of all employees are prioritised, along with the continuous development of their skills and abilities.
- Communities surrounding workplaces are respected and strengthened economically, socially, culturally, and physically, while equality and fairness are promoted.

A review of the literature indicates that most national policies related to Cleaner Production share several common objectives (Kazmierczyk et al., 2002). The first objective is to promote Cleaner Production as an economic instrument that enhances competitiveness and efficiency while ensuring environmental protection, thereby extending support beyond traditional pro-environmental institutions and organisations. The second objective concerns the establishment of appropriate obligations and incentives to stimulate organisations to adopt efficient techniques, practical solutions, and preventive measures for environmental protection.

Another widely recognised objective is the optimisation of natural resource and raw material use, along with the minimisation of emissions and their environmental impacts. These goals can be achieved through strengthened legal frameworks, greener regulations, the promotion of energy efficiency, and the provision of technical and technological support to production sectors. A further objective involves developing mechanisms to reward entities demonstrating strong environmental performance and innovative, proactive approaches to environmental challenges. Such incentives may include additional points awarded to companies certified for Cleaner Production in public procurement procedures.

The final objective commonly identified is the replacement of end-of-pipe pollution control methods with preventive techniques. This shift is necessary because many managers were trained during a period when pollution control was viewed as the primary response to environmental problems. Contemporary Cleaner Production principles therefore emphasise moving away from end-of-pipe solutions toward preventive measures.

Practices of the Cleaner Production Programme

The focus of the Cleaner Production (CP) concept also extends to sustainability practices that enhance the efficiency of production and service processes across specific industries, while mitigating and reducing the risk of negative environmental and social impacts.

The CP concept is at the forefront of green approaches to sustainable production, integrating the use of natural resources with production practices (Çay, 2018). Cleaner Production practices are considered to be of key importance in achieving sustainability goals (Giannetti, 2020). Neto et al. (2019) emphasise that the implementation of these practices leads to improved economic and environmental performance, as well as to the development of environmental awareness among a company's workforce.

The implementation of Cleaner Production practices should be embedded throughout the entire product life cycle (Aranda-Uson et al., 2020). This includes the product design stage (Cui et al., 2020) as well

TABLE 1.2 Application Practices under the Cleaner Production Concept

	CP solutions	Concepts
1	Environmental considerations are taken into account when selecting suppliers.	Identify principles for developing partnerships between businesses and suppliers resulting in environmental performance.
2	Environmental issues play a role in creating an industrial site plan.	Incorporating the plant plan with environmental issues improves the organisation of processes and directs the company towards activities that contribute to reducing environmental impacts.
3	Energy-efficient and energy-minimising technologies.	Using energy rationally and deciding to acquire and configure equipment with a view to using energy, reducing energy consumption while performing the same activities.
4	Environmental considerations are taken into account when selecting equipment for manufacturing products.	Production creates less pollution and is more efficient if new machinery produces fewer defective products.
5	Analyse the feasibility of creating recyclable packaging.	Create and maintain a flow of raw materials from the reuse of manufacturing waste from recycled materials to increase environmental performance and manufacturing efficiency.
6	Analyse the possibility of replacing raw materials with ones that are non-toxic and non-polluting.	Eliminating the toxicity of products results in no toxic waste, which facilitates waste water treatment and is beneficial to health and the environment.
7	Consideration of packaging reduction.	Reducing packaging at the product design stage and considering recycling of packaging reduces environmental impact.
8	Analyse opportunities to reformulate products to increase their recyclability.	Considering the recyclability of a product by making changes to its composition or by substituting a raw material does not necessarily affect the performance of that product at all.
9	The ease of disassembly of products is assessed during the product design process.	Making products easier to disassemble makes their handling more efficient, increases their useful life and improves their recyclability.

Continued on the next page

as product delivery and distribution (Yin et al., 2020), with the overall aim of minimising environmental impacts across all stages (Pazienza & de Lucia, 2020). When considering the process of implementing Cleaner Production practices, five key factors can be identified as having a significant influence on this process (de Oliveira Neto et al., 2017):

TABLE 1.2 *Continued from the previous page*

	CP solutions	Concepts
10	Environmental considerations are taken into account when selecting production systems.	The use of mechanical processes instead of physical-chemical processes and the simplification of the entire production process improve environmental performance.
11	Environmental considerations are taken into account when transporting material.	Consideration of environmental issues in the transport of materials brings benefits to the health and safety of workers.
12	Analyse opportunities for consumers and end-users to access recycling centres.	Direct interactions encourage employees, suppliers and end consumers to participate in recycling programmes increase environmental awareness.
13	Reduction of natural resource consumption is taken into account in the production process.	Improving the efficiency of natural resource extraction, the selection of renewable sources and their rational use increase environmental efficiency.
14	Environmental considerations are taken into account in the production planning and control process.	Consideration of environmental issues in production planning and control results in the rational use of raw materials a reduction in waste and the number of amendments.
15	When assessing the production schedule, consideration is given to environmental issues that may arise from its implementation.	Analysing the environmental risk assessment allows preventive measures to be taken and increases environmental awareness.
16	Opportunities to use energy-efficient and clean technologies are taken into account when making efficiency decisions.	Using clean technologies and investing in innovation minimises environmental damage, reduces waste and improves operational efficiency.
17	Forwarding and returns logistics are taken into account when planning inventory.	A company's introduction of return logistics reduces its environmental impact when the entire life cycle of a product is considered in relation to its proper destination.

Continued on the next page

- material exchange,
- internal organisation,
- internal recycling,
- technological update,
- product improvement.

TABLE 1.2 *Continued from the previous page*

	CP solutions	Concepts
18	Consider increasing the durability of products.	Increasing durability and life cycle length through repairs and by replacing components prevents premature waste.
19	Analyse product recyclability at the design stage.	Considering disposal methods for products and materials at the design stage reduces waste emissions.
20	Analysis of the possible environmental impact of the product during use by the consumer.	Creating or improving the product together with the customer with consideration of possible environmental impacts minimises environmental risks.
21	Environmental issues are taken into account in the planning of logistics networks.	Processing production waste into by-products or raw materials that can be sold to other companies increases environmental efficiency.
22	Designing and planning the collection and distribution of products and components that will be recycled, remanufactured or reused.	Consideration during product design of reuse, remanufacturing and recycling of materials, from the very beginning of planning and collection through to the production process.
23	Promote customer and end-user participation in recycling programmes through initiatives such as education or information sharing.	Environmentally friendly products differentiate themselves from competing products and contribute to environmental protection.
24	Opportunities to use renewable resources are taken into account.	The use of renewable resources contributes to reducing environmental impacts.
25	Proposals for such products that would reduce the amount of packaging used and/or recyclable packaging.	Reducing the amount of packaging used during the product design phase and considering the use of recycled materials for packaging reduces the environmental impact.
26	Minimise waste generation and emissions in the production system.	Opportunities to reduce and eliminate waste preemptively at all stages in the process reduce pollution at the source and are one of CP's primary solutions.

Continued on the next page

Numerous articles and research studies indicate that manufacturers have increased their efforts to implement cleaner manufacturing practices (Yusup et al., 2015). This growing commitment has been driven by an increased awareness among manufacturers that the adoption of

TABLE 1.2 *Continued from the previous page*

	CP solutions	Concepts
27	Efficient use of raw materials and inputs avoid waste.	The rational use of raw material is also linked to continuous improvement practices and the reduction of process variation and environmental performance.
28	Recognition of CP as essential in the environmental management system and periodic audits for continuous improvement.	The use of CP solutions goes hand in hand with the implementation of an environmental management system.
29	Improve the environmental awareness of employees through the transfer of skills and knowledge.	Environmental education requires training of all employees and activities related to environmental impact, environmental management and recycling.
30	Improving working conditions to reduce waste.	Integrating environmental issues into work improves health and safety and reduces waste.
31	Efficient use of water.	By encouraging the rational use of water, preventive measures identify opportunities for reuse and reduce the risk of wastewater pollution, thereby reducing environmental impact.

NOTES Adapted from Yusup et al. (2015), de Oliveira Neto et al. (2015), Yüksel (2008), Sousa-Zomer et al. (2018), and Zeng et al. (2010).

cleaner manufacturing technologies in production operations yields widespread benefits for companies, employees, and the environment alike (Zeng et al., 2010).

Table 1.2 presents selected Cleaner Production practices related to resource use through waste reduction and reduced consumption. Depending on the level of development of an economic entity, many of these solutions can be implemented without additional investment (de Oliveira Neto et al., 2020).

CP Application Options and Implementation Phases

Cleaner Production (CP) options are defined as any improvement or initiative aimed at preventing or reducing emissions arising from production operations (Rahim et al., 2020). These options may require either small or large investments, ranging from good housekeeping practices to the adoption of new technologies. They can be implemented through cleaning practices, modification of production processes, substitution of less harmful materials, technological adaptation, employee training, and the application of the 3RS (reuse, recover, recycle) (Rahim et al., 2015).

To determine the efficiency of selected Cleaner Production options, it is necessary to understand both the benefits achieved by a business organisation and the impact of these options on production processes. In addition, Cleaner Production options should be evaluated financially, and the costs of their implementation should be correlated with the benefits obtained (Guo et al., 2005).

Therefore, to ensure the successful implementation of Cleaner Production options within an enterprise, it is essential to identify as many potential options as possible and then prioritise those that are most feasible. Three general categories of Cleaner Production options can be distinguished (Salem & Sorour, 2022):

1. *Reduction at source;*
    - good operating practices,
    - process changes, including:
        - substitution or change of materials,
        - improved process control,
        - replacement or modification of equipment and machinery,
        - technological changes.
2. *Recycling:*
    - on-site recycling.
3. *Product modification.*

In line with the interdisciplinary approach to Cleaner Production strategies, Fresner (1998) proposed his own classification of options:

- efficient management of materials and energy,
- employee training, improved logistics, enhanced data availability, and better communication between departments,
- replacement of raw and auxiliary materials with less harmful alternatives or materials that can be used more efficiently or recycled internally or externally,
- product modifications to eliminate production stages with high environmental impact,
- process modifications aimed at minimising waste and emissions,
- internal recycling,
- introduction of generated waste into external recycling networks.

The Cleaner Production Programme established in 1994 by the United Nations Industrial Development Organisation (UNIDO) and the United Nations Environment Programme (UNEP) identifies the following options for applying the CP concept (Jain et al., 2018):

- good management,
- change of input materials,
- improved process control,
- modification of equipment,
- change of technology,
- recovery and reuse on site,
- production of useful by-products,
- product modification.

In contrast, researchers from the Danish consultancy COWI identified the following categories of Cleaner Production options (COWI Consulting Engineers and Planners AS, Danish Environmental Protection Agency, Danish Ministry of Environment and Energy, & United Nations Environment Programme, 2000):

- *Caring for cleanliness* – improvements in working practices and proper maintenance that typically involve low costs and yield significant benefits.
- *Process optimisation* – reduction of resource consumption through optimisation of existing processes; these options are typically of medium cost.
- *Raw material substitution* – addressing environmental issues by replacing hazardous materials with more environmentally friendly alternatives; these options may require changes to equipment and process facilities.
- *New technologies* – adoption of new technologies to reduce and minimise waste generation by improving operational efficiency; although often capital-intensive, the payback period may be relatively short.
- *New products or designs* – product redesigns that provide benefits throughout the life cycle, including reduced hazardous substance use, lower waste generation, reduced energy consumption, and more efficient production processes; while long-term and po-

tentially requiring new equipment and marketing efforts, such investments can yield substantial returns.

In recent years, numerous publications have proposed various methodologies and tools to initiate the implementation of Cleaner Production strategies. However, it should be emphasised that many of these approaches are process-specific (Zhang et al., 2015) or industry-specific (Abbasi & Abbasi, 2016). In this context, the work of Olson (2008) is noteworthy; this researcher developed a methodology and toolkit for formulating Cleaner Production strategies that can be integrated with other strategic areas within an organisation, such as business strategy, technology application, and infrastructure development.

Cleaner Production strategies are fundamentally related to operations management, environmental sustainability, and the maximisation of waste reduction, recycling, and reuse at the enterprise level, and are therefore microeconomic in scope (Kalili, 2015).

The definition of a Cleaner Production strategy proposed by de Oliveira Neto, Tucci et al. (2021) describes it as a prudent approach to sustainability that addresses all stages of the life cycle of a product or service and is applied by business units to obtain both economic and environmental benefits. This definition reflects the precautionary nature of the CP approach.

By contrast, da Silva et al. (2021) emphasise resource efficiency in their definition of a Cleaner Production strategy, which they describe as the continuous adoption of practices that improve economic, environmental, and operational performance through the integration of processes and products, enabling increased efficiency in the use of raw materials, water, and energy, with the aim of preventing, reducing, or recycling waste generated during production processes.

Another definition, proposed by Al-Munim and Abdul Hameed (2021), explicitly refers to sustainable development and defines Cleaner Production as a mechanism that promotes sustainable development by reducing industrial waste and emissions and by providing financial and technological resources to support a sustainable economy, thereby reducing environmental costs and benefiting society.

When discussing the implementation of Cleaner Production strategies, it is important to recognise that every product, regardless of its material composition or intended use, exerts a negative environmental impact, whether during raw material extraction, production, use, or disposal (Chehebe, 1998).

Cleaner Production strategies include good operating practices, improved process control, reuse, recovery and recycling on site, production of useful by-products, substitution of raw materials, product reformulation and redesign, equipment modification, and technological change. Good operating practices encompass organisational procedures and methods, management practices, waste segregation, improved material handling, production scheduling, inventory control, and employee training (Nahui-Ortiz et al., 2019).

Cleaner Production represents a comprehensive set of environmental, efficiency, and process optimisation strategies based on a holistic perspective that encompasses the entire product life cycle. These proactive and preventive strategies are environmentally friendly and aim to reduce energy and water consumption, minimise emissions and waste, and support the development of a sustainable production chain (Espinosa et al., 2021).

The adoption of Cleaner Production strategies is defined as the application of CP practices within production systems in order to enable companies to achieve the Sustainable Development Goals (SDGS) (Satyro et al., 2021).

A prerequisite for the effective implementation of a Cleaner Production strategy is adherence to the principle of continuous improvement, which involves systematic actions aimed at reducing adverse environmental impacts. Organisations seeking to implement voluntary Cleaner Production commitment systems are required to accept and comply with the fundamental principles of the CP strategy (Purwanto, 2021).

The process of implementing the Cleaner Production concept is commonly divided in the literature into five successive phases (van Berkel, 2000):

Phase I: Planning and organisation management involvement; creation of a project team; development of an environmental policy; planning of the Cleaner Production assessment.

Phase II: Initial assessment (qualitative review) company description; process flow chart; walk-through or on-site inspection; evaluation of the adopted plan.

Phase III: Evaluation (quantitative review) data collection; material balance; identification of Cleaner Production options; preparation of an options list.

Phase IV: Assessment and feasibility study preliminary assessment;

technical assessment; economic appraisal; non-economic evaluation.

Phase V: Implementation and follow-up preparation of an action plan; implementation of Cleaner Production options; performance monitoring; maintenance of Cleaner Production activities.

Many authors emphasise that Cleaner Production strategies should be regularly reviewed and updated to ensure continued relevance to organisational objectives and compliance with governmental and stakeholder requirements. Continuous monitoring and evaluation are essential to verify whether sustainability goals are being achieved, to identify optimal material and energy use parameters, and to assess the effectiveness of implemented actions (Almeida et al., 2015).

Supporting Factors, Barriers, and Benefits of Cleaner Production Implementation

Indicators Driving the Implementation of the Cleaner Production Concept

A review of the literature on the implementation of the Cleaner Production (CP) concept indicates that both researchers and business practitioners identify a wide range of motivators influencing the development and adoption of this environmental strategy.

According to Jones (1999), one of the most important drivers is the socio-cultural responsibility of a business entity, resulting from a company's involvement in addressing environmental problems within its operating environment. In contrast, Tate et al. (2010) emphasise that pressure exerted by stakeholders is a key rationale for companies to implement CP programmes, ultimately leading to greener products and services. Zhu et al. (2007) identify pressure from market competitors and environmental organisations as a major stimulus influencing the implementation of Cleaner Production within companies. According to Bansal and Roth (2000), the government's ability to formulate and implement effective pro-environmental policies that encourage market participants to adopt CP solutions plays a critical role in promoting this agenda.

Perron et al. (2006) highlight the importance of systematic environmental training and programmes designed to develop CP-related competencies, with training extended to all employees, particularly those directly involved in implementation. According to the French researcher de Grosbois (2016), normative pressure from local actors such as the media, industrial consortia, and educational institutions has a significant influence on management decisions to initiate CP implementation.

Fernandez et al. (2003) identify the development of a strong pro-environmental culture within industrial organisations as an important catalyst for CP adoption. Research by Denton (1999) shows that performance evaluation systems aimed at improving organisational efficiency and productivity are key to expanding CP implementation. Such systems can also serve as tools for assessing employee engagement in CP activities and providing feedback for organisational improvement.

Beard and Rees (2000) emphasise the importance of building and promoting green work teams, particularly in the implementation of cleaner technologies. In the article *Motivating Employees for Environmental Improvement*, Govindarajulu and Daily (2004) underline the need for incentive and reward programmes targeting employees, whose attitudes can significantly reinforce CP implementation.

Research by Ashton et al. (2002) indicates that effective cooperation between the public and private sectors in environmental policy and regulation development, as well as a better understanding of linkages between industry, trade, and international regulation, can form a foundation for CP implementation. According to Horbach et al. (2012), the main drivers of CP adoption are market pull, regulatory frameworks, and technological pressure.

Researchers from Camber University, Gunningham et al. (1997), identify the development of new green technologies and the ability of small and medium-sized enterprises (SMES) to acquire them as positive indicators for CP implementation. Chinese scholars represented by Zhangi et al. (2018) consider institutional pressures to be fundamental motivators and categorise them into four groups:

- pressures arising from government laws and resolutions,
- regulations stemming from international and national standards and customer expectations,
- pressures originating from suppliers aware of supply-chain influence,
- economic pressures related to internal cost reductions.

A different classification was proposed by Khan (2016), who distinguished between internal and external factors in his dissertation *Promoting Cleaner Production and Energy Efficiency in the Industry of Pakistan: A Case Study of the Textile Manufacturing Sector*. Internal factors include:

- environmental management systems and continuous improvement,
- corporate environmental reporting,
- environmental leadership,
- environmental accounting,
- demands of owners and investors,
- higher input costs,
- company recognition and image,
- voluntary environmental initiatives.

External factors include:

- pollution prevention,
- environmental auditors,
- international trade incentives,
- financial incentives,
- loans from financial institutions,
- rising energy prices,
- foreign market product specifications,
- green consumers,
- industry networking,
- buyer–supplier relations,
- supply-chain requirements,
- negotiated self-regulation,
- codes of conduct,
- education and training,
- increasing social pressure,
- community involvement in environmental issues.

Researchers from Camber University (Gunningham et al., 1997) further identified the most significant drivers of CP strategy implementation as:

- government regulation,

- access to information through networking and business partnerships, particularly for SMES,
- the desire to maintain positive relations with local communities, especially among larger companies,
- convergence of efficient production processes with advanced CP tools such as environmental management systems,
- access to financial incentives for investment in cleaner technologies.

Barriers Slowing Down the Implementation of the Cleaner Production Programme

Factors negatively affecting the implementation of the Cleaner Production concept can be grouped into several categories:

1. *Organisational*:
    - risks to enterprise survival (Vieira & Amaral, 2016),
    - lack of corporate focus on CP (Neverauskiene & Rakauskiene, 2018),
    - low environmental awareness (van Berkel, 2007),
    - insufficient managerial competence (Siaminwe et al., 2005),
    - low employee commitment (Chiu et al., 1999),
    - misallocation of resources (Domingues & Paulino, 2009),
    - insufficient managerial motivation (van Hoof & Lyon, 2013),
    - market pressure linked to CP strategy (Shi et al., 2008),
    - inadequate organisational culture (Hitchens et al., 2004),
    - lack of environmental priority (Jabbour, 2016),
    - methodological constraints in CP implementation (Newig et al., 2019),
    - data protection concerns (Staniškis, 2011).
2. *Governmental*:
    - insufficient incentive policies (Koefoed & Buckley, 2008),
    - inadequate support programmes (Mitchell, 2006),
    - limited awareness of available incentives (Shi et al., 2008),
    - legislation favouring end-of-pipe solutions (Silva et al., 2008).
3. *Technical and technological*:
    - lack of skilled labour (de Oliveira & Alves, 2007),
    - insufficient technical knowledge of middle management (Hamed & Mahgary, 2004),

- inadequate technical information (Vieira & Amaral, 2016),
- insufficient infrastructure (Shi et al., 2003),
- lack of financial resources for modernisation (Silvestre & Silva Neto, 2014),
- outdated machinery (Mittal & Sangwan, 2013).

4. *Economic and financial*:
   - limited company assets (Hoof & Lyon, 2013),
   - insufficient funds for environmental investments (Ashton et al., 2018),
   - difficulties in accessing credit (Shi et al., 2003),
   - obstacles to raising capital (Silva et al., 2015),
   - high start-up costs (Chiu et al., 1999).
5. *Cultural*:
   - resistance to change (Severo & Olea, 2010),
   - lack of awareness of potential benefits (Klewitz & Hansen, 2014),
   - insufficient environmental training (Abdulrahman et al., 2015),
   - low environmental awareness among management and staff (Daquino et al., 2014),
   - weak commitment to CP (van Berkel, 2007).
6. *Legal*:
   - insufficient resources to implement legislation (Hilson, 2000),
   - non-compliance with regulations (Gombault & Versteege, 1999),
   - lack of legal knowledge (Hitchens et al., 2004),
   - ineffective enforcement (Shi et al., 2003).
7. *Socio-market*:
   - low societal environmental awareness (Park & Byun, 2001),
   - limited stakeholder interest in CP (Almeida et al., 2015),
   - inadequate societal cooperation in pollution prevention (Zhang, 2000).

Benefits of Implementing a Cleaner Production Strategy

Despite numerous barriers, organisations implementing Cleaner Production strategies can realise substantial benefits, which may be grouped into three categories:

1. *Economic*:
   - reduced operating costs and improved efficiency (Kitazawa & Sarkis, 2000),
   - lower environmental penalties (Berry & Rondinelli, 1998),
   - improved access to international markets (González-Benito & González-Benito, 2006),
   - access to environmentally conscious consumer segments (Ginsberg, 2004),
   - reduced financial risk (Fresner, 1998),
   - increased innovation in products and processes (Azzone et al., 1997),
   - higher company valuation (Preston, 2001),
   - expanded business and market opportunities (Berry & Rondinelli, 1998),
   - increased organisational efficiency (Sh, 2020),
   - improved supply-chain efficiency (Henriques & Catarino, 2015),
   - environmentally responsible economic growth (Gunarathne & Lee, 2021),
   - higher productivity (Dodic et al., 2010),
   - competitive advantage and increased market share (Demirer & Alkaya, 2018).

2. *Social*:
   - increased public trust (Cichy, 2007),
   - higher employee motivation (Popek & Popek, 2020),
   - improved corporate image (Miles & Covin, 2000),
   - better working conditions (Doorasamy, 2015),
   - reduced need for regulatory restrictions (Kituyi et al., 2000),
   - improved public health outcomes (Loiseau et al., 2016).

3. *Environmental*:
   - environmental protection and sustainable production (Zameer et al., 2020),
   - integrated and systemic environmental management (Silva et al., 2013),
   - gradual green transformation of organisations (Filho et al., 2019),
   - continuous greening of manufacturing processes (Schroeder et al., 2019),

- compliance with environmental management systems and ISO 14000 standards (Gavrilescu, 2004),
- reduced risks associated with hazardous waste management (Kituyi & Marani, 2000).

Implementing Sustainability Based on the Cleaner Production Concept

Sustainability and Cleaner Production (CP) are interrelated concepts that are increasingly recognised as key elements of international efforts to address environmental and social challenges. There are many ways in which Cleaner Production contributes to the Sustainable Development Goals (SDGS), with its most prominent contribution being to environmental sustainability.

Despite this recognition, relatively few publications directly address the impact of CP practices on the achievement of specific Sustainable Development Goals, even though the concept is globally acknowledged as a major tool for achieving sustainable development (Giannetti et al., 2020).

Over the past 25 years, the vision of sustainable development has evolved significantly in terms of scope, content, and the sectors applying this approach. Its objectives have shifted from reducing pollution and waste generation primarily during production, to designing products with lower environmental impacts, and further to areas such as sustainable tourism, environmentally friendly healthcare, and improved quality of life in green and smart cities (Hens et al., 2018).

Due to its philosophy, broad scope, and long-term perspective, sustainable development requires capacity building through the balanced development of social patterns and the creation of new visions, paradigms, policies, methodological tools, and applied procedures (Khalili et al., 2014).

The Sustainable Development Goals, adopted by the United Nations in 2015, aim to guide the global development agenda until 2030. They can be interpreted as an attempt to conceptualise sustainable development as 'the art of living well within ecological limits' (Jackson, 2010), while meeting three sets of constraints: techno-economic efficiency, environmental compatibility, and social equity (Clift et al., 2013).

The SDGS are intended to inspire the operationalisation and integration of sustainable development within economic organisations, enabling them to respond to current and future stakeholder needs while contributing to sustainable development at the societal level (Fonseca & Carvalho, 2019).

At this point, it is useful to recall the definition of corporate sustainability. Dyllick and Hockerts (2002) define it as meeting the needs of a company's direct and indirect stakeholders (such as shareholders, employees, customers, pressure groups, and communities) without compromising the firm's ability to meet the needs of future stakeholders.

It is important to emphasise that the Cleaner Production concept is fundamentally grounded in the idea of sustainable development, with a strong emphasis on pollution prevention at the source. Conceptually, Cleaner Production promotes the continuous application of preventive environmental strategies in processes, products, and services aimed at increasing productivity and minimising risks to people and the environment (Alkaya & Demirer, 2014).

Cleaner Production analyses production processes from technical, economic, and environmental perspectives, treating an economic entity as a macro-system capable of transforming inputs into outputs that do not harm the environment. The CP programme identifies opportunities for continuous improvement in environmental performance without increasing costs, based on a systems approach that allows interactions among all elements of production processes (da Silva & Medeiros, 2006). The adoption of CP practices contributes to the conservation of raw materials and energy, reduces or eliminates toxic materials, and minimises the volume and toxicity of emissions and residues during production processes. The textile, apparel, and leather industries are often identified as priority sectors for CP implementation (Ghazinoory, 2005).

The CP concept offers a practical means of translating sustainability principles into concrete actions. It represents a preventive and corrective strategy rather than a reactive approach to addressing global pollution problems (Pandey, 2017). CP also provides a practical pathway for transitioning the economy toward sustainability by enabling manufacturing and service industries to achieve more with fewer resources, including raw materials, energy, waste, and emissions, while reducing environmental impacts and enhancing sustainability. By definition, Cleaner Production also promotes increased profitability through cost reductions, such as lower material requirements, reduced waste disposal fees, and diminished environmental liability and remediation costs (Al-Youfi, 2004).

The CP concept encompasses specific methodologies for integrating environmental and sustainability issues within industry, applies relevant analytical and synthetic tools, and challenges traditional design, manufacturing, and service delivery practices. Cleaner Production combines preventive environmental methods applied to processes, products, and services with the goal of increasing efficiency and reducing risks to society and the environment. These preventive practices contribute to economic savings and improved environmental quality, which align closely with the objectives of the SDGS (Zeng et al., 2010).

Cleaner Production practices contribute to sustainable development in several ways, with their most significant impact on environmental sustainability. CP reduces the negative effects of industrial activities on air and water quality, biodiversity, and ecosystem services that are essential for human well-being and economic development (Santos et al., 2019). The Cleaner Production Programme enables sustainability models to be implemented at the company level (Fresner, 1998).

The link between sustainability and the CP programme is based on two key principles: first, that discussions on waste and emissions should focus on their sources rather than symptoms; and second, that increased efficiency in input use is essential for minimising waste and emissions (Fore & Mbohwa, 2010). Sustainability is therefore a central issue in the implementation of Cleaner Production, particularly when CP practices are extended to public stakeholders and society at large (Cong & Shi, 2019).

Publications by King and Lenox (2002) clearly demonstrate that Cleaner Production contributes to sustainability objectives. Numerous studies also show that, from both economic and social perspectives, CP practices positively influence ecological management and sustainable economic development (Getzner, 2002). In both scientific and business communities, Cleaner Production is widely recognised as an essential tool for promoting sustainable economic development in line with Agenda 21 (Gavrilescu, 2004).

It should be noted that the idea of sustainability is a key issue in the implementation of the Cleaner Production concept, especially when it allows for the extension of CP practices to society and the stakeholders of the organisation concerned (Cong & Shi, 2019). On the other hand, K. Geiser of the University of Massachusetts Lowell established a link between CP strategies and sustainable development in the manufacturing sector, demonstrating that CP has positively influenced industry by enabling the achievement of SDGS through the development of procedures and implementation mechanisms (Almeida et al., 2015).

Cleaner Production is therefore an integral and necessary element in achieving the Sustainable Development Goals. Several of its components directly support sustainable development, including (Kazimierczyk & Schwager-Ouijano, 2002):

- waste reduction at source and reduced raw material consumption, supporting the sustainable use of the planet's limited resources,
- pollution prevention, contributing to the environmental dimension of the triple bottom line,
- enhanced partnerships and communication with local governments, universities, and communities to ensure participation and promote equity,
- return-on-investment calculations that benefit both economic and environmental performance.

Among the specific Sustainable Development Goals, SDG 12 (responsible consumption and production) is particularly relevant to Cleaner Production (Yu & Kuo, 2021). This goal is closely linked to many other SDGS and is considered one of those with the least progress to date. It requires special attention due to the complexity of supply networks and provides a strong foundation for research on integrating SDGS into CP practices (Russell et al., 2019).

Another highly relevant goal is SDG 9 (industry, innovation, and infrastructure) (Ishara & Mekala, 2023). Analyses of the literature on SDG implementation indicate that SDG 9 is the second most frequently addressed goal among researchers in this field (Santos et al., 2019).

Research by Ugandan scholars Mugagga and Nabaasa (2016) highlights the importance of water resources in Africa, demonstrating that sustainable management of SDG 6 (water and sanitation) through CP practices is critical to achieving other SDGS, including SDG 1 (no poverty), SDG 2 (no hunger), SDG 3 (good health), SDG 14 (life below water), and SDG 15 (life on land).

Empirical research conducted by de Oliveira Neto et al. (2022) among Brazilian small enterprises in the metal and mechanical industries confirmed that CP implementation resulted in tangible economic and environmental benefits. The results also demonstrated progress toward SDG 6, SDG 9, SDG 12, and SDG 15.

Globally, the garment industry has operated beyond planetary resource limits for many years (Steffen et al., 2015). Increasing environmental pressure has led to stricter measures aimed at reducing clothing waste, recycling materials, and improving waste management (Jahan, 2017). Studies in the Brazilian textile industry confirmed that CP practices based on technological innovation enabled economic and environmental benefits and supported SDG 9, SDG 12, and SDG 15 (de Oliveira-Neto et al., 2019).

The impact of CP practices on sustainability in the service sector has also been analysed, notably in the Portuguese hospitality market. The tourism industry, while growing rapidly, has significantly increased its environmental footprint (Pereira-Moliner et al., 2012) and is now recognised as a major contributor to environmental degradation and climate change (Beiling et al., 2013). At the same time, tourism is highly sensitive to environmental quality deterioration (Kadriu, 2016). The abovementioned reasons have led the HoReCa industry to start the process of implementing voluntary programmes aimed at reducing the negative impact on the environment, as well as promoting environmentally responsible entities (Leroux & Pupion, 2018). The implemented measures allowed the surveyed entities to achieve large savings in water and wastewater management and contributed to improving energy efficiency (Chen et al., 2018). Through the implementation of CP practices, the sustainability goals of SDG 6 and SDG7 have also been achieved.

When discussing the sustainability impact of CP practices in the service sector, it is worth zooming in on a study carried out in one chain of car dealerships located in the state of Rio Grande do Norte. The improvements consisted in the implementation of a system of selective waste collection and external recycling, thanks to these actions it was possible to implement preventive control of important environmental aspects in the organisation in question (Dias Pimenta et al., 2012).

Over the last two decades, there has been a growing interest in the sustainable management of supply chains among researchers, industry leaders as well as policy makers. Currently, the debate is mainly centred around the topic of configuring them sustainably and the processes for implementing and managing them. There is full consensus in the community that economic objectives must not be pursued at the expense of the environmental and social dimensions (Seuring & Muller, 2008). In designing sustainable supply chains, the aim should be to design them in such a way that all stakeholders are satisfied (Hall et al., 2012). Each actor in the chain, from the supplier to the final consumer, has a role and all interact with each other. The literature defines sustainable supply chains as: those chains that consistently perform well in financial, environmental and social terms (Pagel & Wu, 2009). It is important to bear in mind that managing supply chains responsibly means acting within the boundaries of the planet (Rockström et al., 2009). Applying CP practices throughout the product chain can help individual links in the chain to reduce their individual and collective waste of materials, reduce the level of waste generated and rationalise the energy used (Almeida et al., 2015), thus meeting SDG 7 and SDG 12.

Research by Silvestre (2015) on sustainable supply chains in the Brazilian petrochemical industry confirmed the contextual and complex nature of such processes, limiting the potential for broad generalisation.

The Sustainable Development Goals (SDGS) have ambitious global priorities related to, among other things, increasing access to energy. The aspiration of SDG 7 is, to provide universal access to reliable and modern energy services by 2030. In order for African countries to be able to continuously use energy without fail, they need to reach out to CP practices that allow them to reduce the costs of generation, transmission, increase the level of respect for energy, and increasingly use alternative energy sources (Chirambo, 2018).

It is worth citing the interesting results obtained by a group of Brazilian researchers on the impact of cleaner production practices on the achievement of sustainable development goals in the area of operation of the wood industry in Brazil (Lins et al., 2021). The furniture industry is one of the largest consumers of wood and at the same time a major producer of wood waste, thus having a significant impact on the state of the environment (Aguilar et al., 2017). The implementation of CP practices in the furniture industry operating in the Brazilian state of Minas Gerais, focused on material flow and the identification of CP opportunities to reduce waste, reduce inputs, water, energy and other raw materials. The above measures achieved savings in the area of water and wastewater management of 66%, reduced post-production waste generation from 23% to 93%, and a 3% reduction in input materials. The savings achieved prevented the felling of 3,900 pine trees and reduced carbon dioxide emissions by 13,100 kg. In this context, the implementation of CP practices has enabled the optimisation of material consumption, reduced the level of waste generated, reduced water consumption, energy consumption and the conservation of forest resources (Massote et al., 2013). The tangible benefits obtained have enabled the achievement of the four Sustainable Development Goals: SDG 6, SDG 7, SDG 12 and SDG 15 (sustainable management of forests).

Although Cleaner Production has been designed solely with environmental sustainability in mind, it has the potential to affect related indicators: social, economic and welfare, measured at the macroeconomic level, if its traditional model is extended. Constructing a new CP programme requires extending its traditional dimension to include a more comprehensive understanding of sustainability as a multidimensional goal, which is consistent with the view that environmental, social and economic sustainability are closely linked.

Chapter Two

Cleaner Production Activities

Eco-Design

The origins of the eco-design process can be traced back to the late 1980s, when it became evident that end-of-pipe technologies would not adequately address the two primary sources of environmental problems: resource scarcity and environmental pollution. Researchers and business practitioners were therefore challenged to develop concepts capable of preventing pollution while conserving natural resources. As a result of these efforts, two main areas of focus were identified: production processes and products.

The term *eco-design* is relatively recent in the fields of management and quality sciences. It was first defined in the monograph *Ecological Design* (van der Ryn and Cowan, 1996) as any form of design that minimises destructive environmental impacts through integration with living processes (Kallipoliti et al., 2018).

In the literature, the term eco-design is also referred to using alternative expressions such as ecological design, design for environment, green design, sustainable product design, and life cycle design. These terms are often used interchangeably; however, the term *ecodesign* is the most commonly adopted by researchers (Miroshnychenko et al., 2017).

Eco-design is a concept that integrates human priorities for sustainable development with business objectives. Its primary aim is to improve product development methods in order to significantly reduce environmental burdens (Karlsson & Luttropp, 2006). Eco-design encompasses the use of processes that minimise natural resource consumption, increase product durability, reduce product weight, and limit environmental pollution (Topleva & Prokopov, 2020).

Eco-design covers a broad spectrum of design approaches, ranging from product- and production-oriented solutions to more comprehensive, solution-oriented concepts (Tukker & Andersen, 2006). It serves as a tool for facilitating the systematic integration of environmental aspects into product development processes, addressing and resolving multiple design-related challenges (Byggeth & Hochschorner, 2006).

The eco-design process also incorporates considerations of energy efficiency, the use of renewable energy sources, recycled and reclaimed materials, and materials that can be recycled in the future (Amir et al., 2022). It is grounded in a holistic approach that accounts for the entire product life cycle in relation to environmental, health, and safety objectives (Soh et al., 2014). This approach is characterised by three fundamental aspects (Schafer & Lower, 2021):

1. it refers to the design and development of products,
2. it aims to reduce the environmental impact of these products,
3. it considers the entire life cycle of the product.

These characteristics reflect a broad consensus among researchers. Although eco-design activities are typically led by product development departments, the creation of sustainable products requires the involvement of multiple organisational units and disciplines, including manufacturing, business management, environmental research, and engineering (Thomé et al., 2016).

Green design processes are among the key drivers of closed-loop economy practices, the relationship of which with the United Nations Sustainable Development Goals (SDGS) has been widely documented. Of the 17 SDGS, closed-loop economy practices, supported in part by eco-design, are directly linked to Goal 6 (Clean Water and Sanitation), Goal 7 (Affordable and Clean Energy), Goal 8 (Decent Work and Economic Growth), Goal 12 (Responsible Consumption and Production), and Goal 15 (Life on Land) (Schroeder et al., 2018).

Numerous studies emphasise that eco-design inherently incorporates activities derived from the product life cycle assessment (LCA) concept (Yung et al., 2012). These activities span advanced development, design, raw material selection, production, marketing, distribution, use, and end-of-life disposal (Thamsatitdej et al., 2017). This approach is particularly important given that empirical evidence indicates that 60–80% of a product's environmental impact is determined during the design stage (Posch & Perl, 2007). Consequently, integrating ecological considerations into product design marks the starting point for reducing environmental impacts. The full potential of eco-design, however, is realised when the maximum possible reduction of environmental impacts across the entire product life cycle is achieved (Hubner, 2012).

Over the past two decades, extensive scientific research and practi-

TABLE 2.1 Selected Definitions of the Term Eco-Design

Source	Definition
Platcheck et al. (2008)	A holistic approach in which, from the knowledge of environmental problems and their causes, we begin to influence the concept of material selection, production, use, reuse, recycling and final disposal of industrial products.
Pigosso et al. (2010)	A proactive approach to environmental management that aims to reduce the overall environmental impact of manufacturers.
Plouffe et al. (2011).	A proactive approach to environmental management that aims to reduce the total environmental impact of manufacturers.
Borchardt et al. (2011)	A set of design practices aimed at creating environmentally efficient products and processes.
Dostatni (2018)	A design strategy compatible with the concept of sustainability.
Maccioni et al. (2019)	A method of construction whose action is within the development of a product, aiming at the environmental impact throughout its cycle, while maintaining the same technical parameters.
García-Sánchez et al. (2019)	The systematic integration of environmental considerations into the development of products and processes.
Charter (2019)	The process of integrating environmental considerations into design and development to reduce the environmental impact of products throughout their life cycle.
Schäfer and Löwer (2021)	The practice performed by product developers to reduce the negative environmental impact of a product throughout its life cycle.

cal work have been conducted at various stages of the evolution of the eco-design concept. The most significant developments include:

- the extension of eco-design toward sustainable services (Michelini & Razzoli, 2004),
- the dissemination of the concept through the development of tools and methods for education and implementation among economic operators (Quella, 2001),
- the incorporation of eco-design into standards of both normative character (e.g. the ISO 14000 series) and prescriptive character (e.g. ISO 14062) (Boks, 2006).

Despite extensive academic and practical efforts, no single universally accepted definition of eco-design has been established. Table 2.1 therefore presents selected definitions of the eco-design concept.

In their work, Schäfer and Löwer (2021) identify three defining characteristics of eco-design that are common to most definitions:

1. it concerns the design and development of products,
2. its aim is to reduce the environmental impact of these products,
3. it takes into account the full life cycle of products.

Based on research conducted by Shu-Yang et al. (2004), the eco-design process is founded on seven key principles:

- the need to meet the inherent needs of people and the economy,
- the requirement to maintain the integrity of both structure and function in natural and managed ecosystems,
- the use of nature's inherent designs as models for anthropogenic management systems,
- the need to progress toward a sustainable economy through increased reliance on renewable resources and a stronger emphasis on reuse, recycling, and efficient use of materials and energy,
- the application of ecological economics or full-cost accounting to comprehensively address resource depletion and environmental damage, thereby confronting the issue of natural debt,
- the need to protect natural ecosystems and indigenous biodiversity at a realistic level,
- the requirement to raise environmental awareness in order to build public support for sustainable development, natural resource conservation, and environmental protection.

Within the eco-design process, a range of strategies can be distinguished, including design for recycling, recovery, long-term use, and energy efficiency. All of these strategies aim to improve the environmental performance of products across multiple dimensions and stages of their life cycles (Lindhqvist & Lifset, 1998). The selection and integration of one or more of these strategies into an organisation's corporate strategy remains the responsibility of manufacturers and designers (Quella & Schmidt, 2003).

The systematisation of eco-design strategies contributes to enhanced sustainability of products and services, drawing on diverse application areas of the eco-design concept (Silva et al., 2023).

Table 2.2 presents five eco-design strategies along with their general principles.

In summary, it should be stated that the implementation of an eco-design process by a business organisation contributes to envi-

TABLE 2.2 Eco-Design Strategies and Their General Principles

Strategy	General principles
Design with sustainable sourcing in mind (Hübner 2012).	• use of recycled materials as secondary raw materials, • sourcing primary or renewable raw materials from sustainably managed production processes.
Designing for resource optimisation/LCA (Baptista et al., 2018).	• avoid unnecessary consumption of materials and reduce the quantity of materials, • choose recycled and recyclable materials over non-recyclable ones, • use materials that do not contain hazardous substances, • optimise the process to reduce resource consumption and the environmental impact of by-products, • manufacture without producing hazardous compounds or incorporating them in the product, • use of clean technologies (renewable energy sources).
Designing for environmentally friendly and safe use/energy efficiency energy efficiency (de Grave et al., 2010).	• minimising exposure to hazardous substances during product use, • minimising particulate emissions during use, • minimising the likelihood of littering, • minimising product energy consumption.
Design allowing long-term use/disassembly/maintenance of the product (Rossi et al., 2016).	• easy disassembly of the product to ensure repair/replacement of part of the product instead of replacing the whole product, • creation of durable products, • maintenance of the product to avoid the need for repair or replacement of parts.
Design for reuse/recycling/recovery and recycling of materials (de Grave et al., 2010).	• identifying parts of a product that can be reused properly and parts that can be recycled, • easy disassembly of products to recover and sort parts that are still suitable for reuse or recycling, • use of recyclable polymers and/or polymer blends using existing infrastructure.

ronmental improvement, enhances the economic health of the company, builds stakeholder trust, and strengthens the overall image of the entity. However, despite the numerous benefits associated with eco-design at the current stage of economic development, its level of adoption remains relatively low among companies (Paulson & Sundin, 2015).

Eco-Materials

The early 1980s marked the beginning of a discussion among researchers and economic practitioners on the development of a new, environmentally sensitive approach to material-related issues (Jansen, 2003). The concept of *eco-materials* was formulated in 1991 as a result of discussions held at the international conference of the Rare Metals Forum of the Society of Non-Traditional Technology, which focused on identifying the characteristics of next-generation structural materials (Nishimura & Tada, 2003).

The term *eco-material* refers to environmentally friendly or environmentally oriented materials (Nowosielski et al., 2007). Appropriate material selection is one of the most important phases of the product design process and has a significant impact on the development of sustainable products (Zarandi, 2011). Traditionally, material selection was based primarily on technical and economic criteria such as strength, temperature resistance, density, hardness, and price. Today, however, these criteria are no longer sufficient, as environmental considerations are increasingly taken into account (Deng & Edwards, 2007).

Consequently, sustainable material selection should be regarded as a multi-objective decision-making problem, involving the optimal alignment between available material profiles and project requirements (Dehghan-Manshadi et al., 2007). Since materials are typically used as components of products, life-cycle thinking is closely associated with product design across the entire life cycle (Bovea & Gallardo, 2006). According to Chiner (1988), the selection of sustainable materials is a complex process that requires managing large amounts of information on material properties, often with multiple viable solutions for a given application.

By contrast, Baharetha et al. (2012) argue that material selection should aim to maximise durability, energy efficiency, recyclability, ease of maintenance, and the use of local materials in order to reduce environmental impacts. Eco-materials represent a key concept in technological development, aiming to harmonise materials with their environmental context by minimising environmental burdens throughout their life cycle (Halada, 2003). This concept introduced a new approach whereby materials should be produced with lower environmental impacts while remaining compatible with material flow systems (Halada et al., 2002).

The transformation of conventional materials into environmentally friendly alternatives has become a necessary and indispensable process for addressing major environmental challenges, including resource depletion, climate change, ozone layer depletion, atmospheric pollution by dioxins, and the growing need for recycling technologies (Baba, 1999). The primary objective of eco-material development is to encourage materials that are environmentally benign, impose minimal environmental burdens during production through efficient raw material use, and are highly recyclable (Oyawa, 2004).

The first formal definition of eco-materials was proposed by Japanese researchers Nishimura and Tada (2003), who described them as substances and materials that support societal sustainability in harmony with the global environment. Sustainable materials are often characterised as materials with high recycled content, low emissions (Zhou et al., 2009), rapid renewability (Glavic & Lukman, 2007), and high levels of reuse (Mora, 2007). According to Bontempi et al. (2021), sustainable materials are derived from renewable resources and exhibit minimal or zero environmental and social impacts during extraction and production.

A comprehensive definition was proposed by Yagi (2002), who stated that eco-materials should reduce negative environmental impacts during their life cycle and meet at least one of the following nine characteristics relative to traditional materials:

1. energy-saving capability,
2. resource-saving capability,
3. recyclability,
4. structural reliability,
5. chemical stability,
6. biosecurity,
7. substitutability,
8. cleanability,
9. ease of use.

According to Halada and Yamamoto (2001), eco-materials are materials that enhance environmental performance throughout their life cycle while maintaining responsible functional performance. Mezawa et al. (2019) define eco-materials as materials developed through environmental life-cycle engineering that outperform conventional materials in life-cycle assessments. Ljungberg (2007), by contrast, defines eco-materials as materials that reduce environmental burdens across their entire life cycle (Shinohara, 2004).

From a practitioner's perspective, Heine defines sustainable materials as those that fit within the constraints of a sustainable material system, where both the material and the system must be mutually compatible to achieve sustainability (Mohamed et al., 2019). Sustainable materials are often classified into three main groups: earth materials, natural fibres, and industrial waste materials (Hsieh et al., 2012).

Sustainable materials are characterised by low consumption rates and high ease of integration (Dammann & Elle, 2006), high durability (Mora, 2007), safe use (Zhou, 2009), high user satisfaction (Ljungberg, 2007), and alignment with societal expectations (Glavic & Lukman, 2007).

The implementation of eco-materials in manufacturing processes is driven by several factors, including:

- corporate social responsibility (Bukarica & Robić, 2013),
- access to environmentally oriented financing programmes (Giesekam, 2016),
- improved indoor environmental quality (Tokbolat et al., 2020),
- enhanced corporate image and reputation (Serpell et al., 2013),
- increased energy efficiency (Durdyev, Zavadskas et al. 2018),
- reduced waste generation (Dubem, 2014),
- life-cycle cost savings (Durdyev, Ismail et al. 2018),
- reduced environmental impacts (Organ et al., 2013),
- supportive environmental policies (Bond & Perrett, 2012),
- customer demand for greener products (Giesekam, 2016).

Despite these drivers, several barriers hinder the widespread adoption of eco-materials:

- insufficient financial incentives (Ametepey et al., 2015),
- resistance to changes in manufacturing practices (AlSanad, 2015),
- perceptions of inferior quality (Akadiri, 2015),
- limited supplier availability (Ohiomah et al., 2019),
- lack of demonstration projects (Darko et al., 2017),
- limited awareness of sustainability benefits (Shari & Soebarto, 2013),
- insufficient environmental concern (Durdyev, Zavadskas et al., 2018),

- lack of training and education on eco-materials (Durdyev, Ismail et al. 2018),
- inadequate awareness of green technologies (Häkkinen & Belloni, 2011),
- long payback periods (Dalirazar & Sabzi, 2023).

Trela (2017) proposed six criteria that materials must meet to be considered eco-materials:

- minimal consumption of natural resources,
- environmental protection and purification functions,
- minimal environmental impact during production,
- absence of hazardous substances,
- high operational performance,
- ease of recyclability.

A slightly different set of criteria for confirming that a material is environmentally friendly was published by Metwally (2019), according to whom these are:

- materials of natural or renewable origin,
- materials produced from efficient resources, where production is by industrial processes that consume low amounts of energy, produce no residues and reduce greenhouse gases,
- materials with a local availability which reduces the energy required for their transportation,
- materials with the possibility of being reused or recycled throughout their life cycle,
- materials with a high durability, as with traditional
- materials with a longer lifespan,
- non-toxic or low-toxicity materials,
- materials with low emissions of volatile organic compounds,
- materials resistant to moisture,
- materials with low maintenance costs,
- materials with unlimited flexibility in the design process.

Eco-materials can be classified according to different criteria. Based on their relationship with the environment, Nishimura and Kuniyuki (2002) distinguish three categories:

- materials providing cleaning and catalytic functions,
- system components enabling highly efficient and clean energy systems,
- materials with low environmental loads that contribute through favourable properties such as recyclability.

A second division of eco-materials relating to their recyclability was presented by Halada (1999) grouping them into three levels:

- easily dispersible materials with functional properties (e.g. materials used in packaging, batteries, paints),
- bulk materials with functional properties (e.g. materials used in packaging, batteries, paints),
- transmission materials (e.g. sheets with a high tensile coefficient).

The latter, by contrast, stems from the perspective of the manufacturers themselves. According to this view, eco-materials are classified into the following six categories (Umezawa et al., 2007):

- materials for environmental clean-up,
- materials for enhanced performance,
- materials with no (or minimised) hazardous substances,
- materials with a green environmental profile,
- materials with higher recyclability, and
- materials with higher resource productivity.

Within the framework of the discussed issues, it is worth noting the division of eco-materials prepared by a team of Polish researchers (Nowosielski et al., 2007), who classified eco-materials into four groups according to two criteria, their source of pow and function:

- non-linear source materials,
- materials for ecology and environmental protection,
- materials for society and human health,
- energy materials.

The demand of the world economy for sustainable materials has been slowly increasing over the last two decades. In addition to the ecological aspect, there are several other advantages of their use. However, it should be noted that the implementation rate of eco-materials remains unsatisfactory. There appears to be an immediate need to increase education and information activities to raise awareness of them, particularly in terms of their potential benefits. The following are the benefits associated with the use of green materials:

- reduce manufacturing costs (Ugochukwu & Chioma, 2015),
- reduce global greenhouse gas emissions (Huang et al., 2019),
- improve human well-being (Lomas, 2019),
- can be recycled (Abyzov et al., 2020),
- contribute to the preservation of biodiversity (Omer & Noguchi, 2020),
- are environmentally friendly, safe, non-toxic and also non-radioactive (Chan, 2021),
- promote knowledge transfer through environmental flexibility (Adeniyia et al., 2020),
- increase energy efficiency (Oshike, 2015),
- are accessible and affordable (Danso, 2013),
- are highly energy-efficient and easily accessible to the public (Magutu, 2015),
- contribute to healthier spaces (Venkitaraman & Joshi, 2002),
- influence the achievement of specific sustainable development goals.

In conclusion, the main institutional barriers to the development of green materials can be summarised as the lack of governmental financial incentives and the fragmentation of legal and institutional frameworks. Another major obstacle to expanding their production is the insufficient capacity for effective collaboration among diverse stakeholder groups. Consequently, research and technological development must be accelerated to better align with future market expectations. Raising stakeholder awareness is also crucial for advancing the development of eco-materials. National governments should launch campaigns to encourage both producers and consumers to adopt the concept of eco-materials. Incentive-based policies can serve as a powerful internal driver to increase the adoption of green materials, while legislation promoting environmentally friendly materials can play a significant supporting role. Finally, local economic conditions, regional resources, and existing production capacities should be taken into account when establishing and refining production standards for environmental materials.

Green Technologies

The concept of green technologies and processes emerged in the 1960s as part of the environmental movement in industrialised countries. The application of such technologies and processes is recognised by both researchers and economic practitioners across households, industry, energy systems, and product manufacturing. The implementation of green technologies enables companies to introduce environmentally friendly processes into production, thereby reducing the negative environmental impacts of production activities (Vrchota et al., 2020).

The scope of green processes and operations encompasses product development and life-cycle management, including environmental practices such as eco-design, Cleaner Production, recycling, and reuse, with a particular emphasis on minimising costs associated with production, distribution, use, and disposal (Lai et al., 2012). In general terms, green technologies refer to specific technologies, industrial processes, or stages of product manufacturing that are capable of reducing environmental pollution, promoting the rational use of natural resources, and increasing the utilisation of renewable energy sources (Heng & Zou, 2010). In both scientific research and business practice, the term *green technologies* (greentech) is often used interchangeably with *clean technologies* (cleantech) and *environmental technologies* (envirotech) (Kwazo et al., 2014). Green technologies, however, are frequently understood as broader approaches and solutions that extend beyond conventional environmental technologies. The implementation of green technology projects aims to conserve natural resources and energy while preventing, mitigating, or minimising pollution and environmental degradation (Zhang et al., 2024).

It should be noted that green technologies play a significant role in stimulating sustainable development by identifying environmentally friendly sources of economic growth, fostering the development of new green industries, creating employment opportunities, and supporting the implementation of innovative technologies (Ghisetti & Quatraro, 2017). Sustainable green technologies contribute to the formation and advancement of a sustainable society while simultaneously promoting environmental protection and economic development. Particular attention should therefore be paid to the factors influencing the innovation capacity of green technologies and to differences in development priorities across sectors (Fujii & Managi, 2019).

Business entities, as key actors in market economies, are the primary drivers of green technological innovation (Wang et al., 2019). Companies that successfully implement green technological innovations can gain access to critical resources through their technological competitive advantages (Sellitto et al., 2020). First, green technological innovation helps firms reduce production costs, conserve resources, and minimise environmental pollution generated by production processes (Stucki, 2019). Second, green innovative technologies are increasingly recognised as strategic resources that confer unique competitive advantages (You et al., 2019). Third, the adoption of green technological innovations assists companies in mitigating environmental pressures and operational risks, improving cost control, and enhancing production efficiency (Çop, 2021). Finally, by introducing products based on green technological innovations, companies can command price premiums and strengthen their market competitiveness (Yin, 2020).

Despite extensive discussion in the literature and among practitioners, there is no single universally accepted definition of green technology. Researchers approach the concept from different perspectives based on their disciplinary backgrounds and empirical studies. Table 2.3 therefore presents selected definitions of the term *green technology*.

An analysis of the literature on environmental technologies allows three main categories to be distinguished (Muralikrishna et al., 2017):

- *Low- and zero-waste production technologies*, which aim to minimise waste at all stages of the production cycle through process modifications, good housekeeping practices, recycling and reuse, and the eco-design of equipment, machinery, and product formulations;
- *Recycling technologies*, which focus on the recovery of raw materials, energy, water, and by-products, often within end-of-pipe treatment processes;
- *Waste recovery and recycling technologies*, which enable the manufacture of products with alternative end uses and achieve waste minimisation through the application of selective, environmentally friendly techniques.

Key criteria guiding the implementation of green technologies include (Sood et al., 2015):

TABLE 2.3 Selected Definitions of the Term Green Technology

Sources	Definitions
Braun and Wield (1994)	A general term for process or product technologies that reduce environmental pollution, energy consumption and raw materials.
Barlet and Trifilov (2010)	Innovations in products and processes that provide value to the customer and the company but significantly reduce environmental impact.
Bakar et al. (2011)	An initiative to improve various types of systems and materials, from techniques to energy generation to non-toxic products.
Bhardwaj and Neelam (2015)	The improvement and application of equipment, systems and products used to save nature and environmental resources that will minimise the adverse effect of human activities.
Morioka and de Carvallo (2016)	An integrated environmental strategy from process to end-user that prevents environmental risks, which is closely linked to business performance.
Shafiei and Abadi (2017)	A broad concept and field of new, innovative ways of environmentally friendly manufacturing and changes in everyday life. It is created and used in such a way as to protect natural resources and the environment. It is intended to be an alternative source of technology that reduces the use of fossil fuels and shows less harm to humans, animals and plants and the world at large.
Diana et al. (2017)	Using raw materials that have a low negative impact on the environment, processing them efficiently and promoting the reuse and minimisation of waste and final products thus changing the products and processes of a given production cycle.
Lal (2018)	A technology that has the potential to increase environmental performance towards other technologies.

- energy efficiency (EE),
- indoor environmental quality (EQ),
- sustainable site planning and management (SM),
- materials and resources (MR),
- water conservation (WE),
- innovation (IN).

Green technologies can contribute to addressing societal challenges across both basic and advanced areas of civilisation. The objectives of environmental technologies in selected areas of society are presented in Table 2.4.

The future of sustainable development will depend on the implementation of practical green solutions across many areas that promote

TABLE 2.4 Action areas and objectives of green technologies

Areas	Goals
Agriculture	Avoiding environmental degradation in agricultural processes.
Food processing	To eliminate toxic substances in food and avoid greenhouse gas emissions and environmental degradation in all food packaging processes.
Drinking water	Large-scale filtration of used water and seawater using green processes without environmental degradation.
Sustainable energy	Developing technologies to harness potential natural energy sources to generate energy without environmental degradation.
Consumer products	Production of a variety of new-generation consumer products, packaging manufacture and use by purchasers without side effects or environmental degradation.
Cars	Production of energy-efficient, emission-free cars using renewable energy sources.
Construction	Construction of environmentally friendly, energy-efficient, intelligent buildings.
Industrial automation	Developing industrial processes that are environmentally friendly, with no greenhouse gas emissions, recyclable, products that use green energy.
Air and space travel	Use of green energy and environmentally friendly materials and processes in air and space travel.
Health	Use of green technology and green processes in all health and medical services.
Education	Use of green technology in all education services.
Communication, information and computing	Development and use of environmentally friendly, recyclable electronic and computer components that use renewable energy and are efficient.

NOTES Adapted from Aithal and Aithal (2016).

the development of clean technologies. Green technologies can help create a new relationship between people, nature, and the contemporary world (Wu & Strezov, 2023). The concept of green technology presented by the authors clearly demonstrates that, in order to address growing environmental crises, the global economy must undertake a green transition toward more sustainable modes of production and consumption. An essential element of such a sustainability transition is the implementation of clean and environmentally friendly technologies. Although the green technology market has a relatively short history, it has attracted significant interest from governmental and business stakeholders, as well as from the third sector, due to increasing awareness of climate change impacts and the depletion of natural resources.

Environmental Labels and Declarations

The use of labels and declarations to inform consumers about the environmental performance of products has a long and well-established history. One of the earliest examples is the *Demeter* label, created in 1928 to enable consumers to choose products originating from biodynamic agriculture. The Demeter symbol was registered as a trademark, and the first quality standards were formulated at the same time. Half a century later, the *Blue Angel* label was introduced in 1978 and is widely regarded as the first comprehensive eco-label, incorporating multiple criteria and a life-cycle perspective. Following its introduction, subsequent decades saw a global increase in the number of environmental labels and declarations in operation (Skaar, 2023).

Environmental labelling focuses on the standardised communication of the environmental aspects of manufactured products. It is a global process driven by societal concerns related to safety, health, and environmental performance (Xu et al., 2017). The labelling process serves as a means of communicating product information to consumers through symbols (d'Souza, 2000). The environmental impacts of products are expressed through eco-labels and claims designed to convey environmental information (Charter, 2001), indicating that a product complies with established environmental standards (Witek, 2017).

Eco-labels have been introduced to validate the principles of sustainability, guide green purchasing decisions, and enhance environmental and social performance in relation to products and processes (Yenipazarli, 2015). They function as policy tools that identify the best environmental options available on the market for consumers wishing to express their preferences through purchasing decisions (Harbaugh et al., 2011). Eco-labels also support the cognitive decision-making processes of consumers (Thogersen & Nielsen, 2016).

Although consumers are often not fully aware of the certification and control procedures underlying eco-labelling, which may raise concerns about the authenticity of green products, they nevertheless tend to place trust in certifying organisations and are willing to pay higher prices for labelled products (Gerrard et al., 2013). Consumer trust is therefore one of the most important factors determining the success of external certification programmes (Janssen & Hamm, 2012).

Environmental labels are frequently used by business entities to differentiate their products, position them in the market, and communicate environmentally friendly messages to stakeholders (d'Souza, 2000). According to Russel and Robidas (2019), an environmental label is a seal, symbol, or logo that conveys information indicating that a product meets a broad range of environmental standard criteria during production and even after use.

Baranyi (2008) defines an eco-label as a communication tool indicating that a product bearing such a label has a lower environmental impact throughout its life cycle, from cradle to cradle, compared to similar products or services. Bruce and Laroiya (2007) describe eco-labelling as a market-based technique for communicating consumers' environmental requirements. Truffer et al. (2001) define eco-labelling as the provision of relevant environmental information on product labels in order to promote environmental objectives through consumer choice.

According to Thogersen et al. (2010), eco-labelling involves providing consumers with information on the environmental quality of products at the time of purchase to assist them in selecting environmentally acceptable options. Atkinson and Rosenthal (2014) view eco-labels as information tools designed to inform consumers about the external environmental impacts of products related to their production, consumption, and disposal. The primary purpose of eco-labelling is to reduce information asymmetry between producers and consumers regarding the environmental attributes of products and services (Delmas & Lessem, 2017).

Based on a study conducted by Delmas and Grant (2008), three key steps were identified as crucial in the eco-labelling process:

- adoption of environmentally friendly practices by the company,
- third-party environmental certification of the company,
- communication of certification through labels placed on products for consumers.

Eco-labels perform several important functions (Kowal et al., 2013):

1. *Environmental function*, which is primary and reflects the role of eco-labels as instruments of environmental protection.

2. *Information and education function*, related to providing reliable and transparent information on product characteristics and environmental impacts.
3. *Stimulation function*, encouraging manufacturers to adopt pro-environmental activities in line with Cleaner Production principles.
4. *Marketing function*, supporting the development of competitive advantage, increasing sales of environmentally friendly products, and limiting the market presence of environmentally harmful goods.
5. *Protective function*, including:
   - protection of social interests by transferring environmental costs to producers,
   - protection of consumers through transparent product information,
   - protection of economic operators' interests by reflecting buyer preferences.

The eco-labelling process may take into account different criteria depending on the information that management intends to communicate to consumers. Purchasers may consider one or more of the following product characteristics to be particularly relevant (Gołaszewska-Kaczan et al., 2015):

- presence of toxic substances,
- presence of artificial additives,
- greenhouse gas emissions from production, transport, and consumption,
- resources used in the production process,
- waste generated during production,
- use of non-renewable resources,
- energy consumption,
- water pollution caused by production,
- geographical origin of products and resources,
- use of child labour.

The increasing number of labels and declarations has created a need for greater cooperation among organisations involved in standardisation. Through the International Organization for Standardization

(ISO), a series of standards known as the ISO 14020 family was developed in the late 1990s, establishing principles for communicating environmental performance through labels and declarations (Rusko & Koraus, 2013). Three main types of voluntary environmental labels are defined (Minkov et al., 2018):

1. ISO 14024:1999 – Type I environmental labelling,
2. ISO 14021:1999 – Type II self-declared environmental claims,
3. ISO/TR 14025:2000 – Type III environmental declarations.

Type I labels, also known as official eco-labels, are voluntary schemes certified by third parties that indicate superior environmental performance within a product category and aim to encourage more sustainable consumption patterns (Horne, 2009). Type II labels are self-declared claims by manufacturers, typically addressing a single environmental attribute and often used due to limited regulatory oversight (Lavallée & Plouffe, 2004). Type III labels are life-cycle-based environmental declarations containing verified quantitative data and are the least commonly used form (Struwig & Adendorff, 2018).

In conclusion, it is worth emphasising that over the last few years eco-labels should be seen in the context of the benefits they can bring to both producers and consumers (Wang et al., 2015). Eco-labels have become a strategic means of communication for environmentally friendly products (Clemenz, 2010).They have a positive impact on consumer awareness of the environmental identity of products, which has been recognised by national governments, economic operators and other organisations concerned with environmental issues in the broader sense (Sammer & Wüstenhagen, 2006). From the point of view of a business organisation, eco-labels are expected to promote environmentally friendly products and provide companies with a competitive advantage. For consumers, eco-labels aim to reduce uncertainty about the environmental impact of products and to help customers choose those products that are more environmentally friendly and cause less environmental damage throughout the life cycle of the product (Murali et al., 2018).

Eco-Efficiency in the Context of Cleaner Production

The term *efficiency* has its roots in antiquity and is derived from the Latin *efficiens*, which in turn comes from the verb *ex facio* and means to obtain or accomplish something. The concept can be found in both pre-Roman civilisation and ancient Greece, where the term *oikonomia* first appeared, referring to the efficient management of household resources (Rodica & Ion, 2013).

An important milestone for the concept under discussion is the year 1978, when the notion of eco-efficiency was first described by McIntyre and Thornton (1978). However, it was not until 1992 that the term gained widespread recognition following its popularisation by Stephan Schmidheiny (1992) in his book *Changing Course: A Global Business Perspective on Development and the Environment*. In this monograph, the author sought to change the prevailing perception of industry as the primary cause of environmental degradation, presenting it instead as a key actor and part of the solution for sustainable global development.

It should be noted that over the past decade, owing to the involvement of international institutions such as the Organisation for Economic Co-operation and Development (OECD), the World Business Council for Sustainable Development (WBCSD), and the scientific community, the concept of eco-efficiency has attracted considerable attention from decision-makers and business managers. As a result, it has been widely promoted and implemented across numerous industries.

Eco-efficiency is a key concept that deliberately integrates the economic aspects of production with its environmental impacts. It is achieved through the progressive reduction of environmental burdens and excessive resource use throughout the life cycle of products, to a level that does not exceed the assimilative capacity of the planet (Nowosielski, 2008). Eco-efficiency is regarded as a fundamental principle of environmental action and one of the most desirable approaches in terms of organisational development (Janicke, 2008), administrative compliance, and business challenges (Huppes & Ishikawa, 2005).

According to the literature (Zbierowski, 2010), the concept of efficiency consists of two dimensions: efficiency and flexibility. Efficiency, also referred to as economic efficiency, encompasses economic, technical, and non-economic efficiency (Kowalski, 1992). Efficiency may be understood in two ways: as a general term indicating work that is carried out effectively and economically, and as a technical assessment rooted in industrial experience, closely linked to machine performance and energy thermodynamics (Alexander, 2009).

Glavič et al. (2012) define eco-efficiency as a management strategy of doing more with less, based on creating greater quantities of products and services using fewer natural resources, while generating less waste and pollution. It is a pathway to sustainable development that integrates environmental performance with economic outcomes. Mickwitz et al. (2006), in turn, describe eco-efficiency as a tool for sustainability analysis that reflects the practical relationship between economic activity and environmental costs and impacts.

Spanish researchers from the University of Salamanca, Gallego-Álvarez et al. (2014), identify several elements of environmental performance, including minimising pollutants, conserving resources, reducing waste, saving energy, marketing safe products, and reporting potential risks.

For eco-efficiency to be effectively applied within companies, appropriate environmental performance criteria are required to monitor trends over time. Such criteria include material consumption, energy intensity, pollution emissions, use of renewable resources, and product life extension, all of which are closely linked to production activities. In this context, eco-efficiency is associated with several complementary concepts of sustainable management, including Cleaner Production, industrial ecology, life-cycle thinking, corporate social responsibility, and the circular economy (Rybaczewska-Błażejowska, 2021). Accordingly, eco-efficiency is applied in multiple domains, such as public policy (Hukkinen, 2003), cleaner production (Stevenson & Evans, 2004), industrial ecology (Ehrenfeld, 2005), and environmental management and corporate sustainability (Figge & Hahn, 2004).

A widely accepted definition of eco-efficiency was proposed by the World Business Council for Sustainable Development (WBCSD), according to which eco-efficiency is achieved by providing competitively priced goods that meet human needs while progressively reducing environmental impacts and resource intensity throughout the life cycle (de Simone & Popoff, 2000; WBCSD, 2006). The Organisation for Economic Co-operation and Development (OECD, 1998) defines eco-efficiency as the ratio of the economic value of outputs to the environmental impacts associated with products or services.

Similarly, Huppes and Ishikawa (2005) define the eco-efficiency of a product as the ratio of its economic value to its environmental impact. Michelsen et al. (2006) describe eco-efficiency as the value of a product or service per unit of environmental impact. Reinhard et al. (1999) provide a more detailed definition, describing eco-efficiency as the ratio of the minimum observable use of environmentally harmful inputs, given observed levels of desired outputs and conventional inputs.

Lober (1996) views environmental performance as an organisation's commitment to preserving and protecting its environment across multiple dimensions, including water, air, and soil quality. In contrast, Long et al. (2015) define eco-efficiency as the ability of enterprises to produce goods or services while conserving energy and resources and reducing waste and emissions. According to Möller and Schaltegger (2005), eco-efficiency reflects the relationship between the creation of economic value and the resulting environmental impacts. Levidow et al. (2014) define eco-efficiency as the process of increasing economic benefits while reducing environmental burdens.

Sinkin et al. (2008) describe eco-efficiency as a management philosophy that stimulates environmental improvements yielding parallel economic benefits. Lee et al. (2016) define eco-efficiency in the context of sustainable development strategies as a specific methodology for achieving sustainable development in the actions of governments, businesses, and individuals.

Conducting an eco-efficiency analysis within a business organisation primarily aims to (Czaplicka-Kolarz et al., 2010):

- reduce resource consumption, particularly energy, materials, water, and land;
- reduce environmental impacts by lowering emissions of pollutants and toxic substances and increasing the use of renewable raw materials;
- increase the added value of products through improved functionality, durability, and flexibility with lower material and energy inputs;
- enhance economic efficiency while simultaneously reducing environmental impacts.

The WBCSD has defined a set of eco-efficiency targets that provide guidance for companies seeking to improve their environmental and economic performance (Song et al., 2015):

- reducing resource, material, and energy consumption through increased recycling;
- minimising environmental impacts through sustainable use of renewable resources and reduced emissions and waste;

- providing customers with higher-quality products and services while extending product lifespans, without compromising environmental objectives;
- process re-engineering to reduce resource use, pollution, and costs;
- product re-engineering through the reuse of waste as inputs for secondary products;
- development of new product concepts that require fewer materials and facilitate reuse and recycling;
- rethinking markets to better meet customer needs in more sustainable ways.

For organisations that regard sustainable development as a core element of competitive advantage, it is essential to seek organisational and technological solutions that reduce environmental burdens while improving resource efficiency (Pagan & Prasad, 2007). Measuring eco-efficiency is therefore important for monitoring improvements in material quality, production procedures, technological advancement, customer expectations, and competitive performance (Zielińska-Chmielewska et al., 2021).

Environmental performance measurement enables organisations to identify strengths, weaknesses, threats, trends, and opportunities for improvement in response to evolving market conditions (Bezerra et al., 2019). Eco-efficiency increases when environmental impacts are reduced or stabilised while the economic value of products increases (Picazo-Tadeo et al., 2011). Common economic indicators used in eco-efficiency analysis include (Rybaczewska-Błażejowska & Masternak-Janus, 2017):

- contribution of products to gross domestic product (GDP),
- value added,
- output of the primary industry sector.

Environmental Efficiency Assessment (EEA) is regarded as a validation process involving (Sorvari et al., 2011):

- defining the scope and objectives of the assessment,
- data collection and processing,
- environmental impact assessment,
- interpretation and evaluation of environmental performance.

Eco-efficiency indicators are considered essential tools for sustainability analysis at the corporate level (Zhou et al., 2018), as well as across sectors such as the food industry (Ingaramo, 2009), forestry (Koskela & Vehmas, 2012), urban transport (Moriarty & Wang, 2015), and construction. Over the past two decades, various methodologies have been developed to assess eco-efficiency, including the rational approach (Zhu & Qiu, 2008), the analytic hierarchy process (AHP) (Tian et al., 2009), entropy weighting (Han et al., 2011), grey relational analysis (Pan et al., 2013), and data envelopment analysis (DEA) (Wu et al., 2016). In addition, companies frequently employ self-monitoring systems to support eco-efficiency evaluation (Atienza-Sahuquillo & Barba-Sánchez, 2014).

Eco-efficiency is a key environmental indicator that enables organisations to modify business activities in favour of environmental protection over defined time horizons (Sadorski, 2021). Eco-efficiency and the Cleaner Production Programme share several common dimensions, as both support continuous improvement in reducing resource consumption, environmental burdens, and associated risks and liabilities. While the two concepts may overlap and yield similar outcomes, their perspectives differ: eco-efficiency primarily emphasises cost reduction and value creation, whereas Cleaner Production focuses on minimising negative environmental impacts (Howgrave-Graham & van Berkel, 2006).

Although the term *Cleaner Production* may suggest a narrow focus on production processes, it is now understood as encompassing the entire life cycle of products and services, similar to eco-efficiency. Both concepts support organisations in identifying business opportunities and enhancing efficiency across the supply chain. They are often used interchangeably but should be regarded as complementary. Eco-efficiency focuses on strategic value creation, whereas the Cleaner Production Programme emphasises operational improvements within production processes (van Berkel, 2000). This integrated approach highlights their alignment with other preventive environmental management strategies that incorporate environmental considerations across the full product life cycle, including research and development, design, production, operation, maintenance, and transport (World Business Council for Sustainable Development & United Nations Environment Programme, 1996)).

Table 2.5 presents preventive practices associated with the Cleaner Production concept juxtaposed with eco-efficiency goals.

TABLE 2.5 Preventive Practices of Cleaner Production versus Eco-Efficiency Goals

Preventive practices of Cleaner Production	Eco-efficiency goals
1. Good housekeeping: improving operation, maintenance and management procedures. 2. Input substitution: use of environmentally preferred and 'fit for purpose' process inputs. 3. Technology modification: improvement of the production facility. 4. Product modification: changing the characteristics of a product to reduce its lifecycle environmental impact. 5. (On-site) reuse and recycling: recovery and reuse of materials, energy and water.	1. Reducing the material intensity of goods and services. 2. Minimising the energy intensity of goods and services. 3. Reducing the spread of toxic substances. 4. Increasing the recyclability of materials. 5. Maximising sustainable use of renewable resources. 6. Extending product life. 7. Increasing the service intensity of goods and services.

It is important to emphasise that both strategies discussed above pursue a similar objective, namely the transformation of the economy towards greater sustainability. These evolutionary concepts enable business actors to adapt to dynamic changes occurring in an increasingly competitive market. Both Cleaner Production and eco-efficiency can be implemented and applied by business entities across all sectors, regardless of their size or the level of economic development of the country in which they operate.

In summary, it can be stated that the Cleaner Production programme represents an avant-garde solution within the field of environmental management systems (Çay, 2018). As Hillary (1999) argues, progress towards Cleaner Production requires new attitudes rather than new technologies. A systems approach enables the exploration of as many 'new attitudes as human imagination can generate (Carnegie et al., 2000).

Although the Cleaner Production concept is often presented as a win–win solution, this outcome is not always achieved in practice. Within the CP framework, there are activities that require substantial investment and long payback periods, which may reduce the perceived benefits for some investors (Sarkis & Dijkshoorn, 2007). This partly explains why, despite its many advantages, the programme has encountered difficulties in achieving widespread acceptance among business managers (Khalili et al., 2014). Furthermore, it is argued that the implementation of CP programmes alone does not guarantee continuous environmental improvement unless appropriate management systems are established to ensure cyclical and systematic improvement processes (Zwetsloot, 1995). This highlights the urgent need for policy-makers to develop and implement proactive and integrated policies and strategies that support societies in managing resources in a more sustainable manner (Jegatheesan et al., 2009).

Despite the passage of more than two decades, the observations made by Carnegie et al. (2000) remain highly relevant. They noted that Cleaner Production has evolved from end-of-pipe solutions to higher-level management actions; however, in order to halt the progressive deterioration of the environment, further steps are required. The concept of Cleaner Production must extend beyond the boundaries of industry towards partnerships between the manufacturing sector and society. To achieve this, the increasing complexity of industry, and consequently of sustainability itself, must be presented in a manner that is as simple, accessible, and comprehensible as possible.

Chapter Three

Ecological, Economic and Social Aspects of CP Implementation on the Example of CEMEX Poland

General Characteristics of the Cement Industry

The construction industry is a key element of global development, as cement and concrete materials, being fundamental construction components, are widely used in various infrastructure projects, ranging from urban buildings and industrial facilities to bridges, motorways, ports, and dams (Zheng et al., 2025). As a result, they have become the most widely used materials and the most heavily consumed resources on Earth (Gagg, 2014). This situation is associated with high levels of pollution, depletion of natural resources, and greenhouse gas emissions, leading to significant negative environmental impacts (Sev, 2009). This reality is largely the outcome of dynamic globalisation processes and the ongoing industrialisation of the planet (Ayodele et al., 2017).

It should be emphasised that the construction sector is responsible for nearly 60% of all waste generated worldwide (Abed et al., 2022) and approximately 39% of carbon dioxide (CO_2) emissions released into the atmosphere (Alwis et al., 2025). In addition, it consumes around 40% of global energy resources (Baek et al., 2013), with up to 50% of this consumption attributable to construction materials alone (Reddy & Jagadish, 2003). Furthermore, the high intensity of construction activity results in substantial consumption of natural resources, water, and wood (Khan et al., 2024).

Through the use of innovative technologies, the construction industry is expected to implement sustainable technological solutions; however, many commonly used building materials remain environmentally unfriendly (Global Alliance for Buildings and Construction, International Energy Agency, & United Nations Environment Programme, 2020). Life-cycle studies of building materials (Marinova et al., 2020), considering annual production volumes, raw material use, energy consumption, and pollution during production and recycling, have prompted a reassessment of both production methods and end-use practices. This reassessment has focused attention on choices that lead to a reduction in carbon footprints (Churkina et al., 2020).

Conventional construction techniques are largely based on energy-intensive manufacturing operations, particularly cement production, which is a major contributor to global carbon dioxide (CO_2) emissions, the most problematic greenhouse gas (GHG) (Sanal, 2018). Cement production is a complex process requiring significant quantities of natural raw materials, mainly limestone, fuels for heat generation, electricity, and auxiliary materials such as water and air (Galvez-Martos & Schoenberger, 2014). Its manufacture represents the second-largest industrial source of carbon dioxide emissions, accounting for approximately 5–10% of global anthropogenic CO_2 emissions (Jakobsen et al., 2017) and about 3% of total greenhouse gas emissions (Feiz et al., 2015). Moreover, cement production accounts for roughly 12–15% of total industrial energy consumption worldwide (Usón et al., 2012).

Cement is the principal binder in concrete and provides the mechanical strength required for structures to withstand heavy loads. In the modern industrial world, Portland cement (PC) has become an important and strategic raw material (Phair, 2006). Global cement production exceeded 4 billion Mg/year in 2023, making it one of the largest industrial activities worldwide (Guo et al., 2024). Demand for cement has grown steadily over recent decades and is expected to continue rising (Xu et al., 2023). Forecasts indicate that global cement production may increase by 12–23% by 2050, resulting in annual emissions of approximately 4.3 Gt of CO_2 equivalent, representing a 260% increase compared with 1990 emission levels (Khan et al., 2023).

It is estimated that around 50% of global cement production is used for ready-mix concrete, while the remainder is incorporated into mortars, plasters, screeds, coatings, and other applications (Smith et al., 2002). Portland cement is manufactured from widely available and relatively inexpensive raw materials, making it accessible in almost every region of the world (Scrivener et al., 2018). Fuel and energy costs represent approximately 40% of the total production costs in the cement industry (Kuandykova et al., 2024).

The primary component of cement is clinker, which constitutes 95–100% of cement mass; the remaining portion consists of supplementary materials such as slag, limestone, and gypsum. Chemically, clinker comprises oxides including CaO, SiO_2, Al_2O_3, and Fe_2O_3 (Teplicka et al., 2023). Producing 1 Mg of Portland cement requires, on average, about 1.5 Mg of natural raw materials, 3,300–4,300 MJ of thermal energy, and approximately 100–120 kWh of electrical energy (Luo et al., 2024). Total energy demand depends on factors such as plant location, production capacity, process technology, electricity generation mix, and kiln fuel selection (Gursel et al., 2014).

The largest cement producers are China, India, Vietnam, the United States, Indonesia, Turkey, Iran, Brazil, Russia, Japan, Egypt, and South Korea, with Asia accounting for the largest share of production. These twelve countries collectively produce about 80% of global cement output, with China alone responsible for more than 50%. In terms of demand, the Asia–Pacific region accounts for approximately 75% of global consumption. Meeting future demand remains challenging (Kim et al., 2022), as the cement industry faces issues such as declining fossil fuel availability, natural resource scarcity, increasing demand, heightened environmental scrutiny from stakeholders, and global economic uncertainty (Benhelal et al., 2020).

According to the European standard NF EN 197-1, cement is defined as a hydraulic binder: a finely ground inorganic material that, when mixed with water, forms a paste that sets and hardens through hydration reactions and retains its strength and stability even under water (AFNOR, 2012). When mixed with water and fine aggregates (sand), cement forms mortar, whereas the addition of coarse aggregates (gravel) produces concrete (Krishnya et al., 2021). Among the various types, Portland cement remains the most widely used due to its excellent mechanical properties, durability, versatility, availability, and ease of application (Lin et al., 2025; Nilimaa, 2023).

Cement production has a significant negative impact on the environment, mainly due to its resource-intensive nature and high levels of anthropogenic carbon dioxide emissions (da Cruz et al., 2021), with total carbon dioxide emissions estimated to be around 0.564 Mg CO_2 per 1 Mg of cement produced (Costa & Ribeiro, 2020). This places the industry at the centre of global discussions on sustainability and the reduction of greenhouse gases (GHG) (Miller et al., 2021). It is important to stress that the environmental impact of cement does not end at the production stage.

The cement manufacturing process contributes to environmental pollution and anthropogenic climate change by emitting, in addition to the aforementioned carbon dioxide, a broad spectrum of atmospheric pollutants, including the particularly troublesome $PM_{2.5}$ and PM_{10} (Wang et al., 2006), which account for 40% of total industrial emissions (Sánchez-Soberón et al., 2015), chlorine gas, nitrogen oxides (NO_x), sulphur dioxide (SO_2), ammonia (NH_3), and various greenhouse gases. These emissions mainly originate from two sources: the combustion of fossil fuels in cement kilns and the calcination of limestone, in which calcium carbonate ($CaCO_3$) is transformed into calcium oxide (CaO) while releasing carbon dioxide (CO_2) (Guo et al., 2024). The decarbonisation process of limestone, which is necessary for the production of clinker, accounts for about 60% of the total CO_2 emissions from cement production; CO_2 is, in turn, the dominant greenhouse gas causing global warming (Liao et al., 2022).

Recent studies have identified cement production as one of the main industries responsible for CO_2 emissions (Shivaprasad et al., 2024), second only to the energy sector, as each Mg of Portland cement (PC) produced emits approximately 0.8–0.9 tonnes of CO_2 (Ige et al., 2024). The cement industry is estimated to account for about 6–8% of total global CO_2 emissions (Friedlingstein et al., 2023), which has a significant negative impact on the environment, mainly due to its resource-intensive nature and high levels of anthropogenic carbon dioxide emissions (da Cruz et al., 2021), while total carbon dioxide emissions are estimated at approximately 0.564 Mg CO_2 per 1 Mg of cement produced (Costa et al., 2020).

It should be strongly emphasised that since the beginning of the 1990s, total CO_2 emissions have increased by approximately 200%, mainly due to the increase in demand for cement, despite a decrease in the average clinker content of cement (Andrew, 2018).

The negative environmental impact of cement does not end at the production stage. The life cycle of cement also includes its transport, use in construction, and end-of-life processes such as building demolition and material recycling (Dacić et al., 2024). Life cycle analysis (LCA) is defined as the collection and assessment of inputs, outputs, and potential environmental impacts of a product system throughout its life cycle. This methodology enables the quantification of associated environmental burdens, as well as the identification of processes that significantly contribute to these impacts, and is therefore an essential application tool in the design of materials, products, or systems (Buyle et al., 2013).

LCA of cement allows for a comprehensive assessment of its environmental impact at all stages of production, enabling the identification of key areas where these impacts can be reduced (Qiao et al., 2022).

The cement industry is increasingly interested in identifying substitute materials to replace natural resources due to economic, social, and environmental concerns (Guo et al., 2018).

Reducing the negative environmental impact of cement production requires intervention at multiple stages of the production process. From a technological perspective, one strategy is to improve production lines by upgrading them or replacing inefficient equipment with more efficient and less energy-intensive alternatives (Vinci et al., 2019).

Further measures should focus on optimising the energy efficiency of production systems (Xu et al., 2012), as energy consumption accounts for 50–60% of total production costs, while thermal energy alone represents 20–25% (Sahoo et al., 2022).

An increasing number of cement plants are implementing waste heat recovery systems to achieve higher levels of energy efficiency in line with current requirements, standards, and regulations. Waste heat in the cement industry is typically of a medium grade and ranges from 100 °C to 400 °C (Jouhara et al., 2018). Waste heat from the kiln can be utilised as an energy source, thereby reducing thermal energy losses and improving the overall energy efficiency of the cement production process. Energy efficiency can also be improved through the use of advanced process control and management systems, as well as high-efficiency motors and drives and increasingly efficient grinding technologies (Scripcariu et al., 2021).

Another important area involves the optimisation of production processes by transitioning away from traditional energy sources, such as coal and oil-based fuels, and towards alternative fuels, including RDF (Refuse-Derived Fuel), biomass, or rubber waste (Sousa & Bogas, 2021). It appears that a key strategy for reducing carbon dioxide (CO_2) emissions is the use of various types of substitutes to lower the clinker content, which is the most energy-intensive component of the cement production process (Neto et al., 2025).

Consequently, the reduction of CO_2 emissions is being actively explored by both academic researchers and industrial practitioners. One effective approach is the partial or complete replacement of clinker with various types of additives (Ortega et al., 2017), most of which are waste residues from other industrial processes, such as fly ash, silica dust, ground granulated blast furnace slag, and lime meal (Ortega et al., 2016). Due to the limited availability of these non-clinker raw materials for the decarbonisation of the cement sector, alternative materials are being sought (Baran, 2021). The most favourable solution involves the use of raw materials with pozzolanic properties that do not require additional heat or chemical treatment, including zeolite, spongilite, diatomite, pumice, and trass (Spychał & Kotwa, 2022).

An interesting solution in the production of Portland cement is the use of waste stone meal, such as granite, marble, basalt, or chalcedonite meal (Czarnecki et al., 2023).

The level of clinker substitution with industrial waste has remained stable for several decades at approximately 20% (Habert et al., 2010).

According to Scrivener et al. (2018), the use of substitute cementitious materials could not only reduce CO_2 emissions from cement production by approximately 400 million Mg year^{-1}, but could also have a positive effect on improving the technical properties of cement, particularly its durability and chemical resistance (Hebbache et al., 2024). It should also be noted that an innovative method for reducing CO_2 emissions into the atmosphere is carbon capture and storage (CCS) technology (Clark et al., 2025). Although CCS technologies are well known, they remain costly and are therefore still at the demonstration stage of technological readiness (Bacariza et al., 2020). In addition, the flue gases emitted from the main stack of a cement kiln contain large amounts of pollutants such as N_2, SO_x, NO_x, and CO, which makes it difficult to capture and directly utilise pure CO_2 (Speight, 2019).

Cement production has been identified as a major consumer of natural resources, fossil fuels, and energy, as well as a significant source of numerous pollutants. Furthermore, cement producers are under substantial pressure from stakeholders to reduce the environmental impact of their products and activities; therefore, the implementation of sustainable solutions in the cement industry is of fundamental importance (Rukuni et al., 2022).

Brief Description of the Technological Process

Portland cement is a hydraulic cement composed primarily of calcium silicates, usually with ground clinker as the main ingredient. In the most general terms, the production of Portland cement (PC) involves combining limestone, silica, alumina, iron ore, and trace elements, and then heating the resulting mixture to a high temperature of approximately 1450 °C (Sahoo et al. 2022).

With regard to the moisture content of the raw meal, PC production processes can be classified into dry, semi-dry, semi-wet, and wet processes (Madlool, 2013). It should be noted that cement production requires complete evaporation of water from the raw material components; the higher the water content, the more energy-intensive the process becomes. On the other hand, a higher water content facilitates homogenisation and mixing. The dry process is the most preferred because it consumes less energy than the wet process (Barker et al., 2008).

The dry process, which is the most common method for producing PC, generally follows a four-stage sequence (Schindler et al., 2024):

- In the first stage, limestone and clay (or sand, slate, and slag) are ground and mixed.
- The mixture is then heated to approximately 1500 °C.
- The resulting material is rapidly cooled to form granules known as clinker.
- Finally, a small amount of gypsum (approximately 5% by weight) is added to the clinker to obtain PC.

The first stage of conventional Portland cement production begins with the extraction and grinding of limestone ($CaCO_3$, approximately 80%) and clay or shale (sources of silica SiO_2, alumina Al_2O_3, and hematite Fe_2O_3, approximately 20%) (Hwidi et al., 2018) into a fine powder to produce the raw meal, which is then heated to about 900 °C using cyclones to initiate clinker formation (Verma et al., 2020). This processing step can be carried out using either the dry or wet method. In the dry method, limestone and clay are crushed separately and then fed together into the mill. In contrast, the wet method involves mixing the clay with water to form a paste in a mud mill (i.e. a vessel in which clays are ground in the presence of water), with the crushed limestone added only at the final stage.

The clinker-forming process, which constitutes the main stage of cement production, consumes more than 70% of the total energy required (Ighalo & Adeniyi, 2020).

Clinker formation involves heating the raw material mixture in a rotary kiln to a temperature of approximately 1450 °C (Laita et al., 2019). During this process, limestone undergoes thermal decomposition, releasing carbon dioxide (CO_2) and producing calcium oxide (CaO) (Sousa & Bogas, 2021). Simultaneously, the remaining oxides in the mixture participate in reactions associated with the clinkerisation process, which is facilitated by the rotary motion of the kiln (Antunes et al., 2021).

This high-temperature combination, which inhibits complete melting, promotes the formation of primary tricalcium silicate phases (Ca_3SiO_5) and secondary dicalcium silicate phases ($2CaO{\cdot}SiO_2$), alongside tricalcium aluminate ($3CaO{\cdot}Al_2O_3$) (Andrew, 2019). In general, the energy used to heat the raw material mixture to initiate chemical reactions is partially lost through radiation from the furnace shell (Wang et al., 2014), accounting for approximately 15–16% of total energy consumption (Laita et al., 2019). Additionally, hot gases leave the furnace carrying heat energy in the form of CO_2 and other combustion products. This stage is referred to as the clinkerisation process, during which the initial raw material mixture is transformed into clinker, consisting of grey, spherical nodules with diameters ranging from 5 to 25 mm (Schumacher & Juniper, 2013).

After leaving the kiln, the hot clinker is transferred to a cooler. The large temperature difference between the firing zone and the beginning of the cooling zone (approximately 1200 °C) is crucial for achieving optimal strength properties. The residence time of clinker in the cooler is approximately 30 minutes (Janus et al., 2024); this relatively short cooling period is intended to prevent undesirable chemical reactions (Mikulcic et al., 2016).

The cooled clinker subsequently undergoes grinding in ball mills or, increasingly, in vertical mills or roller presses. Approximately 40% of the total electricity demand is consumed during this stage (Qian et al., 2013). The parameters directly influencing energy consumption during clinker grinding include the type of mill used, rotational speed, power, and the size and quantity of the feed material (Santosh et al., 2023). In addition, the type and dimensions of grinding mills play a key role in determining grinding efficiency and overall energy consumption (Abdelhaffez et al., 2022).

Calcium sulphate ($CaSO_4$, in the form of gypsum, synthetic gypsum, or anhydrite) is added to the fired clinker at a rate of approximately 5%, after which the resulting mixture is subjected to grinding. It should be noted that the grinding of finished cement is carried out in a single step, which is particularly important because the materials involved exhibit markedly different grinding behaviours (Henao-Duque et al., 2021).

In the general production process described above, the most common type of Portland cement is obtained. However, due to the increasing emphasis on reducing the carbon footprint, minimising production costs, and modelling cement parameters, large quantities of hydraulic additives are often introduced during the grinding stage. These additives include granulated blast furnace slag, pozzolanic materials (most notably fly ash from the power industry), or limestone, resulting in a wide range of blended cements.

Gypsum is a critical additive that plays a key role in the production of Portland cement. It is a relatively common mineral composed mainly of calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$) and occurs naturally in various forms, including crystals and precipitates (Luzha et al., 2024). Gypsum is added to regulate the setting time of cement, preventing excessively rapid or delayed setting. Its inclusion improves cement workability by reducing the amount of water required for a given mix, making the cement smoother and easier to handle, and further reducing the risk of cracking and shrinkage (Gyabaah et al., 2022).

The resulting ready-mixed cement is then pneumatically conveyed into specialised silos for storage and subsequently packaged into paper bags or bulk containers (Lavagna & Nistico, 2023).

History and Development of the CEMEX Company

The origins of the CEMEX Group can be traced back to 1906, when Cementos Hidalgo was founded near the city of Monterrey in northern Mexico and commenced operations with a cement plant of an annual capacity of 5,000 Mg. In 1920, Lorenzo Zambrano founded Cementos Portland Monterrey, launching a cement plant with a capacity of 20,000 Mg/year in nearby Monterrey. In 1931, Zambrano orchestrated the merger of these two plants, resulting in the creation of Cementos Mexicanos, later renamed CEMEX (Cawman & Fine-Skalnik, 2021).

The company's original strategy focused on thoroughly understanding and adapting to the specific conditions of the Mexican market. Responding to customer expectations included offering bagged cement to individual customers, which marked a departure from the wholesale-oriented model prevalent in developed markets. For the subsequent 35 years, CEMEX remained a local company. In 1966–1967, through the acquisition of the Mérida plant in Yucatán from Cementos Maya and the construction of new plants in Ciudad Valles (San Luis Potosí) and Torreón (Coahuila), CEMEX became a regional player. Another milestone occurred in 1976, when CEMEX debuted on the Mexican stock exchange while simultaneously acquiring three plants owned by Cementos Guadalajara. In the same year, company management decided to change the corporate name from Cementos Mexicanos S.A. to CEMEX, reflecting the organisation's evolving identity and global ambitions. Following the acquisition of its main national competitor, the Cementos Tolteca Group, in 1989, CEMEX achieved a 65% share of the Mexican cement production market.

Until the late 1980s, the CEMEX Group grew primarily within the domestic market through organic growth and acquisitions of local competitors. International activity during this period was limited to cement and clinker exports, which reached 574,000 Mg/year in 1985 (Lessard & Lucea, 2009). The early 1990s marked the adoption of a new corporate strategy focused on acquiring cement businesses operating in emerging markets. According to CEMEX management, this approach offered several advantages: emerging markets were expected to grow faster than developed economies, and strong economic growth is a fundamental driver of cement industry development; additionally, cement in these markets was perceived as a branded product (Venkataraman et al., 2017).

At the time, it was widely believed that multinational corporations from developed countries could overcome local obstacles in emerging markets due to their innovative technologies, higher organisational maturity, stronger financial positions, and more stable institutional environments in their home countries (Lessard & Lucea, 2008). Another significant milestone in CEMEX's history occurred in 1992, when the company acquired majority stakes in two of Spain's largest cement producers, Valenciana and Sanson. This acquisition increased sales revenues to USD 2.2 billion during the period analysed (Wilson & Chang, 2003).

The breakthrough year for CEMEX was 1995, when operations outside Mexico accounted for 51% of total annual sales of USD 3 billion, offsetting declining revenues from domestic operations (Dombey, 1997). CEMEX's global expansion strategy, largely concentrated on emerging markets, yielded notable benefits at the beginning of the 21st century. The company became the most profitable among its major international competitors, Lafarge and Holcim, due in large part to its focus on high-growth markets with attractive margins. Long-term investments in information technology also provided CEMEX with a productivity advantage ('CEMEX S.A. de C.V. History,' n.d.).

In 2010, the total production capacity of CEMEX plants worldwide reached 96 million tonnes of cement. Globally, the company produced 51 million m^3 of ready-mix concrete and over 158 million tonnes of aggregates. Notably, in that year, approximately 35% of CEMEX revenues originated from European markets (CEMEX Polska, 2010). On the global market, CEMEX has adopted a cost leadership strategy based on efficient logistics, production and sales operations, operational efficiency, and standardised internal practices and procedures. Its advertising slogan, which also reflects the company's mission to remain close to customers and build a shared future with them, accompanies CEMEX in every region where it operates (Wandzik, 2010).

Today, the CEMEX Group is one of the world's largest producers and suppliers of construction materials, operating in more than 50 countries and ranking among the leading global cement producers (Feiz et al., 2015).

Overview of the CP Activities

The CEMEX Group has been present in Poland since March 2005, when it acquired assets from RMC Group Ltd., becoming the owner of two cement plants located in Chełm and Rudniki near Częstochowa, a clinker grinding plant in Gdynia, and a logistics terminal (land and sea) in Szczecin (Krawczyk & Listos-Rodewald, 2008). In 2013, Cementownia Chełm was awarded the title of *Cleaner Production Leader* (Liderzy Czystszej Produkcji, n.d.), followed two years later by Cementownia Rudniki receiving the same distinction ('Cementownia Rudniki,' 2015). These certifications confirm that both plants not only comply with environmental legislation and administrative decisions but also apply responsible business principles and achieve high production efficiency with limited emissions (Rosak-Syrocka, 2018).

At the end of 2022, CEMEX Poland was also awarded the *Cleaner Production and Responsible Enterprise* certificate. This recognition was granted to the Chełm and Rudniki plants, which have been members of the Cleaner Production Movement for many years ('Nagrodzeni za zrównoważony rozwój i wkład w gospodarkę,' n.d.).

Implementation of the Process of Co-Combustion of Alternative Fuels

The first actions undertaken by the new owner focused on optimising production processes by gradually replacing traditional energy sources – coal dust in both cement plants – with alternative fuels, primarily RDF (Refuse Derived Fuel). Numerous scientific studies have confirmed the potential of RDF to enhance the energy efficiency and environmental sustainability of cement production by reducing dependence on fossil fuels and conserving non-renewable natural resources (Tihin et al., 2023).

RDF fuels are classified as non-hazardous waste under code 19 12 10 and can be produced from municipal, industrial, or mixed waste streams. Their quality and quantity depend on the composition of the waste substrate. Typically, RDF consists of paper, cardboard, plastics, textiles, rubber, wood sawdust, tobacco waste, and residues from municipal waste sorting processes (Nowak, 2023). According to Ghenai et al. (2019), alternative fuels are defined as any non-fossil fuels capable of partially replacing the raw materials required for Portland cement production, whether for energy generation or material recovery.

The co-incineration of RDF in clinker kilns fulfils the requirements for thermal waste treatment and residue management. Calcium oxide present in the raw material neutralises acidic gases such as HCl, HF, and SO_2 produced during combustion (Strigáč, 2015). Combustion ash is fully incorporated into the clinker structure, accounting for approximately 3.5–4% of its mass (Castanón et al., 2021). This process enables the simultaneous recovery of thermal energy from the organic fraction of RDF and material recycling of the mineral fraction as part of the raw mix (Smoliński et al., 2010). RDF is partially CO_2-neutral because it contains both fossil-based and biogenic fractions, with the latter typically representing 30–40% of its mass (Kachawalage et al., 2017).

However, RDF exhibits high heterogeneity in chemical and physical properties due to its varied composition and particle geometry. This heterogeneity can affect flame stability, heat transfer, and clinker phase formation, potentially limiting fossil fuel substitution in rotary kilns (Pieper et al., 2020). A major constraint is the presence of chlorine compounds, which may reduce concrete compressive strength and accelerate corrosion of kiln linings (Kara, 2012). According to Naqi and Jang (2019), RDF-based solutions can account for up to 10% of total CO_2 reduction in cement production.

Chełm Cement Plant

The first RDF co-firing trials at the Chełm cement plant began in 2001 with the installation of a simple feeding system based on a Pfister dispenser and a storage facility. Initially, RDF consumption was limited to 5–6 thousand Mg/year. The main development phase occurred between 2005 and 2010, during which several major investments were implemented (Bąbelewski, 2012), including:

- mechanical transport of RDF to the calciner,
- continuous exhaust gas emission monitoring,
- expansion of RDF storage with an automatic crane,
- replacement of the electrostatic precipitator with a bag filter,
- installation of a multifeeder for RDF dosing,
- installation of a biomass shredder and dosing system,
- installation of a Unitherm multi-feed burner,
- installation of air cannons,
- commissioning of liquid waste fuel and sludge feeding systems,
- acquisition of a tyre-shredding machine.

During the analysed period, the composition of alternative fuels was as follows (Sitko-Lutek & Lutek, 2022): RDF (83.45%), meat and bone meal (6.73%), rubber dust and shredded textiles (4.55%), dehydrated sewage sludge (0.87%), and liquid fuels (0.13%).

Interest in meat and bone meal within the cement industry has increased following the European Union's decision to ban its use as an ingredient in animal feed, as well as its disposal in landfills. It should be noted that the standard specification for meat and bone meal requires a combined water and fat content of less than 20%, which contributes to its relatively low calorific value of approximately 18 MJ/kg, as well as to the combustion process requiring a higher air input of 5–10% (Rahman et al., 2015).

In contrast, dewatered sewage sludge, after reaching 90% dry matter content, has a calorific value of 14.4–14.5 MJ/kg and exhibits parameters comparable to those of wood, due to its stable organic content (Chalamoński & Szymczak, 2017). For this reason, sewage sludge must be co-fired with pulverised coal. The mass share of sewage sludge in the mixture with coal fed to the main burner can reach up to 10% (Głodek-Bucyk et al., 2016).

In the case of Cementownia Chełm, the use of meat and bone meal and dewatered sewage sludge resulted in a reduction in the emission rate by an average of 25–32 kg CO_2/Mg_{clk}, depending on the availability and degree of substitution (Radelczuk, 2017).

Among the combustion materials presented above, rubber waste is particularly valuable due to its high calorific value of 26–30 MJ/kg. It also has a positive effect on the quality of the fired clinker and increases the productivity of the entire cement production process. Textile waste, by comparison, has a much lower calorific value of 16–18.5 MJ/kg (Siemeniuk & Szatyłowicz, 2018).

The final category of alternative fuels discussed comprises liquid fuels characterised by a high calorific value of 29–36 MJ/kg. Their undoubted advantage lies in the fact that they do not require mechanical treatment. Owing to their physico-chemical composition, they can be supplied directly to the main burner or the calciner using a fuel oil feeding system (Mikulčić et al., 2016).

When discussing different types of alternative fuels, it is also necessary to mention agricultural waste, which includes materials such as sawdust, tobacco residues, rice husks, hazelnut shells, and biomass, among others (Gunasekaran et al., 2013). Owing to their physico-chemical composition, these materials improve the functional properties of mortars and concretes (Ferrandiz-Mas et al., 2014). Moreover, and very importantly during combustion, up to 95% of the substances contained in agricultural waste are converted into amorphous silica (Gursel et al., 2016).

In 2020, Cementownia Chełm achieved a record fossil fuel substitution level of 95% for the first time, representing the highest result among all Polish cement plants. At present, the average share of alternative fuels used in Poland is approximately 70% (Piestrzycki et al., 2012).

In order to improve the quality of alternative fuels used at Cementownia Chełm, a project was implemented at the end of 2012 to reduce the water content of RDF through the construction of a drum dryer with a capacity of 40 Mg/h. The installed equipment utilises waste hot air from the clinker cooler at temperatures ranging from 250 °C to 350 °C, which ensures high technological efficiency of the applied solution. As a result of this process, the moisture content of RDF was reduced by 35%, enabling an increase in the calorific value of the fuel by nearly 20%, from 14.1 MJ/kg to 17.2 MJ/kg. Furthermore, this resulted in a reduction in CO_2 emissions into the atmosphere by 2–3% (Cichy, 2017).

Another important objective for the plant in establishing the dryer was the reduction of unit heat consumption in the clinker production process by eliminating a portion of the water contained in alternative fuels (up to 8%). This reduction is attributable to the decreased need for water evaporation at the high temperatures characteristic of the manufacturing process (CEMEX Polska, 2015).

Rudniki Cement Plant

At the Rudniki Cement Plant, by contrast, the process of co-combustion of alternative fuels was initiated only at the beginning of 2008. This delay resulted from two main factors. The first was the requirement for the cement works to obtain a decision on the 'environmental conditions for the combustion of alternative fuels in rotary kilns', which was granted in the first quarter of 2007. The second factor was that the issued decision was subsequently challenged by the local community before the Local Government Appeal Board (Gradek, 2007).

The management of the cement plant at the time entered into an open dialogue with the inhabitants of the municipality of Rędziny, with the aim of clarifying and resolving the conflict that had arisen. As a result of the consultations conducted, a convergence of mutual positions was achieved.

Six years after the commencement of the RDF co-firing process, in 2014, the cement plant could report having reached a substitution rate of 55% (Szewczyk, 2014). It should be noted that this level of substitution was achieved solely through the feeding of RDF to the main burner. Any further increase in the share of alternative fuels in the production process required the modernisation of the existing clinker production system.

The first decisions regarding plant modernisation were taken in 2015, followed by a further two-year period devoted to obtaining the necessary environmental approvals and construction permits. Modernisation works commenced in the first quarter of 2018 and were completed at the beginning of the third quarter of 2019. The scope of the modifications included, among other measures, the replacement of three long rotary kilns operating under the dry method with a single short kiln measuring 56 m in length and 3.8 m in diameter, equipped with a 400 kW peripheral drive and a tower of heat exchangers. This configuration allows for highly efficient utilisation of heat from fuels with lower calorific value. The technology provider for the modernised kiln system was Thyssenkrupp Industrial Solutions.

To further improve the efficiency of the entire process, it was also necessary to replace the clinker cooler with a unit characterised by higher operating parameters. A new-generation Polytrack cooler was installed in place of the former clinker coolers and integrated into the existing production line. The completed modernisation enabled the plant to maintain a clinker production capacity of 2 000 tonnes per day, while simultaneously increasing the share of alternative fuels from the previous level of 55% to as much as 85% RDF. The increased use of alternative fuels resulted in a 15% reduction in CO_2 emissions, significantly lowering the plant's negative environmental impact. In addition, the specific heat consumption required to produce one tonne of clinker was reduced by 30% compared to the previous process line (CEMEX Polska, n.d.).

The modernised installation also created an excellent foundation for further reductions in atmospheric emissions of nitrogen oxides, which had not been achievable using the previously operated kilns ('Prace modernizacyjne w cementowniach Rudniki i Małogoszcz,' 2017).

By mid-2022, the use of RDF accounted for more than 90% of all fuels utilised in the production process. In this respect, Cementownia Rudniki ranked second within the entire CEMEX Group ('Cemetownia Rudniki,' 2022).

Modification of Raw Material Composition

In addition to the use of RDF alternative fuels, a second pathway for reducing the energy intensity of the cement production process and CO_2 emissions is the use of industrial by-products as raw materials substituting clinker (Zhaurova et al., 2021).

The classification of alternative additives used in cement production comprises three groups of materials and is primarily based on their role in the cement hardening process (Środa, 2024):

- hydraulic materials (e.g. granulated blast furnace slag),
- pozzolanic materials (e.g. fly ash, burnt slate, silica dust),
- fillers (e.g. fine fractions of construction waste).

The most commonly used industrial wastes as alternative raw materials in the calcination process include blast furnace slags (Giergiczny, 2019), cement kiln dust (Osmanović et al., 2018), regips (Caillahua et al., 2018), fly ash (silica and lime), fertiliser slags, red mud from the aluminium industry, Pb–Zn slags, Cu slags, agricultural waste, and paper sludge (Ishak & Hashim, 2015). To a lesser extent, sludges from oil refineries, bagasse from the sugar industry, rice husks, marble sludge, jarosite, and aluminium scrap processing waste are also used (Abdul-Wahab et al., 2021). Increasingly, the cement industry is also utilising bottom ash from municipal solid waste incineration and dewatered sewage sludge (Kleib et al., 2021). The wider application of silica fly ash or granulated blast furnace slag is constrained by supply limitations. For various reasons, the metallurgical and energy sectors do not provide clinker substitutes in quantities and qualities sufficient to meet the cement industry's demand (Sitko, 2014).

Chełm Cement Plant

At the Chełm cement plant, two components were initially introduced to optimise clinker production: lime fly ash and carbide lime. Lime fly ash (calcareous fly ash) is produced during lignite combustion in pulverised coal boilers. Its main crystalline components include quartz, gehlenite, anorthite, anhydrite, and free calcium oxide (Baran & Drożdż, 2013). As a by-product, it contributes to reducing raw material and energy demand while improving concrete durability by partially replacing clinker. It exhibits both pozzolanic properties and hydraulic activity (Synowiec, 2015).

Carbide lime is generated during acetylene production by reacting calcium carbide with water according to the reaction:

$$CaC_2 + H_2O \rightarrow C_2H_2 + Ca(OH)_2.$$

The properties of crude acetylene, as well as waste carbide lime, depend on the quality of the coke and lime used in the production of carbide. It is a grey–white mass formed by the sedimentation of an aqueous suspension of grains during the acetylene production process. Such lime emits a pungent odour that causes lacrimation and irritation of the mucous membranes (Jaroń-Kocot & Sablik, 2004).

It should be emphasised that the results obtained by cement plants clearly demonstrate that replacing up to 5% of limestone with lime fly ash or 3% with carbide lime reduces carbon dioxide emissions by 16 kg/Mg clinker and 23.5 kg/Mg clinker, respectively. The sinterability of raw material assemblies modified in this manner exhibited better parameters than those of the classic composition based solely on limestone, as well as slightly higher strength characteristics (Baran et al., 2016).

The use of blast furnace slag as a component of the raw material input for clinker production has increased significantly in recent years (Król, 2017). Blast furnace slag is a non-metallic by-product generated during the production of pig iron in a blast furnace at temperatures ranging from 1300 to 1500 °C. After leaving the blast furnace, the slag has a temperature of approximately 1400 °C and is rapidly cooled using a water jet. This latter process, referred to as granulation, results in a product known as granulated blast furnace slag (Ahmad et al., 2022).

Due to its physical and chemical properties, the use of granulated blast furnace slag as part of the raw material mix not only improves the sinterability of the raw materials, but also reduces the demand for limestone and consequently decreases CO_2 emissions associated with limestone decomposition (Ostrowski et al., 2024). In addition, it reduces electricity consumption and limits the exploitation of natural resources (Özbay et al., 2016). The literature confirms the beneficial effect of adding ground granulated blast furnace slag on the corrosion resistance of cement (Dąbrowski & Małolepszy, 2010).

An analysis of the research results presented above indicates that cements containing blast furnace slag exhibit a shorter setting time and a higher rate of strength development compared to mixtures incorporating fly ash (Wieczorek & Pichniarczyk, 2022).

The last decade has also witnessed considerable interest in the use of carbide lime in the clinker production process, due to its potential to conserve limestone resources and reduce CO_2 emissions (Wang et al., 2013).

Carbide lime, also referred to as lime sludge, is a by-product of acetylene production via the hydrolysis of calcium carbide. This waste is generated as an aqueous slurry and consists mainly of calcium hydroxide ($Ca(OH)_2 \approx 85–95\%$) with smaller amounts of calcium carbonate ($CaCO_3 \approx 1–10\%$) (Cardoso et al., 2009).

An analysis of the literature clearly indicates that the use of a 2–5% additive of lime fly ash from the Bełchatów power plant in the raw material mix allows CO_2 emissions to be reduced by 4.0–10.3 kg CO_2 per Mg of clinker. The introduction of a 2–5% carbide lime additive in the raw material mix reduces CO_2 emissions by 9.5–23.9 kg CO_2 per Mg of clinker. In contrast, the introduction of a mixture consisting of 10% carbide lime or blast furnace slag containing 60.2% CaO results in a reduction of CO_2 emissions of nearly 72.4 kg CO_2 per Mg of clinker (Baran et al., 2016).

The composition of raw materials also evolved in subsequent years of the clinker reduction programme, which in 2015 included the following components (CEMEX Polska, 2015):

- fly ash from power plants and combined heat and power plants,
- blast furnace slags from the steel industry,
- ferro-bearing dust, replacing natural raw materials such as iron ore,
- waste gypsum in the form of used gypsum moulds and so-called regips.

Regypsum, calcium sulphate dihydrate ($CaSO_4 \cdot 2H_2O$), is a product of the wet flue gas desulphurisation process resulting from the combustion of solid fuels. It is a material comparable to natural gypsum (Pierzyna & Popczyk, 2014).

During the period analysed, the share of alternative raw materials derived from waste in clinker and cement production at Cementownia Chełm ranged between 11 and 14% (Sitko-Lutek & Lutek, 2022).

The reduction in the clinker index at Cementownia Chełm during the period 2021–2023 exhibited a decreasing trend, amounting to 84.7% in 2021, 80.5% in 2022, and 76.9% in 2023. The clinker reduction level assumed by plant management for 2030 is targeted to reach 65.9% (CEMEX Polska, 2023).

Rudniki Cement Plant

Due to its location in the northern part of the Silesian Voivodeship, the Rudniki Cement Plant was designed from the outset of its operation to maximise the use of waste raw materials, primarily originating from the steel industry. From the beginning, blast furnace slag has served as a so-called low-end raw material component, with its share reaching up to 25%. In addition, the plant was originally equipped with two slag-drying installations that utilise waste furnace gases to reduce moisture content to zero. For many years, the dried slag was supplied to cement mills for the production of metallurgical cements, as well as for current CEM II cements (Portland cement with additives).

However, due to market developments, granulated slag became significantly more expensive and less accessible in 2007. As a result, a decision was made to replace it in the clinker raw material mix with a slag that is chemically identical but mineralogically different. Furthermore, sand (2–6%) and silica ash (1–6%) were gradually introduced to optimise clinker production costs. Converter slag was also incorporated into the raw material mix; in addition to acting as a carrier of the required Fe_2O_3, it introduces already calcined CaO (approximately 22%), thereby further reducing the carbon footprint of the clinker.

The slag used exhibits similar properties, containing approximately 40% feldspathic CaO. Consequently, both raw materials are referred to as decarbonised raw materials, as they significantly reduce specific CO_2 emissions per unit of clinker by substituting part of the calcium oxide otherwise derived from $CaCO_3$ in quarried limestone.

At the cement production stage, the use of granulated slag as the most important slag additive has nevertheless been maintained. As a result, the Rudniki Cement Plant is well known for its broad range of metallurgical cements (CEM III) and cements containing slag additives (CEM II/B-S). However, the rapidly decreasing availability of slag, combined with a sharp increase in its price, prompted the plant to introduce entirely new cement types based on lime ash or limestone, which effectively reduced the overall consumption of slag.

Thanks to the application of numerous alternative additives, the Rudniki Cement Plant has achieved very favourable results in reducing the clinker content in cement, which currently stands at approximately 60%. At the same time, decarbonised waste raw materials account for more than 14% of the material input used for clinker production. Overall, the share of alternative raw materials exceeds 45% by weight of cement ('Cementownia Rudniki,' 2022).

The reduction in the clinker ratio at the Rudniki Cement Plant over the period 2021–2023 was as follows: 65% in 2021, 63.2% in 2022, and 63.5% in 2023. Ultimately, the target value for this indicator in 2030 is set at 57.8% (CEMEX Polska, 2023).

Environmental Measures Oriented Towards Greening

An important investment and organisational initiative within the entire CEMEX Poland Group was the implementation, in 2010, of an Integrated Energy Management System compliant with the requirements of the international ISO 50001 standard and additionally supported, in two cement plants, by the requirements of the EMAS regulation.

Thanks to the implementation of this innovative solution, the involvement of the entire workforce in recognising and addressing issues related to energy conservation and consumption increased significantly. The following outcomes became evident (Nowosad, 2019):

- improvement of organisational management (planning, setting goals and targets, and implementing energy programmes),
- effective energy management within the organisation through the identification and control of energy-intensive areas of activity,
- internal and external audits enabling the rapid identification of weaknesses leading to increased energy consumption,
- application of best practices in energy management and utilisation,
- promotion of an energy management policy and the establishment of an energy-efficiency-oriented mindset within the organisation,
- management commitment ensuring the business success of the system,
- compliance with current and future legal and regulatory requirements related to improving energy efficiency and reducing greenhouse gas emissions,
- reduction of energy costs through a structured approach to identifying, measuring, and managing energy use,
- benefits resulting from formal and legal provisions, such as exemption from the obligation to conduct energy audits under the Energy Efficiency Act,
- acquisition of white certificates derived from energy efficiency investments,
- exemptions from excise duty on process energy and relief from the RES support scheme applicable to industrial customers.

In 2020, CEMEX implemented green hydrogen technology at all cement plants located in Europe. By introducing green hydrogen into cement manufacturing processes as a catalyst, CEMEX optimises the combustion process and increases the use of alternative energy sources, thereby reducing reliance on fossil fuels (Szczepaniak, 2021).

Green hydrogen is defined as hydrogen produced by the electrolysis of water using renewable energy, in which the water molecule is split into hydrogen (H_2) and oxygen (O) (Cacciuttolo et al., 2025). A significant limitation of this solution is that the electrolysers required for this process are typically large and highly complex systems (Tkaczyk, 2024).

The addition of green hydrogen to the fuel mix has an extremely beneficial effect on the decarbonisation process by altering the fuel structure itself, as it releases only water during combustion. In addition, it improves the performance of the combustion process, making it more complete. This is achieved due to the high energy content of GH_2, its combustion temperature, and high flame speed, which enhance fuel efficiency and enable a reduction in fossil fuel consumption while simultaneously reducing emissions of pollutants such as CO and NO_x (Domingues et al., 2024).

The concept of green hydrogen (GH_2) is emerging as a key element in the global energy transition, offering a sustainable pathway for the decarbonisation of energy systems and the achievement of climate goals. Both academic and industrial communities increasingly recognise renewable hydrogen production as a milestone in global efforts to decarbonise the cement industry (Angelico et al., 2025).

Green hydrogen plays a crucial role in achieving the ambitious objective of net-zero carbon emissions by 2050, primarily due to its zero-carbon characteristics and the lowest possible carbon footprint among fuels. Importantly, hydrogen produces only water as a by-product during combustion in fuel cells and emits only minimal amounts of nitrogen oxides during combustion (Chang & Rajuli, 2024).

At the beginning of the third quarter of 2020, the CEMEX Poland Group received a certificate confirming that all electricity purchased between 2020 and 2021 for its production operations originated from renewable sources, including wind energy. This achievement resulted from contractual arrangements and long-term business cooperation with PGE Obrót, an electricity supplier to end users operating within the PGE Group, with which CEMEX Poland has cooperated for more than ten years (Malinowski, 2020).

A joint initiative involving both cement plants was the signing of a long-term corporate power purchase agreement (CPPA) between CEMEX Poland and Statkraft at the beginning of the fourth quarter of 2023. The contract provides for the supply of electricity over a period of eight years, commencing on 1 January 2025. It is expected to secure approximately 30% of the annual energy demand of CEMEX Poland facilities, including the cement plants in Chełm and Rudniki. Under the agreement, electricity for CEMEX plants will be supplied from Polish wind and photovoltaic farms (Ciepiela, 2023).

In March 2025, EDP Energia Poland (EDP EP), part of the global EDP Group and a world leader in business-oriented solar energy investments, signed a cooperation agreement with the CEMEX Poland Group. Under the 15-year partnership, EDP EP will install and manage

25 000 solar panels to provide clean energy to selected CEMEX facilities in Poland. The solar farms will be constructed on the premises of the Chełm cement plant, the Rudniki cement plant, and the Gdynia milling plant, as well as at concrete plants located in Mysłowice, Warsaw, Annopol, Lublin, Szczecin, and Gdańsk. As a result of this investment, CEMEX Polska will reduce CO_2 emissions by approximately 9 600 Mg per year, corresponding to the carbon dioxide absorption capacity of approximately 1.6 million trees (Supernak, 2025).

Chełm Cement Plant

In 2011, the management of the Chełm cement plant decided to construct two concrete silos for clinker storage. The first silo was commissioned in mid-2012, and the second at the end of the same year. The construction of the bowl-shaped silos, each with a diameter of 63.4 m and a height of 43.5 m, was designed by the U.S.-based company Dometech, with a total capacity of 250 Mg (Puzio, 2013). The total investment cost amounted to nearly PLN 67 million and represented the largest environmental investment of the 21st century at the plant. The large storage capacity allows the entire clinker inventory to be stored inside the silos; moreover, their airtight construction significantly reduced dust emissions into the atmosphere resulting from clinker storage and transport (Krechowiecki & Środa, 2013).

Another important infrastructure project implemented between 2013 and 2016 was the modernisation of the chalk mine drainage system, covering an area of 224 ha, carried out under the name 'Barrier Bis' (Wsół, 2015). This decision was taken due to the progression of mining operations into increasingly deeper raw material deposits, which necessitated improved drainage efficiency. As part of the investment, 17 deep wells with depths ranging from 40 m to 60 m were drilled, along with the installation of the required electrical power supply, control systems, and hydraulic infrastructure, including pumping units (Zygmunt, 2025). Water extracted from this intake supplies the municipal drinking water system for the inhabitants of the city of Chełm (Barczyński, 2015).

In response to the need to adapt plant facilities to noise standards in accordance with the guidelines specified in the integrated permit, the management of the cement works developed a noise-reduction programme implemented over the period 2013–2015. As part of this programme, acoustic insulation was applied to the coal dust dosing building in the area housing the dust pumps, as well as to the pneumatic transport system located between the wall of this building and the wall of the compressor room. The openings previously present on two walls of the coal dosing installation were replaced with gates and access doors. In addition, chamber silencers were installed on the air intakes. The implemented measures achieved an acoustic attenuation level of 29.2 dB (CEMEX Polska, 2015).

In September 2017, the plant's coal-fired boiler house was permanently decommissioned. At the same time, the heating system for all buildings located at the plant was modernised by switching to electric heating. As a result of this investment, air quality improved due to reduced dust and gaseous emissions both within the cement works and in the city of Chełm, thereby contributing to an enhanced quality of life for local residents (CEMEX Polska, 2017).

As a consequence of the introduction of new requirements contained in the BAT Conclusions document, a continuous monitoring system for emissions from the rotary kiln was implemented at the plant. A new analyser was installed to measure emission volumes, including so-called ammonia slip. This investment enabled precise dosing of urea solution for the reduction of nitrogen oxides, full control of NH_3 slip, and maintenance of emission levels below the regulatory limit of 50 mg/Nm^3. Measurement results indicated that the average NH_3 concentration was 3.4 mg/Nm^3.

Another important project involved redeveloping the clinker hall dust extraction system. Nine emission points along the clinker transport line were eliminated, and the remaining dust collectors were modernised. These actions significantly reduced dust emissions within the clinker storage hall.

Modernisation activities were also undertaken with respect to the coal dust dosing system, which is a critical element of the clinker firing process. As part of the ongoing project, the coal mill was relocated to the immediate vicinity of the kiln, resulting in reduced energy consumption and a decrease in cooling water usage by approximately 50 000 m^3. The alternative fuel dosing system was also rebuilt through the acquisition of a planetary burner controlling the dosing rate of rubber dust. In addition, a new RDF feeding system based on a triple screw feeder was installed. The final task involved the construction of a new sealed pavement in the manoeuvring area designated for the reception of alternative fuels (CEMEX Polska, 2018).

In 2019, a modification of cement mill operation outside peak energy demand periods was implemented, utilising cement silos as a form of energy storage. This measure reduced energy costs by PLN 2.5 million. A second project involved the modernisation of raw material transport by eliminating idle operation of plate feeders and crushers through the installation of material presence sensors. This change resulted in a reduction in electricity consumption of 290 MWh per year (CEMEX Polska, 2019).

Rudniki Cement Plant

In 2008, an investment was undertaken to soundproof the façades of the production halls and the equipment located within them, install acoustic silencers, and erect soundproof screens along the plant boundary and in the immediate vicinity of the cement plant, near the exhaust fans and rotary kilns (Stowarzyszenie Polski Ruch Czystszej Produkcji, n.d.).

The modernisation of four silos and the construction of a third bulk cement loading station were completed in mid-2009. The installation was equipped with two buffer tanks with a capacity of 220 tonnes each, a cement sifter, an automatic loading head, and weighing systems. The completed investment significantly reduced cement dust emissions into the atmosphere (Płonka, 2009).

In 2010, the cement plant management initiated an investment process involving the construction of a clinker storage silo. The completed facility has a diameter of 37.4 m and a height of up to 45 m and is capable of storing 50 000 Mg of raw material. In the initial phase, preparatory activities were carried out, including the development of the technical design, acquisition of the necessary permits, contracting of equipment supplies, and commencement of demolition works, as the silo was constructed on the site of the former clinker crane warehouse. The works were completed at the end of 2013, with the total investment cost exceeding PLN 48 million. The implementation of this project significantly reduced uncontrolled emissions of clinker dust and flue gases into the atmosphere (CEMEX Polska, 2013).

In the fourth quarter of 2013, the management of the Rudniki cement plant signed a loan agreement with the National Fund for Environmental Protection and Water Management under the energy efficiency programme. Under this agreement, the coal grinding installation was adapted to ATEX requirements (operation in explosive atmospheres), and the energy performance indicators of the coal grinding process were significantly improved. The project delivered the following outcomes (CEMEX Polska, n.d.):

- an increase in mill productivity from 5 to 12 Mg/h,
- electricity savings of 274 MWh/year,
- a reduction in CO_2 emissions of 243.9 Mg/year,
- decommissioning of the remaining coal mills, resulting in the operation of a single coal mill,
- improvement of occupational safety in the coal department through the implementation of ATEX-compliant solutions.

In 2017, the coal and sludge belt dedusting installation was completed. As a result of this investment, dust emissions into the atmosphere were reduced ('Cementownia „Rudniki" w Rudnikach koło Częstochowy,' n.d.).

In 2019, the modernised furnace No. 5 was commissioned, enabling an increase in the substitution of alternative fuels to more than 92%, while simultaneously achieving a 20% reduction in specific heat consumption. These results led to a reduction of more than 15% in specific CO_2 emissions per Mg of clinker.

In 2022, a project involving the replacement and modernisation of the plant's lighting system with energy-efficient LED fixtures was completed at Cementownia Rudniki. This investment reduced annual electricity consumption for lighting purposes by approximately 15 700 kWh (CEMEX Polska, 2022).

In turn, a three-year investment process was initiated in 2023, concerning the construction of an ash–slag mixture drying plant and a lime ash dosing installation for cement mills. The implementation of this project is expected to reduce the clinker ratio to 55% (CEMEX Polska, 2022).

At present, the management of the Rudniki cement plant is analysing several feasibility studies prepared by external entities in order to determine the most appropriate technology, from the plant's perspective, for capturing CO_2 from waste gases. These analyses take into account potential pathways for the utilisation of captured carbon dioxide in products or advanced CO_2-based technologies.

Conclusions

In the opinion of many researchers and practitioners of economic life, the concept of Cleaner Production (CP) presented herein is one of the most important tools enabling enterprises to develop dynamically while respecting the natural environment. It is worth emphasising that the CP concept is voluntary and non-formalised. Its implementation makes it possible to reduce production costs, improve operational efficiency and, in the long term, reduce sources of dust, gas and waste emissions. The CP programme also lays the foundations for the implementation of a circular economy strategy, thereby enabling higher productivity levels, increased revenues and an expanded market share.

This publication presents the practical application of pro-ecological solutions using the cement industry as an example, as implemented by the CEMEX Poland Group. It showcases good practices in climate protection and respect for natural resources.

The solutions presented in the monograph, implemented at both cement plants of the CEMEX Poland Group, have enabled a reduction in greenhouse gas emissions, with particular emphasis on carbon dioxide (CO_2), as well as a decrease in the consumption of fossil raw materials (coal dust). Electricity and heat consumption have been significantly reduced, water and wastewater management has been rationalised, and noise levels have been lowered. Occupational health and safety conditions have also improved substantially.

It should be emphasised that, thanks to the improved co-combustion process of alternative fuels, it has become possible to manage various types of waste, both municipal and industrial, in a waste-free manner.

In addition to the economic and environmental benefits outlined above, the social dimension of the implemented CP solutions is of great importance. In both cement plants, employee interest in plant operations has increased significantly, as evidenced by numerous rationalisation proposals submitted by staff.

The implementation of the CP strategy by the management of both companies has enabled the establishment of social dialogue with stakeholders through cyclical meetings presenting pro-environmental initiatives undertaken within the framework of the implemented concept (Rudniki, 2024).

The fact that CEMEX Poland has obtained Cleaner Production certificates for its cement plants sends a clear signal to its business and social environment that such activities are permanently embedded in the DNA of the entire organisation.

The examples presented in this book regarding the Cleaner Production concept implemented by the CEMEX Poland Group indisputably bring the cement industry closer to achieving a resource-efficient and low-emission economy.

The publication addresses issues related to cleaner production from both the perspective of management and quality sciences, as well as through the presentation of good practices applied in this field. It constitutes a compendium of knowledge in eco-management and may also serve as a textbook for managers, business practitioners, local government representatives, and students of management, economics and environmental protection. The authors hope that this publication will contribute to promoting the concept of Cleaner Production and to building environmental awareness.

References

Abbasi, T., & Abbasi, S. A. (2016). Reducing the global environmental impact of livestock production: The mini-livestock option. *Journal of Cleaner Production, 112,* 1754–1766.

Abdelhaffez, G. S., Ahmed, A. A., & Ahmed, H. M. (2022). Effect of grinding media on the milling efficiency of a ball mill. *Rudarsko-geološko-naftni Zbornik, 38,* 171–177.

Abdulrahman, A. O., Huisingh, D., & Hafkamp, W. (2015). Sustainability improvements in Egypt's oil and gas industry by implementation of flare gas recovery. *Journal of Cleaner Production, 98,* 116–122.

Abdul-Wahab, S. A., Al-Dhamri, H., Ram, G., & Chatterjee, V. P. (2021). An overview of alternative raw materials used in cement and clinker manufacturing. *International Journal of Sustainable Engineering, 14*(4), 743–760.

Abed, M., Rashid, K., Ul Rehman, M., & Ju, M. (2022). Performance keys on self-compacting concrete using recycled aggregate with fly ash by multi-criteria analysis. *Journal of Cleaner Production, 378,* 134398.

Abyzov, V. A., Pushkarova, K. K., Kochevykh, M. O., Honchar, O. A., & Bazeliuk, N. L. (2020). Innovative building materials in creating an architectural environment. *IOP Conference Series: Materials Science and Engineering, 907*.

Adamczyk, J., & Nitkiewicz, T. (2007). *Programowanie zrównoważonego rozwoju przedsiębiorstw.*. PWE.

Adeniyi, S. M., Mohamed, S. F., & Rasak, K. O. (2020). Socio-economic benefits of using green materials for the construction of low-cost buildings in Nigeria. *American Scientific Research Journal for Engineering, Technology, and Sciences, 67*(1), 99–110.

AFNOR. (2012). *NF EN 197-1: Cement-Part 1: Composition, specifications and conformity criteria for common cements.* Saint-Denis, France.

Aguilar, C. M. G., Panameno, R., Velazquez, A. P., Álvarez, B. E. A., Kiperstok, A., & César, S. F. (2017). Cleaner production applied in a small furniture industry in Brazil: Addressing focused changes in design to reduce waste. *Sustainability, 9*(10), 1867.

Ahmad, J., Kontoleon, K. J., Majdi, A., Naqash, M. T., Deifalla, A. F., Kahla, N. B., Isleem, H. F., & Qaidi, S. M. A. (2022). A comprehensive review on the ground granulated blast furnace slag (GGBS) in concrete production. *Sustainability, 14*(14), 8783.

Aithal, S., & Aithal, S. (2016). *Opportunities and challenges for green tech-*

nologies in the 21st century. Munich Personal RePEc Archive (MPRA Paper No. 73661). https://mpra.ub.uni-muenchen.de/73661/1/MPRA_paper_73661.pdf

Akadiri, P. O. (2015). Understanding barriers affecting the selection of sustainable materials in building projects. *Journal of Building Engineering, 4,* 86–93.

Alexander, J. K. (2009). The concept of efficiency: An historical analysis. In A. Meijers (Ed.), *Handbook of the philosophy of science,* Volume 9: *Philosophy of technology and engineering sciences* (pp. 1007–1030). Elsevier.

Alkaya, E., & Demirer, G. N. (2014). Sustainable textile production: A case study from a woven fabric manufacturing mill in Turkey. *Journal of Cleaner Production, 65,* 595–603.

Almeida, C. M. V. B., Agostinho, F., Giannetti, B. F., & Huisingh, D. (2015). Integrating cleaner production into sustainability strategies: An introduction to this special volume. *Journal of Cleaner Production, 96,*(S) 1–9.

Al-Munim, M. A. H., & Abdul Hameed, M. M. (2021). Investment trends for Iraqi industries in terms of clean production (selected model). *Journal of Economics and Administrative Sciences, 27*(130), 155–169.

AlSanad, S. (2015). Awareness, drivers, actions, and barriers of sustainable construction in Kuwait. *Procedia Engineering, 118,* 969–983.

Altham, J., & Guerin, T. F. (2005). Cleaner production. In V. Rajaram, S. Dutta, & K. Parameswaran (Eds.), *Sustainable mining practices: A global perspective* (pp. 93–120). Taylor & Francis.

Alwis, A. M. L., Bazli, M., & Arashpour, M. (2025). Automated recognition of contaminated construction and demolition wood waste using deep learning. *Resources, Conservation and Recycling, 219,* 108278.

Al-Youfi, A. B. (2004). Cleaner production for sustainable industrial development: Concept and applications. *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, 8*(4), 265–273.

Ametepey, O., Aigbavboa, C., & Ansah, K. (2015). Barriers to successful implementation of sustainable construction in the Ghanaian construction industry. *Procedia Manufacturing, 3,* 1682–1689.

Amir, S., Bonifacius, N., & Poerwoningsih, D. (2022). Eco-design concept of street corridors as a city image forming. *IOP Conference Series: Earth and Environmental Science, 999*(1), 012018.

Andrew, R. M. (2018). Global CO_2 emissions from cement production. *Earth System Science Data, 10,* 195–217.

Andrew, R. M. (2019). Global CO_2 emissions from cement production, 1928–2018. *Earth System Science Data, 11,* 1675–1710.

Angelico, R., Giametta, F., Bianchi, B., & Catalano, P. (2025). Green hydrogen for energy transition: A critical perspective. *Energies, 18*(2), 404.

Antunes, M., Santos, R. L., Pereira, J., Rocha, P., Horta, R. B., & Colaço, R. (2021). Alternative clinker technologies for reducing carbon emissions in the cement industry: A critical review. *Materials, 15,* 209.

Aranda-Usón, A., Portillo-Tarragona, P., Scarpellini, S., & Llena-Macarulla, F. (2020). The progressive adoption of a circular economy by businesses for cleaner production: An approach from a regional study in Spain. *Journal of Cleaner Production, 247,* 119648.

Ashton, S. A., Panedo, M. A., Cruz, C. I., & Martin, H. M. (2018). Financing resource efficiency and cleaner production in Central America. *Clean Technologies and Environmental Policy, 20*(1), 53–63.

Ashton, W., Ehrenfeld, J. R., & Luque, A. (2002). *Best practices in cleaner production: Promotion and implementation for smaller enterprises.* Multilateral Investment Fund, Inter-American Development Bank.

Atienza-Sahuquillo, C., & Barba-Sánchez, V. (2014). Design of a measurement model for environmental performance. *Environmental Engineering and Management Journal, 13,* 1463–1472.

Atkinson, L., & Rosenthal, S. (2014). Signaling the green sell: The influence of ecolabel source, argument specificity, and product involvement on consumer trust. *Journal of Advertising, 43*(1), 33–45.

Nagrodzeni za zrównoważony rozwój i wkład w gospodarkę. (N.d.). *Zrownowazona przyszlosc.* https://www.zrownowazonaprzyszlosc.pl/artykul/31-nagrody-i-wyroznienia/106-nagrodzeni-za-zrownowazony-rozwoj-i-wklad-w-gospodarke

Ayodele, A., Ayoninuoluwa, O., Binuyo, B., & Olanrewaju, G. O. R. (2017). Impact of globalisation on industrial growth in Nigeria (1981–2014): Implications for psychologists and economists. *European Journal of Business Economics & Accountancy, 5*(5), 52–60.

Azzone, G., Bertele, U., & Noci, G. (1997). At last we are creating environmental strategies that work. *Long Range Planning, 30*(4), 562–571.

Baas, L. W. (1995). Cleaner production: Beyond projects. *Journal of Cleaner Production, 3,* 55–59.

Baba, F. (1999). Ecomaterials. *Mitsubishi Electric Advance: Quarterly Survey of New Products, Systems, and Technology, 87,* 17–19.

Bąbelewski, P. (2012, June 14). *Co-combustion of alternative fuels in the cement plants Cemex-Poland* [Conference presentation]. Waste to Energy Conference, Warsaw.

Bacariza, M. C., Spataru, D., Karam, L., Lopes, J. M., & Henriques, C. (2020). Promising catalytic systems for CO_2 hydrogenation into CH_4: A review of recent studies. *Processes, 8,* 1646.

Baek, C., Park, S.-H., Suzuki, M., & Lee, S.-H. (2013). Life cycle carbon dioxide assessment tool for buildings in the schematic design phase. *Energy and Buildings, 61,* 275–287.

Baharetha, S. M., Al-Hammad, A. A., & Alshuwaikhat, H. M. (2013). Towards a unified set of sustainable building materials criteria. In *ICSDEC 2012: Developing the frontier of sustainable design, engineering, and construction – Proceedings of the 2012 International Conference on Sustainable Design and Construction* (pp. 732–740). American Society of Civil Engineers.

Bakar, K. A., Sam, M. F. M., Tahir, M. N. H., Rajiani, I., & Muslan, N. (2011). Green technology compliance in Malaysia for sustainable business development. *Journal of Global Management, 2*(1), 55–65.

Bansal, P., & Roth, K. (2000). Why companies go green: A model of ecological responsiveness. *Academy of Management Journal, 43*(4), 717–736.

Baptista, A. J., Peixoto, D., Ferreira, A. D., & Pereira, J. P. (2018). Lean design-for-X methodology: Integrating modular design, structural optimization and ecodesign in a machine tool case study. *Procedia CIRP, 69,* 722–727.

Baran, T. (2021). The use of waste and industrial by-products and possibilities of reducing CO_2 emissions in the cement industry-Industrial trials. *Cement Lime Concrete, 26*(3), 169–184.

Baran, T., & Drożdż, W. (2013). Evaluation of properties of domestic calcareous fly ash and its processing methods. *Roads and Bridges, 12,* 5–15.

Baran, T., Garbacik, A., Ostrowski, M., & Radelczuk, H. (2016). Solutions for the production of Portland clinker with low CO_2 emissions. In *Concrete Days 2016 Conference Proceedings* (pp. 439–448).

Baran, T., Ostrowski, M., Radelczuk, H., & Francuz, P. (2016). Opportunities to reduce CO_2 emissions in the Portland clinker production process. *Cement Lime Concrete, 6,* 389–395.

Baranyi, R. (2008). Criteria groups in the eco-labelling process system. *Periodica Polytechnica Social and Management Sciences, 16*(1), 45–54.

Barczyński, J. (2015, April 8). Chełm on water stands: How to sell it to neighbouring municipalities. *Dziennik Wschodni.*

Barker, D., Holmes, D., Hunt, J., Napier-Moore, P., Turner, S., & Clark, M. (2008). *CO_2 capture in the cement industry* (Technical Report). IEA Greenhouse Gas R&D Programme.

Bartlett, D., & Trifilova, A. (2010). Green technology and eco-innovation: Seven case studies from a Russian manufacturing context. *Journal of Manufacturing Technology Management, 21*(8), 910–929.

Beard, C., & Rees, S. (2000). Green teams and the management of environmental change in a UK county council. *Environmental Management and Health, 11*(1), 27–38.

Beiling, M., Su, L., Yajun, D., & Xiaoging, H. (2013). Understanding the relationships among destination social responsibility, resident benefits, trust and support for tourism development. *Information Technology Journal, 12*(20), 5947–5954.

Benhelal, E., Shamsaei, E., & Rashid, M. I. (2020). Challenges against CO_2 abatement strategies in cement industry: A review. *Journal of Environmental Sciences, 104,* 84–101.

Berry, M. A., & Rondinelli, D. A. (1998). Proactive environmental management: A new industrial revolution. *Academy of Management Executive, 12*(2), 38–50.

Berry, M. A., & Rondinelli, D. A. (1998). Proactive environmental management: A new industrial revolution. *Academy of Management Executive, 12*(2), 38–50.

Bezerra, P. R. C., Vieira, M. M., & de Rezende, J. F. D. (2019). Measurement of the eco-efficiency of small businesses in the oil and gas supply chain applying the CE7 taxonomy. *Acta Scientiarum Technology, 41*.

Bhardwaj, M., & Neelam. (2015). The advantages and disadvantages of green technology. *Journal of Basic and Applied Engineering Research, 2*(22), 1957–1960.

Boks, C. (2006). The soft side of ecodesign. *Journal of Cleaner Production, 14,* 1346–1356.

Bond, S., & Perrett, G. (2012). The key drivers and barriers to the sustainable development of commercial property in New Zealand. *Journal of Sustainable Real Estate, 4*(1), 48–77.

Bontempi, E., Sorrentino, G. P., Zanoletti, A., Alessandri, I., Depero, L. E., & Caneschi, A. (2021). Sustainable materials and their contribution to the sustainable development goals (SDGS): A critical review based on an Italian example. *Molecules, 26*(5).

Borchardt, M., Wendt, M. H., Pereira, G. M., & Sellitto, M. A. (2011). Redesign of a component based on ecodesign practices: Environmental impact and cost reduction achievements. *Journal of Cleaner Production, 19,* 49–57.

Bourke, I. (2024). The environmental cost of China's addiction to cement. *BBC Future*. Retrieved August 20, 2025, from https://www.bbc.com/future/article/20240419-the-environmental-cost-of-chinas-addiction-to-cement

Bovea, M. D., & Gallardo, A. (2006). The influence of impact assessment methods on materials selection for eco-design. *Materials & Design, 27,* 209–215.

Braun, E., & Wield, D. (1994). Regulation as a means for the social control of technology. *Technology Analysis & Strategic Management, 6*(3), 259–272.

Bruce, C., & Laroiya, A. (2007). The production of eco-labels. *Environmental and Resource Economics, 36,* 275–293.

Bukarica, V., & Robić, S. (2013). Implementing energy efficiency policy in Croatia: Stakeholder interactions for closing the gap. *Energy Policy, 61,* 414–422.

Buyle, M., Braet, J., & Audenaert, A. (2013). Life cycle assessment in the construction sector: A review. *Renewable and Sustainable Energy Reviews, 26,* 379–388.

Byggeth, S., & Hochschorner, E. (2006). Handling trade-offs in ecodesign tools for sustainable product development and procurement. *Journal of Cleaner Production, 14*(15–16), 1420–1430.

Cacciuttolo, C., Huertas, A., Montoya, B., & Cano, D. (2025). The present and future of production of green hydrogen, green ammonia, and green e-fuels for the decarbonization of the planet from the Magallanes Region, Chile. *Applied Sciences, 15*(11), 6228.

Cadix, A., & James, S. (2022). Cementing additives. In Q. Wang (Ed.), *Fluid chemistry, drilling and completion* (pp. 187–254). Gulf Professional Publishing.

Caillahua, M. C., & Moura, F. J. (2018). Technical feasibility for use of FGD gypsum as an additive setting time retarder for Portland cement. *Journal of Materials Research and Technology, 7*(2), 190–197.

Carbone, C., Ferrario, D., Lanzini, A., Stendardo, S., & Agostini, A. (2022). Evaluating the carbon footprint of cement plants integrated with the calcium looping CO_2 capture process. *Frontiers in Sustainability, 3,* 809231.

Cardoso, D., Correia, J. F., Silva, P. C., Gaiola, D., & Lucato, W.-C. (2019). Cleaner production in the textile industry and its relationship to sustainable development goals. *Journal of Cleaner Production, 228,* 1514–1525.

Cardoso, F. A., Fernandes, H. C., Pileggi, R. G., Cincotto, M. A., & John, V. M. (2009). Carbide lime and industrial hydrated lime characterisation. *Powder Technology, 195,* 143–149.

Carnegie, K. L., Nielsen, H., & Glover, C. (2000). Stepping upstream 'naturally' for cleaner production through community environmental learning. *Journal of Cleaner Production, 8,* 391–396.

Castanón, A. M., Sanmiquel, L., Bascompta, M., Vegay de la Fuente, A., Contreras, V., & Gómez-Fernández, F. (2021). Used tires as fuel in clinker production: Economic and environmental implications. *Sustainability, 13,* 10455.

Cawman, M., & Fine-Skalnik, P. (2021). Playing global monopoly in cement: The globalization of CEMEX. *Case Studies in Business and Management, 8*(1), 10–35.

Çay, A. (2018). Energy consumption and energy saving potential in the clothing industry. *Energy, 159,* 74–85.

Cementownia Rudniki – CEMEX Polska liderem czystszej produkcji. (2015). *Forum odpowiedzialnego biznesu.* https://odpowiedzialnybiznes.pl/aktualnosci/cementownia-rudniki-cemex-polska-liderem-czystszej-produkcji-2015/

Cemetownia Rudniki: Wykorzystanie paliw alternatywnych przekracza 90 proc. (2022, June 6). *Infrastructure Market.* https://www.rynekinfrastruktury.pl/wiadomosci/biznes-i-przemysl/cemetownia-rudniki-wykorzystanie-paliw-alternatywnych-przekracza-90-proc-----81674.html

Cementownia „Rudniki" w Rudnikach koło Częstochowy. (N.d.). *Inwestor.* http://www.inwestor-urbaniak.pl/cementownia-rudniki-ref.

CEMEX Polska. (2010). *Raport zrównowazonego rozwoju CEMEX Polska 2010*. https://raportyzr.pl/wp-content/uploads/2011/09/CEMEX_Raport_2010_PL.pdf

CEMEX Polska. (2013). *Inwestycje w Cementowni Rudniki.* https://www.cemex.pl/-/inwestycje-w-cementowni-rudniki

CEMEX Polska. (2015). *Deklaracja środowiskowa Cementowni Chełm.* https://www.cemex.pl/documents/46481509/46532590/CEMEX_deklaracja_srodowiskowa_cementownia_chelm_2015.pdf

CEMEX Polska. (2017). *Deklaracja środowiskowa: Cementownia Chełm, Przemiałownia Gdynia.* https://www.cemex.pl/documents/46481509/46484549/Deklaracja_Srodowiskowa_2017.pdf

CEMEX Polska. (2018). *Deklaracja środowiskowa: Cementownia Chełm, Przemiałownia Gdynia.* https://www.cemex.pl/documents/46481509/0/CEMEX_deklaracjasrodowiskowa_2018.pdf

CEMEX Polska. (2019). *Deklaracja środowiskowa.* https://www.cemex.pl/documents/46481509/46532590/Deklaracja_Srodowiskowa_CEMEX_2019.pdf

CEMEX Polska. (2022). *Deklaracja środowiskowa.* https://www.cemex.pl/documents/46481509/46484597/Cemex-Polska-Deklaracja-Środowiskowa-2022.pdf

CEMEX Polska. (2023). *Raport zrównoważonego rozwoju 2022–2023*. https://www.cemex.pl/raport-zrownowazonego-rozwoju-2022-2023

CEMEX Polska. (N.d.). *Cementownia Rudniki.* https://www.cemex.pl/cementownia-rudniki.aspx

Chalamoński, M., & Szymczak, M. (2017). Dried sewage sludge as an alternative fuel. *Journal of Civil Engineering, Environment and Architecture, 34*(64), 35–42.

Chan, P., Khoeng, K., Ung, H. K., Tang, T., Eung, K., Uth, S., Meng, S., Sun, L., Em, S., Toum, H., Phok, O., Sry, R., Mok, L., Lo, R., Vat, C., Phay, S., Hor, O., Cheath, C. V., Lim, M., An, P., Sareun, M., Sot, S., Va, S., Chea, Y., & Piseth, M. R. (2021). Plan-design, construction, performance, and renovation criteria for sustainable buildings: Data review. *Preprints.org.*

Chang, S. M., & Rajuli, M. F. (2024). An overview of pure hydrogen production via electrolysis and hydrolysis. *International Journal of Hydrogen Energy, 84,* 521–538.

Charter, M. (Ed.). (2019). *Designing for the circular economy.* Routledge.

Charter, M., Young, A., Kielkiewicz-Young, A., & Belmane, I. (2001). Integrated product policy (IPP) and eco-product development (EPD). In *Proceedings of the Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing* (pp. 672–677). IEEE.

Chehebe, J. R. B. (1998). *Life cycle analysis (Análise do ciclo de vida de produtos: ferramenta gerencial da ISO 14000).* Qualitymark.

Chen, J., Hu, L., Sun, H., Fan, Y., Zhou, X., He, Y., Su, X., Wang, Y., Hou, L., & Ma, W. (2025). Examination of spatial and temporal evolution characteristics of carbon emission and influencing factors in territorial functional areas: A case study of the mountainous city Chongqing. *Integrated Environmental Assessment and Management, 21,* 360–373.

Chen, S., Chen, H. H., Zhang, K. Q., & Xu, X. L. (2018). A comprehensive theoretical framework for examining learning effects in green and conventionally managed hotels. *Journal of Cleaner Production, 174,* 1392–1399.

Chen, W., Warren, K. A., & Duan, N. (1999). Incorporating cleaner production analysis into environmental impact assessment in China. *Environmental Impact Assessment Review, 19,* 457–476.

Chia, X. K., & Hadibarata, T. (2021). Cleaner production: A brief review on definitions, trends and the importance in environmental protection. *Environmental and Toxicology Management, 1*(2), 23–27.

Chiner, M. (1988). Planning of expert systems for materials selection. *Materials & Design, 9*(4), 195–203.

Chirambo, D. (2018). Towards the achievement of SDG 7 in sub-Saharan Africa: Creating synergies between Power Africa, Sustainable Energy for All and climate finance to achieve universal energy access before 2030. *Renewable and Sustainable Energy Reviews, 94,* 600–608.

Chiu, S. Y., Huang, J. H., Lin, C. S., Tang, Y. H., Chen, W. H., & Su, S. C. (1999). Applications of a corporate synergy system to promote cleaner production in small and medium enterprises. *Journal of Cleaner Production, 7,* 351–358.

Churkina, G., Organschi, A., Reyer, C. P. O., Ruff, A., Vinke, K., Liu, Z., Reck, B. K., Graedel, T. E., & Schellnhuber, H. J. (2020). Buildings as a global carbon sink. *Nature Sustainability, 3,* 269–276.

Cichy, M. J. (2007). *Czystsza produkcja i jej model fenomenologiczny.* Wydawnictwo Politechniki Śląskiej.

Cichy, M. J. (2017). Robimy to już od dawna! – Kluczowa rola Czystszej Produkcji w Gospodarce Obiegu Zamkniętego. *Czystsza Produkcja i Eko-zarządzanie, 1*(2017), 1–10.

Ciepiela, D. (2023, October). Norweska państwowa spółka sprzeda zieloną energię polskim cementowniom. *WNP.* https://www.wnp.pl/energia/norweska-panstwowa-spolka-sprzeda-zielona-energie-polskim-cementowniom,767503.html

Clark, G., Davis, M., & Kumar, A. (2025). The development of a framework to compare carbon capture and storage technologies as a means of decarbonizing cement production. *Renewable and Sustainable Energy Reviews, 214*.

Clemenz, G. (2010). Eco-labelling and horizontal product differentiation. *Environmental and Resource Economics, 45*(4), 481–497.

Clift, R., Sim, S., & Sinclair, P. (2013). Sustainable consumption and production: Quality, luxury and supply chain equity. In I. S. Jawahir, S. Sikhdar, & Y. Huang (Eds.), *Treatise in sustainability science and engineering* (pp. 291–309). Springer.

Cong, W., & Shi, L. (2019). Heterogeneity of industrial development and evolution of cleaner production: A bibliometric analysis based on the Journal of Cleaner Production. *Journal of Cleaner Production, 212,* 822–836.

Çop, S., Olorunsola, V. O., & Alola, U. V. (2021). Achieving environmental sustainability through green transformational leadership policy: Can green team resilience help? *Business Strategy and the Environment, 30,* 671–682.

Costa, F., & Ribeiro, D. (2020). Reduction in CO_2 emissions during production of cement with partial replacement of traditional raw materials by civil construction waste. *Journal of Cleaner Production, 276,* 123302.

COWI Consulting Engineers and Planners AS, Danish Environmental

Protection Agency, Danish Ministry of Environment and Energy, & United Nations Environment Programme. (2000). *Cleaner production assessment in dairy processing*. United Nations Environment Programme.

Cui, J., Li, J., Xiao, J., Yao, J., & Yang, Z. (2020). Reclamation pathway of waste piles: A case study in Shanghai. *Journal of Cleaner Production, 253,* 119919.

Czaplicka-Kolarz, K., Burchart-Korol, D., & Krawczyk, P. (2010). Methodology of eco-efficiency analysis. *Journal of Ecology and Health, 14*(6), 267–271.

Czarnecki, S., Chajec, A., Malazdrewicz, S., & Sadowski, Ł. (2023). Prediction of abrasion resistance of mortars modified with granite powder and fly ash using artificial neural networks. *Applied Sciences, 13,* 4011.

da Cruz, T. T., Balestieri, J. A. P., de Toledo Silva, J. M., Vilanova, M. R. N., Oliveira, O. J., & Ávila, I. (2021). Life cycle assessment of carbon capture and storage/utilisation. *International Journal of Greenhouse Gas Control, 108,* 103309.

da Silva, F. J. G., & Gouveia, R. M. (2020). *Cleaner production: Toward a better future.* Springer.

da Silva, G. C. S., & Medeiros, D. D. (2006). Metodologia de Checkland aplicada a implementaçao da produçao mais limpa em serviços. *Gestao e Produçao, 13*(3), 411–422.

da Silva, P. C., de Oliveira Neto, G. C., Correia, J. M. F., & Tucci, H. N. P. (2021). Evaluation of economic, environmental and operational performance of the adoption of cleaner production: Survey in large textile industries. *Journal of Cleaner Production, 278,* 123855.

Dąbrowski, M., & Małolepszy, J. (2010). Properties of concretes made of slag–lime cements. *Drogi i Mosty, 4,* 5–28.

Dacić, A., Mester, E., Fenyvesi, O., & Szalay, Z. (2024). Life cycle assessment of concrete incorporating all concrete recycling products. *Case Studies in Construction Materials, 21,* e03910.

Dalirazar, S., & Sabzi, Z. (2023). Strategic analysis of barriers and solutions to development of sustainable buildings using the PESTLE technique. *International Journal of Construction Management, 23*(1), 167–181.

Dammann, S., & Elle, M. (2006). Environmental indicators: Establishing a common language for green building. *Building Research & Information, 34*(4), 387–404.

Danso, H. (2013). Building houses with locally available materials in Ghana: Benefits and problems. *International Journal of Science and Technology, 2*(2), 225–231.

Daquino, S. F., Prá, F. D. B., Goulart, M. C., Campos, L. M., & Miguel, P. A. C. (2014). Uma análise da aplicaçao empírica da produçao mais limpa na manufatura. *Journal of Cleaner Production, 73,* 246–258.

Darko, A., Chan, A. P. C., Ameyaw, E. E., He, B. J., & Olanipekun, A. O. (2017). Examining issues influencing green building technologies adoption: United States green building experts' perspectives. *Energy and Buildings, 144,* 320–332.

de Grave, A., Olsen, S. I., Hansen, H. N., & Arentoft, M. (2010). Sustainability of micro-manufacturing technologies. In Y. Qin (Ed.), *Micromanufacturing engineering and technology* (pp. 394–404). Elsevier.

de Grosbois, D. (2016). Corporate social responsibility reporting in the cruise tourism industry: A performance evaluation using a new institutional theory-based model. *Journal of Sustainable Tourism, 24*(2), 245–269.

de Guimaraes, J. C. F., Severo, E. A., & Vieira, P. S. (2017). Cleaner production, project management and strategic drivers: An empirical study. *Journal of Cleaner Production, 141,* 881–890.

de Long, M., Casto, M. A., Min, S., & Goncu-Berk, G. (2017). Exploring an up-cycling design process for apparel design education. *Fashion Practice, 9,* 48–68.

de Oliveira, J. F. G., & Alves, S. M. (2007). Adequaçao ambiental dos processos de usinagem utilizando produçao mais limpa como estratégia de gestao ambiental. *Produçao, 17*(1), 129–138.

de Oliveira, J. A., Lopes Silva, D. A., Devós Ganga, G. M., Filho, M. G., Ferreira, A. A., Esposto, K. F., & Ometto, A. R. (2019). Cleaner production practices, motivators and performance in Brazilian industrial companies. *Journal of Cleaner Production, 231,* 359–369.

de Oliveira Neto, G. C., Correia, J. M. F., Silva, P. C., Sanches, A. G., & Lucato, W. C. (2019). Cleaner production in the textile industry and its relationship to sustainable development goals. *Journal of Cleaner Production, 228,* 1514–1525.

de Oliveira Neto, G. C., Correia, J. M. F., Tucci, H. N. P., da Silva, P. C., & da Silva, D. (2021). Relationship between cleaner production practices and company size in the Brazilian textile industry. *Environmental Engineering and Management Journal, 20,* 203–216.

de Oliveira Neto, G. C., da Silva, P. C., Tucci, H. N. P., & Amorim, M. (2021). Reuse of water and materials as a cleaner production practice in the textile industry contributing to the blue economy. *Journal of Cleaner Production, 305,* 127075.

de Oliveira Neto, G. C., Leite, R. R., Lucato, W. C., Vanalle, R. M., Amorim, M., Matias, J. C. O., & Kumar, V. (2022). Overcoming barriers to the implementation of cleaner production in small enterprises in the mechanics industry: Exploring economic gains and contributions for sustainable development goals. *Sustainability, 14*(5), 2944.

de Oliveira Neto, G. C., Leite, R. R., Shibao, F. Y., & Lucato, W. C. (2017). Framework to overcome barriers in the implementation of cleaner production in small and medium-sized enterprises: Multiple case studies in Brazil. *Journal of Cleaner Production, 142,* 50–62.

de Oliveira Neto, G. C., Shibao, F. Y. G., Filho, M. G., & Chaves, L. E. C. (2015). Cleaner production: A study of the environmental and economic advantage in polymer recycling. *Interciencia, 40*(6), 364–373.

de Oliveira Neto, G. C., Tucci, H. N. P., Correia, J. M. F., da Silva, P. C., & Ganga, G. M. D. (2020). Assessing the implementation of Cleaner Production and company sizes: Survey in textile companies. *Journal of Engineered Fibers and Fabrics, 15*, 1558925020915585.

de Oliveira Neto, G. C., Tucci, H. N. P., Correia, J. M. F., da Silva, P. C., da Silva, D., & Amorim, M. (2021). Stakeholders' influences on the adoption of cleaner production practices: A survey of the textile industry. *Sustainable Production and Consumption, 26,* 126–145.

Dehghan-Manshadi, B., Mahmudi, H., Abedian, A., & Mahmudi, R. (2007). A novel method for materials selection in mechanical design: Combination of non-linear normalisation and a modified digital logic method. *Materials & Design, 28*(1), 8–15.

Delmas, M. A., & Grant, L. E. (2008). *Eco-labeling strategies: The eco-premium puzzle in the wine industry*. Institute for Social, Behavioral, and Economic Research.

Delmas, M. A., & Lessem, N. (2017). Eco-premium or eco-penalty? Eco-labels and quality in the organic wine market. *Business & Society, 56*(2), 318–335.

Demirer, G., & Alkaya, E. (2018). *Cleaner production guide for the textile sector: Efficiency in use of resources, decrease in costs, harmony with the environment.* WWF-Turkey.

Deng, Y. M., & Edwards, K. L. (2007). The role of materials identification and selection in engineering design. *Materials & Design, 28,* 131–139.

Denton, D. K. (1999). Employee involvement, pollution control and pieces to the puzzle. *Environmental Management and Health, 10*(2), 105–111.

DeSimone, L. D., & Popoff, F. (2000). *Eco-efficiency: The business link to sustainable development.* MIT Press.

Diana, G. C., Jabbour, C. J. C., de Sousa Jabbour, A. B. L., & Kannan, D. (2017). Putting environmental technologies into the mainstream: Adoption of environmental technologies by medium-sized manufacturing firms in Brazil. *Journal of Cleaner Production, 142,* 4011–4018.

Dias Pimenta, H. C., Gouvinhas, R. P., & Evans, S. (2012). Cleaner production as a corporate sustainable tool: A study of companies from Rio Grande do Norte state, Brazil. In G. Seliger (Ed.), *Sustainable manufacturing: Shaping global value creation* (pp. 23–32). Springer.

Dodic, S. N., Vucurovic, D. G., Popov, S. D., Dodic, J. M., & Zavargo, Z. Z. (2010). Concept of cleaner production in Vojvodina. *Renewable and Sustainable Energy Reviews, 14*(6), 1629–1634.

Dombey, D. (1997, May 5). Well-built success. *Industry Week,* 32–39.

Domingues, B. C., Santos, D. M. F., Mateus, M., & Cecilio, D. (2024). Techno-economic analysis of cement decarbonization techniques: Oxygen enrichment vs. hydrogen fuel. *Hydrogen, 5*(1), 59–69.

Domingues, R. M., & Paulino, S. R. (2009). Potencial para implantaçao da produçao mais limpa em sistemas locais de produçao: O polo joalheiro de Sao José do Rio Preto. *Gestao & Produçao, 16*(4), 691–704.

Doorasamy, M. (2015). Identifying environmental and economic benefits of cleaner production in a manufacturing company: A case study of a paper and pulp manufacturing company in KwaZulu-Natal. *Investment Management and Financial Innovations, 12*(1), 235–246.

Dostatni, E. (2018). Recycling-oriented eco-design methodology based on decentralised artificial intelligence. *Management and Production Engineering Review, 9*(3), 79–89.

D'Souza, C. (2000). Bridging the communication gap: Dolphin-safe ecolabels. *Corporate Communications: An International Journal, 5*(2), 185–190.

Dubem, I., Stephen, O. O., & Anthony, O. U. (2014). An investigation on policy direction and drivers for sustainable facilities management practice in Nigeria. *Journal of Facilities Management, 12*(3), 303–322.

Duflou, J., & Kellens, K. (2019). Cleaner production. In L. Laperriere & G. Reinhart (Eds.), *CIRP encyclopedia of production engineering.* Springer.

Dunn, R., & Bush, G. E. (2001). Using process integration technology for cleaner production. *Journal of Cleaner Production, 9*(1), 1–23.

Durdyev, S., Ismail, S., Ihtiyar, A., Baker, N. F., & Darko, A. (2018). A partial least squares structural equation modelling (PLS-SEM) of barriers to sustainable construction in Malaysia. *Journal of Cleaner Production, 204,* 564–572.

Durdyev, S., Zavadskas, E. K., Thurnell, D., Banaitis, A., & Ihtiyar, A. (2018). Sustainable construction industry in Cambodia: Awareness, drivers and barriers. *Sustainability, 10*(2).

Dyllick, T., & Hockerts, K. (2002). Beyond the business case for corporate sustainability. *Business Strategy and the Environment, 11*(2), 130–141.

Eder, P. (2003). Expert inquiry on innovation options for cleaner production in the chemical industry. *Journal of Cleaner Production, 11,* 347–364.

Ehrenfeld, J. R. (2005). Eco-efficiency. *Journal of Industrial Ecology, 9*(4), 6–8.

Espinosa, R. V., Soto, M., García, M.-V., & Naranjo, J. E. (2021). Challenges of implementing cleaner production strategies in the food and beverage industry: A literature review. In *Advances and applications in computer science, electronics and industrial engineering* (pp. 121–133). Springer.

Feiz, R., Ammenberg, J., Baas, L., Eklund, M., Helgstrand, A., & Marshall, R. (2015). Improving the CO_2 performance of cement, part III: The relevance of industrial symbiosis and how to measure its impact. *Journal of Cleaner Production, 98,* 145–155.

Feiz, R., Ammenberg, J., Baas, L., Eklund, M., Helgstrand, A., & Marshall, R. (2015). Improving the CO_2 performance of cement, part I: Utilizing life-cycle assessment and key performance indicators to assess development within the cement industry. *Journal of Cleaner Production, 98,* 272–281.

Fernández, E., Junquera, B., & Ordiz, M. (2003). Organisational culture and human resources in the environmental issue: A review of the literature. *International Journal of Human Resource Management, 14*(4), 634–656.

Ferrandiz-Mas, V., Bond, T., García-Alcocel, E., & Cheeseman, C. (2014). Lightweight mortars containing expanded polystyrene and paper sludge ash. *Construction and Building Materials, 61,* 285–292.

Figge, F., & Hahn, T. (2004). Sustainable value added: Measuring corporate contributions to sustainability beyond eco-efficiency. *Ecological Economics, 48*(2), 173–187.

Figge, F., & Hahn, T. (2004). Sustainable value added: Measuring corporate contributions to sustainability beyond eco-efficiency. *Ecological Economics, 48*(2), 173–187.

Filho, W. L., Skouloudis, W. A., Brandli, L. L., Salvia, A. L., Avila, L. V., & Rayman-Bacchus, L. (2019). Sustainability and procurement practices in higher education institutions: Barriers and drivers. *Journal of Cleaner Production, 231,* 1267–1280.

Fonseca, L., & Carvalho, F. (2019). The reporting of SDGS by quality, environmental, and occupational health and safety-certified organizations. *Sustainability, 11*(20).

Fore, S., & Mbohwa, G. T. (2010). Cleaner production for environmentally conscious manufacturing in the foundry industry. *Journal of Engineering Design and Technology, 8*(3), 314–333.

Fore, S., & Mbohwa, G. T. (2010). Cleaner production for environmentally conscious manufacturing in the foundry industry. *Journal of Engineering Design and Technology, 8*(3), 314–333.

Fresner, J. (1998). Cleaner production as a means for effective environmental management. *Journal of Cleaner Production, 6*(3–4), 171–179.

Fresner, J. (2004). Small and medium-sized enterprises and experiences with environmental management. *Journal of Cleaner Production, 12*(6), 545–547.

Friedlingstein, P., O'Sullivan, M., Jones, M. J., Andrew, R. M., Baker, D. C. E., Hauck, J., Landschützer, P., Le Quéré, C., Luijkx, I. T., Peters, G. P., et al. (2023). Global carbon budget 2023. *Earth System Science Data, 15,* 5301–5369.

Fujii, H., & Managi, S. (2019). Decomposition analysis of sustainable green technology inventions in China. *Technological Forecasting and Social Change, 139,* 10–16.

CEMEX S.A. de C.V. history. (N.d.). *FundingUniverse.* https://www.fundinguniverse.com/company-histories/cemex-s-a-de-c-v-history/

Gagg, C. R. (2014). Cement and concrete as an engineering material: An historic appraisal and case study analysis. *Engineering Failure Analysis, 40,* 114–140.

Gallego-Álvarez, I., Vicente-Galindo, M. P., Galindo-Villardón, M. P., & Rodríguez-Rosa, M. (2014). Environmental performance in countries worldwide: Determinant factors and multivariate analysis. *Sustainability, 6*(11), 7807–7832.

Galvez-Martos, J. L., & Schoenberger, H. (2014). An analysis of the use of life cycle assessment for waste co-incineration in cement kilns. *Resources, Conservation and Recycling, 86,* 118–131.

García-Ávila, F., Cabello-Torres, R., Iglesias-Abad, S., García-Mera, G., García-Uzca, C., Valdiviezo-Gonzales, L., & Donoso-Moscoso, S. (2023). Cleaner production and drinking water: Perspectives from a scientometric and systematic analysis for sustainable performance. *South African Journal of Chemical Engineering, 45,* 136–148.

García-Sánchez, I. M., Gallego-Álvarez, I., & Zafra-Gómez, J. L. (2019). Do eco-innovation and ecodesign strategies generate value added in munificent environments? *Business Strategy and the Environment, 29,* 1021–1033.

Gavrilescu, M. (2004). Cleaner production as a tool for sustainable development. *Environmental Engineering and Management Journal, 3*(1), 45–70.

Gerrard, C., Janssen, M., Smith, L., Hamm, U., & Padel, S. (2013). UK consumer reactions to green certification logos. *British Food Journal, 115*(5), 727–742.

Getzner, M. (2002). The quantitative and qualitative impacts of clean technologies on employment. *Journal of Cleaner Production, 10*(4), 305–319.

Ghazinoory, S. (2005). Cleaner production in Iran: Necessities and priorities. *Journal of Cleaner Production, 13*(8), 755–762.

Ghenai, C., Inayat, A., Shanableh, A., Al-Sarairach, E., & Janajreh, I. (2019). Combustion and emission analysis of spent pot lining (SPL) as alternative fuel in the cement industry. *Science of the Total Environment, 684,* 510–526.

Ghisetti, C., & Quatraro, F. (2017). Green technologies and environmental productivity: A cross-sectoral analysis of direct and indirect effects in Italian regions. *Ecological Economics, 132,* 1–13.

Giannetti, B. F., Agostinho, F., Cabello Eras, J. J., Yang, Z., & Almeida, C. M. V. B. (2020). Integrating cleaner production into sustainability strategies: An introduction to this special volume. *Journal of Cleaner Production, 271*, 122127.

Giergiczny, Z. (2019). Fly ash and slag. *Cement and Concrete Research, 124,* 1–18.

Giesekam, J. (2016). *Drivers and barriers to the adoption of sustainable materials.* Centre for Industrial Energy, Materials and Products.

Ginsberg, J. M., & Bloom, P. N. (2004). Choosing the right green marketing strategy. *MIT Sloan Management Review, 48*(1), 79–85.

Glavič, P. (2021). Evolution and current challenges of sustainable consumption and production. *Sustainability, 13*(16), 9379.

Glavič, P., & Lukman, R. (2007). Review of sustainability terms and their definitions. *Journal of Cleaner Production, 15*(18), 1875–1885.

Glavič, P., Lesjak, M., & Hirsbak, S. (2012, May 2–4). *European training course on eco-efficiency* [Conference presentation]. 15th European Roundtable on Sustainable Consumption and Production, Bregenz.

Global Alliance for Buildings and Construction, International Energy Agency, & United Nations Environment Programme. (2020). *Global ABC roadmap for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector*. Paris, France.

Głodek-Bucyk, E., Sładeczek, F., Kalinowski, W., & Dudkiewicz, M. (2016). Influence of the use of sewage sludge in Portland clinker production technology on the level of CO_2 emissions. *Prace Instytutu Ceramiki i Materiałów Budowlanych, 26,* 40–50.

Gołaszewska-Kaczan, U., Kruk, M., & Śleszyńska-Świderska, A. (2015). Eco-labelling as a tool of CSR: Opportunities and threats. *Optimum. Studia Ekonomiczne, 5*(77), 179–194.

Gombault, M., & Versteege, S. (1999). Cleaner production in SMES through a partnership with local authorities: Successes from The Netherlands. *Journal of Cleaner Production, 7,* 249–261.

González-Benito, J., & González-Benito, O. (2006). A review of determinant factors of environmental proactivity. *Business Strategy and the Environment, 15,* 87–102.

Govindarajulu, N., & Daily, B. F. (2004). Motivating employees for environmental improvement. *Industrial Management and Data Systems, 104*(4), 364–372.

Gradek, V. (2007, February 23). Rudniki: Residents challenged the municipality's decision. *Częstochowa Nasze Miasto*.

Gunarathne, N., & Lee, K. H. (2021). Corporate cleaner production strategy development and environmental management accounting: A contingency theory perspective. *Journal of Cleaner Production, 308,* 127402.

Gunarathne, N., & Sankalpani, U. (2021). Diffusion of cleaner production in a developing country: The case of Sri Lanka. *Journal of Cleaner Production, 311,* 127626.

Gunasekaran, K., Annadurai, R., & Kumar, P. (2013). Plastic shrinkage and deflection characteristics of coconut shell concrete slab. *Construction and Building Materials, 43*(6), 203–207.

Gunningham, N., Sinclair, D., & Burritt, P. (1997). *ACEL final report: Barriers and motivators to the adoption of cleaner production practices*. Australian Centre for Environmental Law, The Australian National University.

Guo, H. C., Chen, B., Yu, X. L., Huang, G. H., Liu, L., & Nie, X. H. (2005). Assessment of cleaner production options for the alcohol industry of China: A study in the Shouguang Alcohol Factory. *Journal of Cleaner Production, 14,* 94–103.

Guo, J., Bao, Y., & Wang, M. (2018). Steel slag in China: Treatment, recycling, and management. *Waste Management, 78,* 318–330.

Guo, Y., Luo, L., Liu, T., Hao, L., Li, Y., Liu, P., & Zhu, T. (2024). A review of low-carbon technologies and projects for the global cement industry. *Journal of Environmental Sciences, 136,* 682–697.

Guo, Y., Luo, L., Liu, T., Hao, L., Li, Y., Liu, P., & Zhu, T. (2024). A review of low-carbon technologies and projects for the global cement industry. *Journal of Environmental Sciences, 136,* 682–697.

Gursel, A. P., Maryman, H., & Ostertag, C. A. (2016). Life-cycle approach to environmental, mechanical, and durability properties of green concrete mixes with rice husk ash. *Journal of Cleaner Production, 112,* 823–836.

Gursel, P., Masanet, E., Horvath, A., & Stadel, A. (2014). Life-cycle inventory analysis of concrete production: A critical review. *Cement and Concrete Composites, 51,* 38–48.

Gyabaah, G., Miyazawa, S., & Nito, N. (2022). Effects of gypsum and limestone powder on fresh properties and compressive strength of concrete containing ground granulated blast furnace slag under different curing temperatures. *Construction Materials, 2*(2), 114–126.

Habert, G., Billard, C., Rossi, P., Chen, C., & Roussel, N. (2010). Cement production technology improvement compared to factor 4 objectives. *Cement and Concrete Research, 40,* 820–826.

Habib, M. A., Karim, M. R., Dulal, M., & Munir, M. S. (2022). Impact of institutional pressure on cleaner production and sustainable firm performance. *Sustainability, 14,* 16748.

Hájek, P., Zhunissova, G., Oralbaeva, Z., Zhidebekkyzy, A., & Baidildina, A. (2019). Competitiveness and economic profit analysis of Kazakhstan's poultry companies. *Journal of International Studies, 12*(2), 147–164.

Häkkinen, T., & Belloni, K. (2011). Barriers and drivers for sustainable building. *Building Research & Information, 39*(3), 239–255.

Halada, K. (1999). Progress of ecomaterials research towards a sustainable society. In *Proceedings of the First International Symposium on Environmentally Conscious Design and Inverse Manufacturing.* IEEE.

Halada, K. (2003). Progress of ecomaterials towards a sustainable society. *Current Opinion in Solid State and Materials Science, 7,* 209–216.

Halada, K., Aizawa, T., & Mabuchi, M. (2002). New step of ecomaterial to break through the barrier between ecomaterial selection and ecodesign. *Materials Transactions, 43*(3), 397–405.

Halada, K., & Yamamoto, R. (2001). The current status of research and development on eco-materials around the world. *MRS Bulletin, 26*(11), 871–878.

Hall, J., Matos, S., & Silvestre, B. (2012). Understanding why firms should invest in sustainable supply chains: A complexity approach. *International Journal of Production Research, 50*(5), 1332–1348.

Hamed, M. M. E., & Mahgary, Y. (2004). Outline of a national strategy for cleaner production: The case of Egypt. *Journal of Cleaner Production, 12,* 327–336.

Han, R. L., Tong, L. J., & Song, Y. N. (2011). Analysis of circular economy of Liaoning Province based on eco-efficiency. *Acta Ecologica Sinica, 31,* 4732–4740.

Harbaugh, R., Maxwell, J. W., & Roussillon, B. (2011). Label confusion: The Groucho effect of uncertain standards. *Management Science, 57*(9), 1512–1527.

Hebbache, K., Boutlikht, M., Douadi, A., Belebchouche, C., Benrebouh, I., Hammouche, R., Moretti, L., Chajec, A., & Czarnecki, S. (2024). Integrated techno-environmental analysis of finely ground silica sand in sustainable mortar production. *Buildings, 14*(10), 3295.

Henao-Duque, S., Acosta, D. A., Tobón, J. A., & Builes, S. (2021). Resistance to grinding and cement paste performance of blends of clinker, limestone, and gypsum. *Journal of the Institution of Engineers, 102,* 535–543.

Heng, X., & Zou, C. (2010). How can green technology be possible? *Asian Journal of Social Science, 6*(5), 110–114.

Henriques, J., & Catarino, J. (2015). Sustainable value and cleaner production: Research and application in 19 Portuguese SMES. *Journal of Cleaner Production, 96,* 379–386.

Hens, L., Block, C., Cabello-Eras, J. J., Sagastume-Gutierez, A., Garcia-Lorenzo, D., Chamorro, C., Mendoza, K. H., Haeseldonckx, D., & Vandecasteele, C. (2018). On the evolution of cleaner production as a concept and a practice. *Journal of Cleaner Production, 172,* 3323–3333.

Hicks, C., & Dietmar, R. (2007). Improving cleaner production through the application of environmental management tools in China. *Journal of Cleaner Production, 15*(5), 395–408.

Hilson, G. (2000). Pollution prevention and cleaner production in the mining industry: An analysis of current issues. *Journal of Cleaner Production, 8,* 119–126.

Hillary, R. (1999). Regulatory and self-regulatory measures as routes to promote cleaner production. *Journal of Cleaner Production, 7*(6), 421–428.

Hitchens, D., Clausen, J., Trainor, M., Keil, M., & Thankappan, S. (2004). Competitiveness, environmental performance and management of SMES. *Greener Management International, 44,* 44–57.

Horbach, J., Rammer, C., & Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact. *Ecological Economics, 78,* 112–122.

Horne, R. E. (2009). Limits to labels: The role of eco-labels in the assessment of product sustainability and routes to sustainable consumption. *International Journal of Consumer Studies, 33*(2), 175–182.

Howgrave-Graham, A., & van Berkel, R. (2006). Assessment of cleaner production uptake: Method development and trial with small businesses in Western Australia. *Journal of Cleaner Production, 15*(8–9), 787–797.

Hsieh, T., Chiang, C., Ho, M., & Lai, K. (2012). The application of green building materials to sustainable building for environmental protection in Taiwan. *Advanced Materials Research, 344,* 267–272.

Huang, B., Chen, Y., McDowall, W., Turkeli, S., Bleischwitz, R., & Geng, Y. (2019). Embodied greenhouse gas emissions of building materials in Shanghai. *Journal of Cleaner Production, 210,* 777–785.

Hübner, R. (2012). *The use-time and obsolescence of durable goods: Eco-design-Reach, limits and challenges after 20 years*. Forum Ware International.

Hukkinen, J. (2003). From groundless universalism to grounded generalism: Improving ecological economic indicators of human-environmental interaction. *Ecological Economics, 44*(1), 11–27.

Huppes, G., & Ishikawa, M. (2005). Eco-efficiency and its terminology. *Journal of Industrial Ecology, 9*(4), 43–46.

Hwidi, R. S., Izhar, T. N. T., & Saad, F. N. M. (2018). Characterization of limestone as raw material to hydrated lime. *E3S Web of Conferences, 34,* 02042.

Ige, O. E., von Kallon, D. V., & Desai, D. (2024). Carbon emissions mitigation methods for the cement industry using a system dynamics model. *Clean Technologies and Environmental Policy, 26,* 579–597.

Ighalo, J. O., & Adeniyi, A. G. (2020). A perspective on environmental sustainability in the cement industry. *Waste Disposal and Sustainable Energy, 2,* 161–164.

Ingaramo, A., Heluane, H., Colombo, M., & Cesca, M. (2009). Water and wastewater eco-efficiency indicators for the sugar cane industry. *Journal of Cleaner Production, 17*(4), 487–495.

Ishak, S. A., & Hashim, H. (2015). Low carbon measures for cement plant: A review. *Journal of Cleaner Production, 103,* 260–274.

Ishara, G. K. K., & Mekala, K. G. H. (2023). Introduction of cleaner production and sustainable development goals. *Journal of Research in Technology and Engineering, 4*(2), 160–172.

Jabbour, C. J. C. (2010). Non-linear pathways of corporate environmental management: A survey of ISO 14001-certified companies in Brazil. *Journal of Cleaner Production, 18*(12), 1222–1225.

Jabbour, C. J. C., Jabbour, A. B. L. S., Govindan, K., de Freitas, T. P., Soubihia, D. F., Kannan, D., & Latan, H. (2016). Barriers to the adoption of green operational practices at Brazilian companies: Effects on green and operational performance. *International Journal of Production Research, 54,* 3042–3058.

Jackson, T. (2010). Keeping out the giraffes. In A. Tickell (Ed.), *Long horizons* (pp. 17–20). British Council.

Jahan, I. A. (2017). Study on waste management and minimisation in ready-made garments (RMG). *American Scientific Research Journal for Engineering, Technology, and Sciences, 35,* 266–273.

Jain, K. P., Pruyn, J., & Hopman, H. (2018). Strategic guidance based on the concept of cleaner production to improve the ship recycling industry. *Environmental Systems Decisions, 38,* 250–260.

Jakobsen, J., Roussanaly, S., & Anantharaman, R. A. (2017). A techno-economic case study of CO_2 capture, transport and storage chain from a cement plant in Norway. *Journal of Cleaner Production, 144,* 523–539.

Jänicke, M. (2008). Ecological modernisation: New perspectives. *Journal of Cleaner Production, 16*(5), 557–565.

Jansen, L. (2003). The challenge of sustainable development. *Journal of Cleaner Production, 11,* 231–245.

Janssen, M., & Hamm, U. (2012). The mandatory EU logo for green food: Consumer perceptions. *British Food Journal, 114,* 335–352.

Janus, M., Strzałkowski, J., Zając, K., & Kusiak-Nejman, E. (2024). Cement clinker modified by photocatalyst: Selected mechanical properties and photocatalytic activity during NO and BTEX decomposition. *Applied Sciences, 14*(19), 8855.

Jaroń-Kocot, M., & Sablik, J. (2004). Waste carbide lime as a component of hydromixes placed in post-mining voids at the bottom of mines. *Prace Naukowe GIG: Górnictwo i Środowisko, 4,* 99–113.

Jegatheesan, V., Liow, J. L., Shu, L., Kim, S. H., & Visvanathan, C. (2009). The need for global coordination in sustainable development. *Journal of Cleaner Production, 17,* 637–643.

Jiang, Y., Asante, D., Chen, D., & Zhang, J. (2021). Evaluation of low-carbon competitiveness based on a system evaluation method: A case study of three Chinese steel companies. *Mathematical Problems in Engineering, 2021,* 6664216.

Jones, M. T. (1999). The institutional determinants of social responsibility. *Journal of Business Ethics, 20*(2), 163–179.

Jouhara, H., Khordehgah, N., Almahmoud, S., Delpech, B., Chauhan, A., & Tassou, S. A. (2018). Waste heat recovery technologies and applications. *Thermal Science and Engineering Progress, 6,* 268–289.

Kachawalage, A. C., Mellaaen, M. C., & Tokheim, L. A. (2017). Substitution of coal by refuse derived fuels (RDF) in the precalciner of a cement kiln system. *Transactions on Ecology and the Environment, 224,* 411–423.

Kadriu, A. (2016). Tourism development and its impact on the overall economic and environmental development of the country. *Journal of Environmental Protection and Ecology, 17*(1), 268–275.

Kalili, N. R. (2015). From cleaner production to sustainable development: The role of academia. *Journal of Cleaner Production, 96,* 30–43.

Kallipoliti, L. (2018). *History of ecological design.* Oxford Research Encyclopedias. Retrieved September 25, 2023.

Kara, M. (2012). Environmental and economic advantages associated with the use of RDF in cement kilns. *Resources, Conservation & Recycling, 68,* 21–28.

Karadag, A. A., & Korkut, D. S. (2012). Examining the sensibilities of the different sectors active in Düzce concerning clean production. *International Journal of Physical Sciences, 7*(1), 153–165.

Karlsson, R., & Luttropp, C. (2006). EcoDesign: What's happening? An overview of the subject area of EcoDesign and of the papers in this special issue. *Journal of Cleaner Production, 14*(15–16), 1291–1298.

Kazmierczyk, P., Osuna, M. R. S., & Schwager-Quijano, P. (2002). *Manual on the development of cleaner production policies: Approaches and instruments.* UNIDO Cleaner Production Programme.

Khalili, N. R., Duecker, S., Ashton, W., & Chavez, F. (2014). From cleaner production to sustainable development: The role of academia. *Journal of Cleaner Production, 96,* 30–43.

Khan, O. U. R. (2016). *Promoting cleaner production and energy efficiency in the industry of Pakistan: A case study of the textile manufacturing sector* (Master's thesis). University of Twente.

Khan, Z. A., Balunaini, U., Costa, S., & Nguyen, N. (2024). A review on sustainable use of recycled construction and demolition waste aggregates in pavement base and subbase layers. *Cleaner Materials, 13,* 100266.

Khan, Z. A., Salami, B. A., Hussain, S. A., Hasan, M. A., Al-Ramadan, B., & Rahman, S. M. (2023). Dynamics of greenhouse gas emissions from cement industries in Saudi Arabia: Challenges and opportunities. *IEEE Access, 11,* 125631–125647.

Khorshidi, F. H., Ray, C., & Faezipour, M. M. (2021). An analysis of cleaner production planning by applying analytic hierarchy process. *International Journal of Sustainable Engineering, 14*(3), 245–254.

Kim, J., Tae, S., & Kim, R. (2018). Theoretical study on the production of environment-friendly recycled cement using inorganic construction wastes as secondary materials in South Korea. *Sustainability, 10*(12), 4449.

Kim, J.-H., Kim, H.-S., Kim, H.-J., Kang, S.-H., Ryu, J.-H., & Shim, S.-S. (2022). Reduction of NO_x emissions from the cement industry in South Korea: A review. *Atmosphere, 13*(1), 121.

King, A., & Lenox, M. (2002). Exploring the locus of profitable pollution reduction. *Management Science, 48*(2), 289–299.

Kitazawa, S., & Sarkis, J. (2000). The relationship between ISO 14001 and continuous source reduction programs. *International Journal of Operations and Production Management, 20*(2), 225–248.

Kituyi, E., & Marani, M. (2000). Cleaner production in Kenyan small and medium enterprises: Prerequisites for successful technology adoption. In *Proceedings of the EXPO 2000 Conference* (pp. 1–10).

Kleib, J., Aouad, G., Abriak, N.-E., & Benzerzour, M. (2021). Production of Portland cement clinker from French municipal solid waste incineration bottom ash. *Case Studies in Construction Materials, 15,* e00900.

Klewitz, J., & Hansen, E. G. (2014). Sustainability-oriented innovation of SMEs: A systematic review. *Journal of Cleaner Production, 65,* 57–75.

Koefoed, M., & Buckley, C. (2008). Clean technology transfer: A case study from the South African metal finishing industry, 2000–2005. *Journal of Cleaner Production, 16,* 78–84.

Koskela, M., & Vehmas, J. (2012). Defining eco-efficiency: A case study on the Finnish forest industry. *Business Strategy and the Environment, 21*(8), 546–566.

Kowal, E., Kucińska-Landwójtowicz, A., & Misiołek, A. (2013). *Zarządzanie środowiskowe* (pp. 197–198). Polskie Wydawnictwo Ekonomiczne.

Kowalski, Z. (1992). Selected problems of defining and assessing the effectiveness of farming in agriculture. *Zagadnienia Ekonomiki Rolnej,* (1–3), 2–22.

Krawczyk, G., & Listos-Rodewald, U. (2008). Foreign direct investment in the ecological development of local systems: A case study (Cementownia Chełm S.A.). *Rocznik Żyrardowski, 6,* 233–252.

Krechowiecki, G., & Środa, B. (2013). Zmodernizowani i przygotowani (I). *Budownictwo, Technologie, Architektura, 1*(93), 76–77. https://www.bta-czasopismo.pl/wp-content/uploads/2019/05/2016.pdf

Krishnya, S., Elakneswaran, Y., & Yoda, Y. (2021). Proposing a three-phase model for predicting the mechanical properties of mortar and concrete. *Materials Today Communications, 29*.

Król, A. (2017). The role of the granulated blast furnace slag in sustainable cement production and waste management. *Economic and Environmental Studies, 17*(3), 613–624.

Kuandykova, A., Taimasov, B., Potapova, E., Sarsenbaev, B., Kolesnikov, A., Begentayev, M., Kuldeyev, E., Zhanikulov, N., Amiraliyev, B., Abdullin, A., & Sedláková, Z. (2024). Production of composite cement clinker based on industrial waste. *Journal of Composites Science, 8*(7), 257.

Kwazo, H. A., Muhammad, M. U., Tafida, G. M., & Mohammed, S. (2014). Environmental impact of technologies. *Academic Journal of Interdisciplinary Studies, 3*(7), 83–86.

Lai, K. H., & Wong, C. W. Y. (2012). Green logistics management and performance: Some empirical evidence from Chinese manufacturing exporters. *Omega, 40,* 267–282.

Laita, E., Bauluz, B., & Yuste, A. (2019). High-temperature mineral phases generated in natural clinkers by spontaneous combustion of coal. *Minerals, 9*(4), 213.

Lal, K. (2018). Green globalization as green technology and renewable energy. *Journal of Engineering Research and Application, 8*(9), 41–53.

Lavagna, L., & Nistico, R. (2023). An insight into the chemistry of cement: A review. *Applied Sciences, 13*(1), 203.

Lavallée, S., & Plouffe, S. (2004). The ecolabel and sustainable development. *The International Journal of Life Cycle Assessment, 9*(6), 349–354.

Lee, K., Chae, C. U., & Tae, S. (2016). Proposal for the evaluation of eco-efficient concrete. *Sustainability, 8*(8), 705.

Leroux, E., & Pupion, P. (2018). Factors of adoption of eco-labelling in the hotel industry. *Technological Forecasting and Social Change, 129,* 194–209.

Lessard, D., & Lucea, R. (2008). *Mexican multinationals: Insights from CEMEX* (MIT Sloan Research Paper No. 4721–08). Massachusetts Institute of Technology.

Lessard, D., & Lucea, R. (2009). Embracing risk as a core competence: The case of CEMEX. *Journal of International Management, 15*(3), 296–305.

Levidow, L., Lindgaard-Jorgensen, P., Nilsson, A., Alongi Skenhall, S., & Assimacopoulos, D. (2014). Eco-efficiency improvements in industrial water-service systems: Assessing options with stakeholders. *Water Science & Technology, 69*(10), 2113–2121.

Liao, S., Wang, D., Xia, C., & Tang, J. (2022). China's provincial process CO_2 emissions from cement production during 1993–2019. *Scientific Data, 9,* 165.

Liderzy Czystszej Produkcji. (N.d.). https://www.cp.org.pl/p/liderzy-cp.html

Lin, C., Zhao, Z., Tao, J., Ye, T., Yao, L., Ji, C., & Duan, Z. (2025). Properties of cement-based materials made with sediment and calcined sediment: A critical review. *Journal of Building Engineering, 106,* 112609.

Lindhqvist, T., & Lifset, R. (1998). Getting the goal right: EPR and DfE. *Journal of Industrial Ecology, 2,* 6–8.

Lins, P. S., Kiperstok, A., Cunha, R. D. A., Raposo, A. L. Q., Merino, E. A. D., & César, S. F. (2021). (Re)layout as a strategy for implementing cleaner production: Proposal for a furniture industry company. *Sustainability, 13*(23), 13109.

Liu, X., Yang, L., Du, J., Zhang, H., Hu, J., Chen, A., & Lv, W. (2024). Carbon and air pollutant emissions forecast of China's cement industry from 2021 to 2035. *Resources, Conservation and Recycling, 204,* 107498.

Ljungberg, L. Y. (2007). Materials selection and design for development of sustainable products. *Materials & Design, 28*(2), 466–479.

Lober, D. J. (1996). Evaluating the environmental performance of corporations. *Journal of Managerial Issues, 8,* 184–205.

Loiseau, E., Saikku, L., Antikainen, R., Droste, N., Hansjürgens, B., Pitkänen, K., Leskinen, P., Kuikman, P., & Thomsen, M. (2016). Green economy and related concepts: An overview. *Journal of Cleaner Production, 139,* 361–371.

Lomas, T. (2019). The elements of eco-connection: A cross-cultural lexical enquiry. *International Journal of Environmental Research and Public Health, 16*(24), 1–16.

Long, X., Zhao, X., & Cheng, F. (2015). The comparative analysis of total factor productivity and eco-efficiency in China's cement manufacturers. *Energy Policy, 81,* 61–66.

Louafi, A. E., & Boutora, F. (2020). The importance of cleaner production in the cement industry. *Algerian Review of Economic Development, 7*(2), 415–428.

Luo, J., Huang, R., Wang, J., & Zhang, Y. (2024). Carbon sequestration by preparing recycled cement, recycled aggregates, and recycled concrete from construction and demolition (C&D) wastes. *Materials, 17,* 5020.

Luzha, I., Aliu, B., & Zguro, T. (2024). The importance of gypsum in the process of hydration of cement. In *Proceedings of the UBT International Conference.* https://knowledgecenter.ubt-uni.net/conference/2024UBTIC/CEIE/16

Maama, H., Doorasamy, M., & Rajaram, R. (2021). Cleaner production, environmental and economic sustainability of production firms in South Africa. *Journal of Cleaner Production, 298*(4), 126707.

Maccioni, L., Borgianni, Y., & Basso, D. (2019). Value perception of green products: An exploratory study combining conscious answers and unconscious behavioural aspects. *Sustainability, 11*(5), 1–41.

Madlool, N., Saidur, R., Rahim, N., & Kamalisarvestani, M. (2013). An overview of energy saving measures for cement industries. *Renewable and Sustainable Energy Reviews, 19,* 18–29.

Magutu, J. (2015). Towards popularization of low-cost building materials and technologies for urban housing in developing countries. *International Journal of Scientific Research and Innovative Technology, 2*(1), 20–43.

Malinowski, D. (2020, July 7). Cały prąd dla Cemex w Polsce z OZE. *WNP Budownictwo*. https://www.wnp.pl/budownictwo/caly-prad-dla-cemex-w-polsce-z-oze,405213.html

Marinova, S., Deetman, S., van der Voet, E., & Daioglou, V. (2020). Global construction materials database and stock analysis of residential buildings between 1970 and 2050. *Journal of Cleaner Production, 247,* 119146.

Massote, C. H. R., & Santi, A. M. M. (2013). Implementation of a cleaner production programme in a Brazilian wooden furniture factory. *Journal of Cleaner Production, 46,* 89–97.

McIntyre, R., & Thornton, J. (1978). On the environmental efficiency of economic systems. *Soviet Studies, 30*(2), 173–192.

Metwally, E. (2019). Use energy efficiency, eco-design, and eco-friendly materials to support eco-tourism. *Journal of Power and Energy Engineering, 7*(12).

Mezawa, O., Shinohara, Y., & Halada, K. (2019). Growth of ecomaterials and eco-efficiency in major metallic structural materials. In L. M. T. Martínez, O. V. Kharissova, & B. I. Kharisov (Eds.), *Handbook of ecomaterials* (pp. 2261–2280). Springer.

Michelini, R. C., & Razzoli, R. P. (2004). Product-service for environmental safeguard: A metrics to sustainability. *Resources, Conservation and Recycling, 42,* 83–98.

Michelsen, O., Fet, A. M., & Dahlsrud, A. (2006). Eco-efficiency in extended supply chains: A case study of furniture production. *Journal of Environmental Management, 79,* 290–297.

Mickwitz, P., Melanen, M., Rosenström, U., & Seppälä, J. (2006). Regional eco-efficiency indicators: A participatory approach. *Journal of Cleaner Production, 14*(18), 1603–1611.

Mikulčić, H., Klemeš, J. J., Vujanović, M., Urbaniec, K., & Duić, N. (2016). Reducing greenhouse gas emissions by fostering the deployment of alternative raw materials and energy sources in the cleaner cement manufacturing process. *Journal of Cleaner Production, 136*(B), 119–132.

Miles, M. P., & Covin, J. G. (2000). Environmental marketing: A source of reputational, competitive and financial advantage. *Journal of Business Ethics, 23*(3), 299–311.

Miller, S. A., Habert, G., Myers, R. J., & Harvey, J. T. (2021). Achieving net zero greenhouse gas emissions in the cement industry via value chain mitigation strategies. *One Earth, 4,* 1398–1411.

Minkov, N., Lehmann, A., Winter, L., & Finkbeiner, M. (2018). Characterisation of environmental labels beyond the criteria of ISO 14020. *The International Journal of Life Cycle Assessment, 25*(8), 17–32.

Miroshnychenko, I., Barontini, R., & Testa, F. (2017). Green practices and financial performance: A global outlook. *Journal of Cleaner Production, 147,* 340–351.

Mitchell, C. L. (2006). Beyond barriers: Examining root causes behind commonly cited cleaner production barriers in Vietnam. *Journal of Cleaner Production, 14,* 1576–1585.

Mittal, V. K., & Sangwan, K. S. (2013). Assessment of hierarchy and interrelationships of barriers to environmentally conscious manufacturing adoption. *World Journal of Science, Technology and Sustainable Development, 10*(4), 297–307.

Mohamed, F., Jamil, M., & Zain, M. F. M. (2019). Sustainable materials: Challenges and prospects. *Journal of Advanced Research in Materials Science, 57*(1), 7–18.

Möller, A., & Schaltegger, S. (2005). The sustainability balanced scorecard as a framework for eco-efficiency analysis. *Journal of Industrial Ecology, 9*(4), 73–84.

Mora, E. P. (2007). Life cycle, sustainability and the transcendent quality of building materials. *Building and Environment, 42*(3), 1329–1334.

Moriarty, P., & Wang, S. J. (2015). Eco-efficiency indicators for urban transport. *Journal of Sustainable Development of Energy, Water and Environment Systems, 3*(2), 183–195.

Morioka, S. M., & de Carvalho, M. M. (2016). A systematic literature review towards a conceptual framework for integrating sustainability performance into business. *Journal of Cleaner Production, 136,* 134–146.

Mugagga, F., & Nabaasa, B. B. (2016). The centrality of water resources to the realisation of sustainable development goals (SDGS). *International Soil and Water Conservation Research, 4,* 215–223.

Murali, K., Lim, M. K., & Petruzzi, N. C. (2018). The effects of ecolabels and environmental regulation on green product development. *Manufacturing & Service Operations Management, 21*(3), 479–511.

Muralikrishna, I. V., & Manickam, V. (2017). Industrial wastewater treatment technologies, recycling, and reuse. In V. Manickam, I. V. Muralikrishna, N. Davergave, & A. Shah (Eds.), *Environmental management: Science and engineering for industry* (pp. 295–336). Elsevier.

Nahui-Ortiz, J., Mendoza, A., & Sotelo, F. (2019). A methodology for cleaner production implementation at a university campus in Lima, Peru. In *Proceedings of the 17th LACCEI International Multi-Conference for Engineering, Education, and Technology: Industry, innovation, and infrastructure for sustainable cities and communities*. http://dx.doi.org/10.18687/LACCEI2019.1.1.459

Naqi, A., & Jang, J. G. (2019). Recent progress in green cement technology utilising low-carbon emission fuels and raw materials: A review. *Sustainability, 11*(2), 537.

Nasrin, K., Susanna, D., Weslynne, A., & Francisco, C. (2015). From cleaner production to sustainable development: The role of academia. *Journal of Cleaner Production, 96,* 30–43.

Neha, M., & Rambeer, J. (2021). Renewable energy sources: A review. *Journal of Physics: Conference Series, 1979,* 012023.

Neto, J. S. A., Carvalho, I. C., Monteiro, P. J. M., de Matos, P. R., & Kirchheim, A. P. (2025). Unveiling the key factors for clinker reactivity and cement performance: A physico-chemical and performance investigation of 40 industrial clinkers. *Cement and Concrete Research, 187,* 107717.

Neverauskiene, L. O., & Rakauskiene, O. G. (2018). Identification of employment increasing possibilities in the context of the EU socioeconomic environment evaluation: The case of Lithuania. *Economics and Sociology, 11*(4), 51–68.

Newig, J., Jahn, S., Lang, D. J., Kahle, J., & Bergmann, M. (2019). Linking modes of research to their scientific and societal outcomes. *Environmental Science and Policy, 101,* 147–155.

Nilimaa, J. (2023). Smart materials and technologies for sustainable concrete construction. *Developments in the Built Environment, 15,* 100177.

Nishimura, C., & Kuniyuki, T. (2002). Trends in ecomaterials: Approach of materials science to global environmental problems. *Science & Technology Trends,* 36–46.

Nishimura, C., & Tada, K. (2003). Trends in ecomaterials: Approach of materials science to global environmental problems. *Quarterly Review, 7,* 36–46.

Nowak, M. (2023). Features of refuse derived fuel in Poland: Physicochemical properties and availability of refuse derived fuel. *Journal of Ecological Engineering, 24*(3), 1–9.

Nowosad, J. (2019). Energy efficiency in Cemex Polska. *Energetyka Cieplna i Zawodowa,* (2), 17–19.

Nowosielski, R. (2008). *Czystsza produkcja i zrównoważone technologie.* Wydawnictwo Politechniki Śląskiej.

Nowosielski, R., Kania, A., & Spilka, M. (2007). Development of ecomaterials and materials technologies. *Journal of Achievements in Materials and Manufacturing Engineering, 21*(1), 27–30.

Nowosielski, R., Spilka, M., & Kania, A. (2010). *Environmental management and environmental management systems.* Wydawnictwo Politechniki Śląskiej.

Nowosielski, S. (2008). Efficiency and effectiveness of the implementation of economic processes. In T. Dudycz (Ed.), *Mikroekonomiczne aspekty funkcjonowania przedsiębiorstw* (pp. 39–46). Wydawnictwo Politechniki Wrocławskiej.

Ohiomah, I., Aigbavboa, C., & Thwala, W. D. (2019). An assessment on the drivers and obstacles of sustainable project management in South Africa: A case study of Johannesburg. *IOP Conference Series: Materials Science and Engineering, 640*.

Olson, E. G. (2008). Creating an enterprise-level green strategy. *Journal of Business Strategy, 29*(2), 22–30.

Omer, M. A. B., & Noguchi, T. (2020). A conceptual framework for understanding the contribution of building materials to the achievement of sustainable development goals (SDGS). *Sustainable Cities and Society, 52,* 101869.

Ometto, A. R. (2013). Quality tools applied to cleaner production programs. *Journal of Cleaner Production, 47,* 174–187.

Organ, S., Proverbs, D., & Squires, G. (2013). Motivations for energy efficiency refurbishment in owner-occupied housing. *Structural Survey, 31*(2), 101–120.

Organisation for Economic Co-operation and Development. (1998). *Eco-efficiency*. OECD.

Ortega, J. M., Esteban, M. D., Rodríguez, R. R., Pastor, J. L., & Sánchez, I. (2016). Microstructural effects of sulphate attack in sustainable grouts for micropiles. *Materials, 9,* 905.

Ortega, J. M., Esteban, M. D., Rodríguez, R. R., Pastor, J. L., Ibanco, F. J., Sánchez, I., & Climent, M. A. (2017). Long-term behaviour of fly ash and slag cement grouts for micropiles exposed to a sulphate aggressive medium. *Materials, 10,* 598.

Oshike, E. E. (2015). Building with earth in Nigeria: A review of past and present efforts to enhance future housing developments. *International Journal of Science, Environment and Technology, 4*(1), 646–660.

Osmanović, Z., Haračić, N., & Zelić, J. (2018). Properties of blast furnace cements (CEM III/A, B, C) based on Portland cement clinker, blast furnace slag and cement kiln dusts. *Cement and Concrete Composites, 91,* 189–197.

Ostrowski, M., Baran, T., Giergiczny, Z., Miera, P., & Janic, A. (2024). Influence of mechanical activation of components and water–cement ratio on the strength of CEM III metallurgical cement. *Cement Lime Concrete, 29*(4), 254–264.

Oyawa, W. O. (2004). Eco-materials for developing countries. *Structural Engineering International, 14*(3), 208–212.

Özbay, E., Erdemir, M., & Durmu, H. I. (2016). Utilization and efficiency of ground granulated blast furnace slag on concrete properties: A review. *Construction and Building Materials, 105,* 423–434.

Pagan, B., & Prasad, P. (2007). The Queensland food eco-efficiency project. *Journal of Cleaner Production, 15,* 764–771.

Pagel, M., & Wu, Z. (2009). Building a more complete theory of sustainable supply chain management using case studies of ten exemplars. *Journal of Supply Chain Management, 45*(2), 37–56.

Pan, X. X., He, Y. Q., & Hu, X. F. (2013). Evaluation and spatial econometric analysis on regional ecological efficiency. *Resources and Environment in the Yangtze Basin, 22,* 640–646.

Pandey, A. K. (2007). *Identification and assessment of cleaner production technologies and appropriate technology management strategies and methods in the South African vehicle industry* (MEng dissertation). University of Pretoria.

Park, W., & Byun, C. (2021). Effect of SMEs' managerial ability and executive compensation on firm value. *Sustainability, 13*(21), 11828.

Paulson, F., & Sundin, E. (2015). Challenges and trends within eco-design. In *Proceedings of the International Conference on EcoDesign.* Tokyo.

Pazienza, P., & de Lucia, C. (2020). For a new plastics economy in agriculture: Policy reflections on the EU strategy from a local perspective. *Journal of Cleaner Production, 253*(6), 119844.

Pereira-Moliner, J., Claver-Cortés, E., Molina-Azorín, J. F., & Tarí, J. J. (2012). Quality management, environmental management and firm performance: Direct and mediating effects in the hotel industry. *Journal of Cleaner Production, 37,* 82–92.

Perron, G. M., Côté, R., & Duffy, J. M. (2006). Improving environmental awareness training in business. *Journal of Cleaner Production, 14*(6), 551–562.

Phair, J. W. (2006). Green chemistry for sustainable cement production and use. *Green Chemistry, 8,* 763–780.

Picazo-Tadeo, A. J., Gómez-Limón, J. A., & Reig-Martínez, E. (2011). Assessing farming eco-efficiency: A data envelopment analysis approach. *Journal of Environmental Management, 92*(4), 1154–1164.

Pieper, C., Liedmann, B., Wirtz, S., Bodendiek, N., Schaefer, S., & Scherer, V. (2020). Interaction of the combustion of refuse derived fuel with the clinker bed in rotary cement kilns: A numerical study. *Fuel, 266,* 117040.

Pierzyna, P., & Popczyk, M. (2014). Recovery of energy waste from wet flue gas desulphurisation method for decommissioning redundant mine workings. *Energy Policy Journal, 17*(3), 341–354.

Piestrzycki, P. (2012). Cement plants are a permanent and important element of the Polish waste management system. *Nowoczesne Budownictwo Inżynieryjne, 2*(95), 54–56.

Pigosso, D., Zanette, E. T., Filho, A. G., Ometto, A. R., & Rozenfeld, H. (2010). Ecodesign methods focused on remanufacturing. *Journal of Cleaner Production, 18,* 21–31.

Platcheck, E. R., Schaeffer, L., Kindlein, W., Jr., & Candido, L. H. A. (2008). Methodology of ecodesign for the development of more sustainable electro-electronic equipment. *Journal of Cleaner Production, 16,* 75–86.

Płonka, P. (2009, May). W oczekiwaniu na nowe serce. *Kierunek Surowce*. https://www.kieruneksurowce.pl/artykul,2258,w-oczekiwaniu-na-nowe-serce.html

Popek, S., & Popek, A. (2020). Cleaner production (CP) programme as an organisational management strategy and its application to the realisation of sustainability. *Contemporary Management Issues, 8*(2), 33–46.

Popek, S., & Popek, A. (2020). Cleaner production (CP) programme as an organisational management strategy and its application in the implementation of sustainable development. *Contemporary Management Problems, 8*(2), 33–46.

Posch, A., & Perl, E. (2007). Regionale Verwertungsnetzwerke und industrielle Symbiosen. In R. Isenmann & M. von Hauff (Eds.), *Industrial ecology: Mit Ökologie zukunftsorientiert wirtschaften* (pp. 265–277). Elsevier Spektrum Akademischer Verlag.

Prace modernizacyjne w cementowniach Rudniki i Małogoszcz. (2021). *Budownictwo, Technologie, Architektura, 1*(93), 76–77.

Preston, L. (2001). Sustainability at Hewlett-Packard: From theory to practice. *California Management Review, 43*(3), 26–37.

Purwanto, P. (2021). Cleaner production and waste minimization. In *Global classroom solid and scheduled waste management conference* (pp. 1–45). Faculty of Civil Engineering Technology.

Puzio, P. (2013, July 22). Cementownia Chełm: Klinkier schowany w wielkich silosach. *Dziennik Wschodni*. https://www.dziennikwschodni.pl/artykul/30750%2Ccementownia-chelm-klinkier-schowany-w-wielkich-silosach

Qian, H. Y., Kong, Q. G., & Zhang, B. L. (2013). The effects of grinding media shapes on the grinding kinetics of cement clinker in a ball mill. *Powder Technology, 235,* 422–425.

Qiao, L., Tang, Y., Li, Y., Liu, M., Yuan, X., Wang, Q., & Ma, Q. (2022). Life cycle assessment of three typical recycled products from construction and demolition waste. *Journal of Cleaner Production, 376,* 134139.

Quella, F. (2001). Environmentally compatible product design: The business strategy of Siemens. In *Proceedings of the Second International Symposium on Environmentally Conscious Design and Inverse Manufacturing* (pp. 49–53). IEEE.

Quella, F., & Schmidt, W. P. (2003). Integrating environmental aspects into product design and development: The new ISO TR 14062. *The International Journal of Life Cycle Assessment, 8,* 113–114.

Radelczuk, H. (2017). Ways to reduce CO_2 emissions in the cement industry on the example of Cement Plant 'Chełm' – CEMEX Poland. *Prace Instytutu Ceramiki i Materiałów Budowlanych, 30,* 107–116.

Rahim, R., & Raman, A. A. A. (2015). Cleaner production implementation in a fruit juice production plant. *Journal of Cleaner Production, 101,* 215–221.

Rahim, R., Raman, A. A. A., Shah, R. S. S., & Chiong, K. S. (2020). A methodology for identifying cleaner production options to reduce carbon emissions in the manufacturing industry. *Research Communication in Engineering Science and Technology, 4,* 24–37.

Rahman, A., Rasul, M. G., Khan, M. M. K., & Sharma, S. (2015). Recent development on the uses of alternative fuels in cement manufacturing process. *Fuel, 145*(1), 84–99.

Reddy, B. V. V., & Jagadish, K. S. (2003). Embodied energy of common and alternative building materials and technologies. *Energy and Buildings, 35,* 129–137.

Reinhard, S., Knox Lovell, C. A., & Thijssen, G. (1999). Econometric estimation of technical and environmental efficiency: An application to Dutch dairy farms. *American Journal of Agricultural Economics, 81*(1), 44–60.

Remmen, A. (2001). Greening of Danish industry: Changes in concepts and policies. *Technology Analysis and Strategic Management, 13,* 53–69.

Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., & Schellnhuber, H. J. (2009). A safe operating space for humanity. *Nature, 461,* 472–475.

Rodica, C., & Ion, C. (2013). The concept of economic efficiency in agriculture. In *Agrarian economy and rural development: Realities and perspectives for Romania* (pp. 258–263). Research Institute for Agricultural Economy and Rural Development.

Rosak-Syrocka, J. (2018). Quality improvement in cleaner production aspect. *MATEC Web of Conferences, 183,* 03013.

Rosak-Szyrocka, J., Krynke, M., & Knop, K. (2017). *Doskonalenie przedsię-*

biorstw w aspekcie czystszej produkcji i zrównoważonego rozwoju. https://www.researchgate.net/publication/340310512

Rossi, M., Germani, M., & Zamagni, A. (2016). Review of ecodesign methods and tools: Barriers and strategies for an effective implementation in industrial companies. *Journal of Cleaner Production, 129,* 361–373.

Rudniki: Cemex Polska zorganizował kolejne spotkanie z interesariuszami. (2024). *Gazeta Częstochowska,* (43).

Rukuni, T. F., Maziriri, E. T., Booysen, K., & Zondo, M. P. (2022). Examining factors influencing green supply chain management implementation in the cement manufacturing industry in South Africa. *Journal of Contemporary Management, 19,* 157–185.

Rusko, M., & Koraus, A. (2013). Types I, II and III of ecolabels. *Journal of Environmental Protection, Safety, Education and Management, 1*(2).

Russel, A. H., & Robidas, L. C. (2019). Opportunities and challenges of eco-label practices in Bangladesh for promoting environmentally conscious consumers. *European Journal of Business and Management Research, 4*(6), 1–7.

Russell, E., Lee, J., & Clift, R. (2019). Can the SDGs provide a basis for supply chain decisions in the construction sector? *Sustainability, 10*(3).

Rybaczewska-Błażejowska, M. (2021). Assessing and improving the eco-efficiency of manufacturing: Learning and challenges from a Polish case study. *Energies, 14*(23), 8125.

Rybaczewska-Błażejowska, M., & Masternak-Janus, A. (2017). Comprehensive regional eco-efficiency analysis based on data envelopment analysis: The case of Polish regions. *Journal of Industrial Ecology, 21*(1), 180–190.

Saade, M. R. M., da Silva, M. G., Gomes, V., & Lavor, B. (2014). Material eco-efficiency indicators for Brazilian buildings. *Smart and Sustainable Built Environment, 3*(1), 54–71.

Sadorsky, P. (2021). Eco-efficiency for the G18: Trends and future outlook. *Sustainability, 13*(20), 11196.

Sahoo, N., Kumar, A., & Samsher. (2022). Review on energy conservation and emission reduction approaches for the cement industry. *Environmental Development, 44,* 100767.

Salem, A. S., & Sorour, M. J. (2022). The role of the cleaner production strategy in enhancing the main success factors. *International Journal of Research in Social Sciences and Humanities, 12*(4), 250–264.

Sammer, K., & Wüstenhagen, R. (2006). The influence of eco-labelling on consumer behaviour: Results of a discrete choice analysis for washing machines. *Business Strategy and the Environment, 15*(3), 185–199.

Sanal, I. (2018). Significance of concrete production in terms of carbon dioxide emissions: Social and environmental impacts. *Politeknik Dergisi, 21*(2), 369–378.

Sánchez-Soberón, F., Rovira, J., Mari, M., Sierra, J., Nadal, M., Domingo, J. L., & Schuhmacher, M. (2015). Main components and human health risks assessment of PM_{10}, $PM_{2.5}$, and PM_1 in two areas influenced by cement plants. *Atmospheric Environment, 120,* 109–116.

Santos, D. F. L., Rezende, M. D. V., & Basso, L. F. C. (2019). Eco-innovation and business performance in emerging and developed economies. *Journal of Cleaner Production, 237,* 117674.

Santosh, T., Eswaraiah, C., Soni, R. K., & Kumar, S. (2023). Size reduction performance evaluation of HPGR/ball mill and HPGR/stirred mill for PGE-bearing chromite ore. *Advanced Powder Technology, 34,* 103907.

Sarkis, J., & Dijkshoorn, J. (2007). Relationships between solid waste management performance and environmental practice adoption in Welsh small and medium-sized enterprises (SMEs). *International Journal of Production Research, 45*(21), 4989–5015.

Satish, J., & Nagesha, N. (2018). Cleaner production: A brief literature review. *Materials Today: Proceedings, 5*(9), 17944–17951.

Satyro, W. C., Contador, J. C., Contador, J. L., Fragomeni, M. A., Ribeiro, A. F., de Lima, A. F., Gomes, J. A., do Nascimento, J. R., de Araújo, J. L., Junior, G. G. S., & Prado, R. G. (2021). Implementing Industry 4.0 through cleaner production and social stakeholders: A holistic and sustainable model. *Sustainability, 13*(22), 12479.

Schäfer, M., & Löwer, M. (2021). Ecodesign: A review of reviews. *Sustainability, 13*(1), 315.

Scheverin, V. N., Fossati, A., Horst, F., Lassalle, V., & Jacobo, S. (2020). Magnetic hybrid gels for emulsified oil adsorption: An overview of their potential to solve environmental problems associated with petroleum spills. *Environmental Science and Pollution Research, 27,* 861–872.

Schindler, A. K., Duke, S. R., & Galloway, W. B. (2024). Co-processing of end-of-life wind turbine blades in Portland cement production. *Waste Management, 182,* 207–214.

Schmidheiny, S. (1992). *Changing course: A global business perspective on development and the environment.* MIT Press.

Scrivener, K. L., John, V. M., & Gartner, E. M. (2018). Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry. *Cement and Concrete Research, 114*, 2–26.

Schroeder, A., Bigdeli, A. Z., Zarco, C. G., & Baines, T. (2019). Capturing the benefits of Industry 4.0: A business network perspective. *Production Planning and Control, 30*(16), 1305–1321.

Schroeder, P., Anggraeni, K., & Weber, U. (2018). The relevance of circular economy practices to the sustainable development goals. *Journal of Industrial Ecology, 23*(1), 77–95.

Schumacher, G., & Juniper, L. (2013). Coal utilisation in the cement and concrete industries. In D. Osborne (Ed.), *The coal handbook: Towards cleaner production* (Vol. 2, pp. 387–426). Woodhead Publishing.

Scripcariu, M., Gheorghiu, C., Gheorghiu, M., & Dobrica, A. G. (2021). Improving energy performance of a cement manufacturing factory by using waste heat recovery systems: Estimated vs. actual achievements. *E3S Web of Conferences, 286,* 01007.

Sellitto, M. A., Camfield, C. G., & Buzuku, S. (2020). Green innovation and competitive advantages in a furniture industrial cluster: A survey and structural model. *Sustainable Production & Consumption, 23,* 94–104.

Serpell, A., Kort, J., & Vera, S. (2013). Awareness, actions, drivers and barriers of sustainable construction in Chile. *Technological and Economic Development of Economy, 19*(2), 272–288.

Seuring, S., & Müller, M. (2008). Core issues in sustainable supply chain management: A Delphi study. *Business Strategy and the Environment, 17,* 455–466.

Sev, A. (2009). How can the construction industry contribute to sustainable development? A conceptual framework. *Sustainable Development, 17,* 161–173.

Severo, E. A., & Olea, P. M. (2010). Metodologias de produçao mais limpa: Um estudo de caso no polo metal-mecânico da Serra Gaúcha. *Inovaçao, Gestao e Produçao, 2,* 73–81.

Sh, S. (2020). Cleaner production in order to save the health of humans and the environment: A review. *Journal of Quality in Health Care and Economics, 3*(1), 1–3.

Shafiei, M. W. M., & Abadi, H. (2017). The importance of green technologies and energy efficiency for environmental protection. *International Journal of Applied Environmental Sciences, 12*(5), 937–951.

Shari, Z., & Soebarto, V. (2013). Investigating sustainable practices in Malaysian office building developments. *Construction Innovation, 14*(1), 17–37.

Shi, H., Peng, S. Z., Liu, Y., & Zhong, P. (2008). Barriers to the implementation of cleaner production in Chinese SMEs: Government, industry and expert stakeholders' perspectives. *Journal of Cleaner Production, 16,* 842–852.

Shi, L., Huang, J., Shi, H., & Qian, Y. (2003). Modelling cleaner production promotion with system dynamics methodology: A case study of process industries in China. *Process Systems Engineering, 15,* 322–327.

Shinohara, Y. (2004). Eco-materials guideline project in Japan. In *Proceedings of the 1st Japan–China Symposium on Eco-Materials, Recycling-Oriented Industry and Environmental Management.*

Shivaprasad, K. N., Yang, H. M., & Singh, J. K. (2024). A path to carbon neutrality in construction: An overview of recent progress in recycled cement usage. *Journal of CO_2 Utilization, 83,* 102816.

Shu-Yang, F., Freedman, B., & Côté, R. (2004). Principles and practice of ecological design. *Environmental Reviews, 12*(2), 97–112.

Siaminwe, L., Chisembu, K. C., & Syakalima, M. (2005). Policy and operational constraints for the implementation of cleaner production in Zambia. *Journal of Cleaner Production, 13,* 1037–1047.

Siemeniuk, J., & Szatyłowicz, E. (2018). Reducing CO_2 emissions in the cement production process. *Civil and Environmental Engineering, 9,* 81–86.

Silva, A. L. E., Morales, J. A. R., & Machado, E. L. (2015). Proposta de produçao mais limpa voltada as práticas de ecodesign e logística reversa. *Engenharia Sanitária e Ambiental, 20*(1), 29–37.

Silva, B. Q., Vasconcelos, M. W., & Smetana, S. (2023). Conceptualisation of an ecodesign framework for sustainable food product development across the supply chain. *Environments, 10,* 59.

Silva, D. A. L., Delai, I., de Castro, M. A., & Ometto, A. R. (2013). Quality tools applied to cleaner production programs: A first approach toward a new methodology. *Journal of Cleaner Production, 47,* 174–187.

Silvestre, B. S. (2015). A hard nut to crack! Implementing supply chain sustainability in an emerging economy. *Journal of Cleaner Production, 96,* 171–181.

Silvestre, B. S., & Silva Neto, R. (2014). Are cleaner production innovations the solution for small mining operations in poor regions? The case of Paduá in Brazil. *Journal of Cleaner Production, 84,* 809–817.

Sinkin, C., Wright, C. J., & Burnett, R. D. (2008). Eco-efficiency and firm value. *Journal of Accounting and Public Policy, 27*(2), 167–176.

Sitko, J. (2014). Metallurgical slag utilisation technologies: A literature study. *Engineering Technical Systems: Support Systems in Manufacturing Engineering, 2*(8), 200–210.

Sitko-Lutek, A., & Lutek, W. (2022). *Zasobooszczędna i niskoemisyjna gospodarka na przykładzie branży cementowej.* Wydawnictwo Uniwersytetu Marii Curie-Skłodowskiej.

Skaar, C. (2023). Communicating product life cycle performance through labels and declarations. In A. M. Fet (Ed.), *Business transitions: A path to sustainability - The Cap SEM model* (pp. 57–65). Springer.

Smith, R. A., Kersey, J. R., & Griffiths, P. J. (2002). The construction industry mass balance: Resource use, wastes and emissions. *Construction, 4,* 680.

Smoliński, A., Stańczyk, K., & Howaniec, N. (2010). Steam gasification of selected energy crops in a fixed bed reactor. *Renewable Energy, 35,* 397–404.

Soh, S., Ong, S., & Nee, A. Y. C. (2014). Design for disassembly for remanufacturing: Methodology and technology. *Procedia CIRP, 15,* 407–412.

Song, M., Zhang, J., & Wang, S. (2015). Review of the network environmental efficiencies of listed petroleum enterprises in China. *Renewable and Sustainable Energy Reviews, 43,* 65–71.

Sood, S. M., Chua, K. H., & Peng, L.-Y. (2015). Sustainable development in the building sector: Green building framework in Malaysia. In *Proceedings of the 15th International Conference on ISO & TQM*. Malaysia.

Sorvari, J., Porvari, P., & Koskela, S. (2011). *Survey on the environmental efficiency assessment methods and indicators*. Cleen.

Sousa, V., & Bogas, J. A. (2021). Comparison of energy consumption and carbon emissions from clinker and recycled cement production. *Journal of Cleaner Production, 306,* 127277.

Sousa-Zomer, T. T., Magalhaes, L., Zancul, E., Campos, L. M. S., & Cauchick-Miguel, P. A. (2018). Cleaner production as an antecedent for circular economy paradigm shift at the micro-level. *Journal of Cleaner Production, 185,* 740–748.

Speight, J. G. (2019). *Handbook of industrial hydrocarbon processes* (2nd ed., pp. 421–463). Elsevier.

Spychał, E., & Kotwa, A. (2022). Assessment of the possibility of using chalcedonite powder as a component of mortars. *Structure and Environment, 4,* 119–125.

Staniškis, J. K. (2011). Water saving in industry by cleaner production. In *Water Purification and Management* (NATO Science for Peace and Security Series C: Environmental Security, Vol. 101, pp. 171–203). Springer.

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., & de Wit, C. A. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science, 347*(6223), 1259855.

Stevenson, R. S., & Evans, J. W. (2004). Editorial: Cutting across interests-Cleaner production, the unified force of sustainable development. *Journal of Cleaner Production, 12*(3), 185–187.

Stevenson, R. S., & Evans, J. W. (2004). Editorial: Cutting across interests-Cleaner production, the unified force of sustainable development. *Journal of Cleaner Production, 12*(3), 185–187.

Stowarzyszenie Polski Ruch Czystszej Produkcji. (N.d.). *CP and OP report card: CEMEX Polska Sp. z o.o., Rudniki cement plant.* https://www.prcpiop.pl/pliki/laureaci/17270949500049802600.pdf

Strigáč, J. (2015). Effect of selected alternative fuels and raw materials on the cement clinker quality. *Journal of Civil Engineering, 10,* 1–92.

Struwig, M., & Adendorff, C. (2018). Consumers' perception of eco-labels in South Africa. *Athens Journal of Business & Economics, 4*(2), 163–178.

Stucki, T. (2019). Which firms benefit from investments in green energy technologies? The effect of energy costs. *Research Policy, 48,* 546–555.

Supernak, B. (2025, March 6). EDP will install 25,000 PV panels (14 MWp) at eight Cemex plants. *Inwestycje.pl.* https://inwestycje.pl/biznes/edp-zainstaluje-25-tys-paneli-pv-o-mocy-14-mwp-w-osmiu-zakladach-firmy-cemex/

Sygut, P. (2016). Cleaner production strategy as a possibility of waste reduction in wood sawing. *Technical Transactions: Mechanics,* (4 M), 53–58.

Synowiec, K. (2015). The influence of fly ash type on properties of cement composites. *Engineering Transactions, 63*(2), 191–201.

Szczepaniak, J. (2021, March 12). *CEMEX wdraża przełomową technologię opartą na wodorze* [Conference presentation]. Wodór paliwem przyszłości w kierunku dekarbonizacji przemysłu, online. https://powermeetings.eu/tag/dekarbonizacja-w-przemysle-cementowym/

Szewczyk, S. (2014, May 19). Rudniki alternatywnie. *Kierunek Surowce.* https://www.kieruneksurowce.pl/artykul,8662,rudniki-alternatywnie.html

Środa, B. (2024). Cement and its composition in the era of decarbonisation. *Construction, Technology, Architecture,* 58–62.

Tamta, S., Chaudhury, R., Sharma, U., Hanifa, M., Thapliyal, P. C., & Singh, L. P. (2025). Low lime-low carbon cement: Achieving sustainability through reduction of CO_2 emissions and utilizing limestone mining rejects. *Construction and Building Materials, 470,* 140476.

Tate, W. L., Ellram, L. M., & Kirchoff, J. F. (2010). Corporate social responsibility reports: A thematic analysis related to supply chain management. *Journal of Supply Chain Management, 46*(1), 19–44.

Tayyab, M., Jemai, J., Lim, H., & Sarkar, B. (2020). A sustainable development framework for a cleaner multi-item multi-stage textile production system with a process improvement initiative. *Journal of Cleaner Production, 246,* 119055.

Teplicka, K., & Sedláková, Z. (2023). Evaluation of the quality of the cement production process in terms of increasing the company's performance. *Processes, 11*(3), 791.

Thamsatitdej, P., Boon-itt, S., Samaranayake, P., Wannakarn, M., & Laosirihongthong, T. (2017). Eco-design practices towards sustainable supply chain management: An interpretive structural modelling (ISM) approach. *International Journal of Sustainable Engineering, 10*(6), 326–337.

Thogersen, J., & Nielsen, K. S. (2016). A better carbon footprint label. *Journal of Cleaner Production, 125,* 86–94.

Thogersen, J., Haugaard, P., & Olesen, A. (2010). Consumer responses to ecolabels. *European Journal of Marketing, 44*(11/12), 1787–1810.

Thomé, A. M. T., Scavarda, A., Ceryno, P. S., & Remmen, A. (2016). Sustainable new product development: A longitudinal review. *Clean Technologies and Environmental Policy, 18*(7), 2195–2208.

Tian, J., Wang, C. R., & Lu, G. F. (2009). Application of analytic hierarchy process in eco-efficiency assessment. *China Environmental Protection Science, 35,* 118–120.

Tihin, G. L., Mo, K. H., Onn, C. C., Ong, H. C., Taufiq-Yap, Y. H., & Lee, H. V. (2023). Overview of municipal solid wastes-derived refuse-derived fuels for cement co-processing. *Alexandria Engineering Journal, 84,* 153–174.

Tkaczyk, W. (2024). Green hydrogen as a way to decarbonise. *MM Industrial Magazine,* (9).

Tokbolat, S., Karaca, F., Durdyev, S., & Calay, R. K. (2020). Construction professionals' perspectives on drivers and barriers of sustainable construction. *Environment, Development and Sustainability, 22*(5), 4361–4378.

Topleva, S. A., & Prokopov, T. V. (2020). Integrated business model for sustainability of small and medium-sized enterprises in the food industry. *British Food Journal, 122,* 1463–1483.

Torres-Ortega, R., Torres-Sánchez, D., & López-Lara, T. (2025). Mechanical properties of hydraulic concretes with partial replacement of Portland cement by pozzolans obtained from agro-industrial residues: A review. *Heliyon, 11*(1), e41004.

Trela, W. N. (2017). *Ecological materials for interior design use: Impact of wood and recycling materials on people's lives and the environment* (pp. 12–13). Universidade de Lisboa,.

Truffer, B., Markard, J., & Wüstenhagen, R. (2001). Eco-labeling of electricity: Strategies and trade-offs in the definition of environmental standards. *Energy Policy, 29*(11), 885–897.

Tukker, A., & Andersen, M. M. (2006). *Perspectives on radical changes to sustainable consumption and production (SCP).* SCORE Workshop Proceedings, Copenhagen.

Ugochukwu, I. B., & Chioma, M. I. B. (2015). Local building materials: Affordable strategy for housing the urban poor in Nigeria. *Procedia Engineering, 118,* 42–49.

Umezawa, O., Halada, K., & Shinohara, Y. (2007). Ecomaterials in the global eco-society: Present situation and future prospects. *Materials Science Forum, 555,* 1–7.

United Nations Environment Programme. (2022). *International declaration on cleaner production: Implementation guidelines for facilitating organizations.* https://www.unep.org/resources/report/international-declaration-cleaner-production-implementation-guidelines

Usón, A. A., Ferreira, G., López-Sabirón, A. M., Sastresa, E. L., & de Guinoa, A. S. (2012). Characterisation and environmental analysis of sewage sludge as secondary fuel for cement manufacturing. *Chemical Engineering Transactions, 29,* 457–462.

van Berkel, R. (2000). Cleaner production in Australia: Revolutionary strategy or incremental tool? *Australian Journal of Environmental Management, 7*(3), 132–146.

van Berkel, R. (2007). Cleaner production and eco-efficiency initiatives in Western Australia 1996–2004. *Journal of Cleaner Production, 15,* 741–755.

van der Ryn, S., & Cowan, S. (1996). *Ecological design.* Island Press.

van Hoof, B., & Lyon, T. P. (2013). Cleaner production in small firms taking part in Mexico's Sustainable Supplier Program. *Journal of Cleaner Production, 41,* 270–282.

Vargas, B., Mino, G., Vega, P., & Marino, J. (2019). Application of resource-efficient and cleaner production through best management practices in a pallet manufacturer sawmill located in Puyo, Ecuador. *Maderas: Ciencia y Tecnología, 21*(3), 367–380.

Veleva, V., & Ellenbecker, M. (2001). Indicators of sustainable production: Framework and methodology. *Journal of Cleaner Production, 9,* 519–549.

Venkataraman, S., Allayan, G., & Yemen, G. (2017). *Taking a Mexican company global: The CEMEX way.* Darden Business Publishing.

Venkitaraman, A. K., & Joshi, N. (2002). A critical examination of a community-led ecovillage initiative: The case of Auroville, India. *Climate Action, 1*(1), 15–19.

Verma, Y. K., Mazumdar, B., & Ghosh, P. (2020). Thermal energy consumption and its conservation for a cement production unit. *Environmental Engineering Research, 26,* 200111.

Vieira, L. C., & Amaral, F. G. (2016). Barriers and strategies applying cleaner production: A systematic review. *Journal of Cleaner Production, 113,* 5–16.

Vieira, L. C., & Amaral, F. G. (2016). Barriers and strategies applying cleaner production: A systematic review. *Journal of Cleaner Production, 113,* 5–16.

Vinci, G., D'Ascenzo, F., Esposito, A., Musarra, M., Rapa, A., & Rocchi, A. (2019). A sustainable innovation in the Italian glass production: LCA and Eco-Care matrix evaluation. *Journal of Cleaner Production, 223,* 587–595.

Vrchota, J., Pech, M., Rolínek, L., & Bedná, I. (2020). Sustainability outcomes of green processes in relation to Industry 4.0 in manufacturing: A systematic review. *Sustainability, 12*(15), 5968.

Wandzik, A. (2010). *Globalna integracja zwana „The CEMEX Way".* Gdańska Fundacja Kształcenia Menedżerów. https://atwdb.pl/artykuly/artykul4.pdf

Wang, L., Cui, Z., & Liang, X. (2015). Does it pay to be green? Financial benefits of environmental labelling among Chinese firms, 2000–2005. *Management and Organization Review, 11*(3), 493–519.

Wang, M., Li, Y., Li, M., Shi, W., & Quan, S. (2019). Will carbon tax affect the strategy and performance of low-carbon technology sharing between enterprises? *Journal of Cleaner Production, 210,* 724–737.

Wang, Y. L., Dong, S. J., Liu, L. L., & Cui, S. P. (2013). Using calcium carbide slag as one of calcium-containing raw materials to produce cement clinker. *Materials Science Forum, 743–744,* 171–174.

Wang, Y., Cui, S., Lan, M., Tian, G., & Liu, L. (2014). Influence of characteristics of alumina–silicate raw materials on the formation process of clinker. *Journal of Wuhan University of Technology: Materials Science Edition, 29,* 966–971.

Wang, Y., Hang, Y., Wang, Q., Zhou, D., & Su, B. (2021). Cleaner production vs. end-of-pipe treatment: Evidence from industrial SO_2 emissions abatement in China. *Journal of Environmental Management, 277,* 111429.

Wang, Z., Zhang, X., Chen, Z., & Zhang, Y. (2006). Mercury concentrations in size-fractionated airborne particles at urban and suburban sites in Beijing, China. *Atmospheric Environment, 40*(12), 2194–2201.

Wieczorek, M., & Pichniarczyk, P. (2022). Properties of cement with low Portland clinker content and varying amounts of silica fly ash and granulated blast furnace slag. *Cement Lime Concrete, 27*(4), 285–299.

Wilson, D., & Chang, C. (2003). CEMEX promotes a sustainable approach with manufacturing excellence. *Environmental Quality Management,* 23–34.

Witek, L. (2017). *Sustainable consumption: Eco-labelling and its impact on consumer behaviour-Evidence from Polish consumers* (Working Papers 142/2017). Institute of Economic Research.

World Business Council for Sustainable Development. (2006). *Eco-efficiency learning module*. WBCSD.

World Business Council for Sustainable Development & United Nations Environment Programme. (1996). *Cleaner production and eco-efficiency: Complementary approaches to sustainable development*. WBCSD/UNEP.

Wsół, E. (2015, July 26). Chalk-white gold for the Chełm cement plant. *Infrastructure Market*.

Wu, J., & Strezov, V. (2023). Green technologies and sustainability: A new trend. *Green Technologies and Sustainability, 1*(1), 100008.

Wu, J., Yin, P. Z., Sun, J. S., Chu, J. F., & Liang, L. (2016). Evaluating the environmental efficiency of a two-stage system with undesirable outputs by a DEA approach: An interest preference perspective. *European Journal of Operational Research, 254,* 1047–1062.

Xu, C., Gong, Y., & Yan, G. (2023). Research on cement demand forecast and low-carbon development strategy in Shandong Province. *Atmosphere, 14*(2), 267.

Xu, D., Karray, M. H., & Archimede, B. (2017). A semantic-based decision support platform to assist products' eco-labelling process. *Industrial Management & Data Systems, 117*(7), 1340–1361.

Xu, J.-H., Fleiter, T., Eichhammer, W., & Fan, Y. (2012). Energy consumption and CO_2 emissions in China's cement industry: A perspective from LMDI decomposition analysis. *Energy Policy, 50,* 821–832.

Yagi, K. (2002). Concept and development of ecomaterials. In *Proceedings of the International Workshop on Eco-materials*. National Institute for Materials Science.

Yenipazarli, A. (2015). The economics of eco-labelling: Standards, costs and prices. *International Journal of Production Economics, 170*(Part A), 275–286.

Yin, S., Shao, Y., Wu, A., Wang, H., Liu, X., & Wang, Y. (2020). A systematic review of paste technology in metal mines for cleaner production in China. *Journal of Cleaner Production, 247*(1), 119590.

Yin, S., Zhang, N., & Li, B. (2020). Enhancing the competitiveness of multi-agent cooperation for green manufacturing in China: An empirical study of green technology innovation capabilities and their influencing factors. *Sustainable Production & Consumption, 23,* 63–76.

You, D., Zhang, Y., & Yuan, B. (2019). Environmental regulation and firm eco-innovation: Evidence of moderating effects of fiscal decentralisation and political competition from listed Chinese industrial companies. *Journal of Cleaner Production, 207,* 1072–1083.

Yu, H. C., & Kuo, L. (2021). Corporate philanthropy strategy and sustainable development goals. *Sustainability, 13*(10), 5655.

Yüksel, H. (2008). An empirical evaluation of cleaner production practices in Turkey. *Journal of Cleaner Production, 16*(1), 50–57.

Yung, W., Chan, H., Wong, D., So, J., Choi, A., & Yue, T. (2012). Eco-redesign of a personal electronic product subject to the Energy-using Product Directive. *International Journal of Production Research, 50*(5), 1411–1423.

Yusup, M. Z., Mahmood, W. H. W., Salleh, M. R., & Ab Rahman, M. N. (2015). The implementation of cleaner production practices from Malaysian manufacturers' perspectives. *Journal of Cleaner Production, 108,* 659–672.

Zameer, H., Wang, Y., & Yasmeen, H. (2020). Reinforcing green competitive advantage through green production, creativity and green brand image: Implications for cleaner production in China. *Journal of Cleaner Production, 247*(2), 119119.

Zarandi, M. H. F., Mansour, S., Hosseinijou, S. A., & Avazbeigi, M. (2011). A material selection methodology and expert system for sustainable product design. *International Journal of Advanced Manufacturing Technology, 57,* 885–903.

Zbierowski, P. (2010). Struktura i systemy firm wysokiej efektywności – wyniki badań. *Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, 144*, 616–631.

Zeng, S., Meng, X., Yin, H., Tam, C. M., & Sun, L. (2010). Impact of cleaner production on business performance. *Journal of Cleaner Production, 18*(10–11), 975–983.

Zhang, P., Duan, N., Dan, Z., & Shi, F. (2018). An understandable and practicable cleaner production assessment model. *Journal of Cleaner Production, 187,* 1094–1102.

Zhang, T. Z. (2000). Policy mechanisms to promote cleaner production in China. *Journal of Environmental Science and Health, 35*(10), 1989–1994.

Zhang, X., Wei, Y., Pan, H., Xiao, H., Wu, J., & Zhang, Y. (2015). The comparison of performances of a sewage treatment system before and after implementing the cleaner production measure. *Journal of Cleaner Production, 91,* 216–228.

Zhang, Y., Liu, X., & Yang, J. (2024). Digital economy, green dual innovation and carbon emissions. *Sustainability, 16,* 7291.

Zhaurova, M., Soukka, R., & Horttanainen, M. (2021). Multi-criteria evaluation of CO_2 utilisation options for cement plants using the example of Finland. *International Journal of Greenhouse Gas Control, 112,* 103481.

Zheng, Y., Zhong, H., Sun, K., Shen, B., Cui, K., Zhao, Y., Xiong, G., & Qin, Q. (2025). Effect of composite activator on hydration kinetics and micromechanical properties of alkali-activated slag. *Cement and Concrete Composites, 160,* 106047.

Zhou, C. C., Yin, G. F., & Hu, X. B. (2009). Multi-objective optimization of material selection for sustainable products: Artificial neural networks and genetic algorithm approach. *Materials & Design, 30*(4), 1209–1215.

Zhou, C., Shi, C., Wang, S., & Zhang, G. (2018). Estimation of eco-efficiency and its influencing factors in Guangdong Province based on Super-SBM and panel regression models. *Ecological Indicators, 86,* 67–80.

Zhu, D. J., & Qiu, S. F. (2008). Eco-efficiency indicators and their demonstration as circular economy measurement in China. *Resources and Environment in the Yangtze Basin, 17*(1), 1–5.

Zhu, Q., Sarkis, J., & Lai, K. (2007). Green supply management: Pressures, practices, and performance within the Chinese automobile industry. *Journal of Cleaner Production, 15*(11–12), 1041–1052.

Zielińska-Chmielewska, A., Olszańska, A., Kaźmierczyk, J., & Adrianova, E. V. (2021). Advantages and constraints of eco-efficiency measures: The case of the Polish food industry. *Agronomy, 11*(2), 299.

Zwetsloot, G. I. J. M. (1995). Improving cleaner production by integration into the management of quality, environment and working conditions. *Journal of Cleaner Production, 3,* 61–66.

Zygmunt, W. (2025, January 12). Cementownia Chełm is 60 years old. *Log24.* https://log24.pl/news/cementownia-chelm-ma-60-lat-video/

Reviews

The reviewed monograph is a valuable, timely, and mature contribution to the discussion on the implementation of the Cleaner Production (CP) concept in industrial enterprises. The authors address an issue of high cognitive and practical relevance, firmly embedded in contemporary debates on sustainable development, energy transition, and corporate environmental responsibility. The publication is solidly grounded both in an extensive theoretical framework and in an in-depth empirical case study of one of the key actors in the Polish cement industry – the Cemex Poland Group.

Particular attention should be paid to the fact that the monograph goes beyond a purely descriptive presentation of the Cleaner Production concept. Instead, it consistently treats CP as a modern management strategy integrating environmental, economic, and social dimensions. The authors convincingly demonstrate that Cleaner Production is not merely an environmental protection tool, but a genuine instrument for enhancing organizational efficiency, process innovation, and long-term competitiveness, even in highly emission-intensive industrial sectors.

The monograph is clearly interdisciplinary in nature, combining insights from management and quality sciences, environmental economics, production engineering, and sustainability studies. This approach significantly broadens the group of potential readers and makes the publication relevant not only for academic researchers, doctoral candidates, and students, but also for business practitioners, including managers, process engineers, and ESG and environmental specialists.

The structure of the monograph is logical, transparent, and well aligned with the clearly formulated research objective. The authors guide the reader in a coherent manner from theoretical considerations, through a discussion of Cleaner Production tools and practices, to a comprehensive empirical analysis. The layout of the work facilitates both continuous reading and selective use of individual chapters, which further enhances its didactic and practical value.

The first chapter provides a comprehensive and well-documented introduction to the Cleaner Production concept. The authors skillfully embed CP within the historical evolution of environmental management thinking – from end-of-pipe solutions, through pollution prevention approaches, to contemporary holistic sustainability strategies. They not only review a wide range of definitions and interpretations of Cleaner Production found in international literature, but also offer a thoughtful synthesis that highlights both common elements and conceptual differences. This demonstrates a high level of scholarly competence and a critical understanding of the state of the art.

The second chapter, devoted to Cleaner Production activities such as eco-design, eco-materials, green technologies, and eco-efficiency, has a distinctly application-oriented character. The systematic presentation of specific practices, tools, and technological solutions makes this part of the book particularly valuable for practitioners. The authors clearly show that Cleaner Production is not an abstract or normative concept, but a set of concrete actions that can be successfully implemented even in industries facing significant technological and regulatory constraints.

The third chapter, based on a detailed case study of the Cemex Poland Group, constitutes the strongest element of the monograph. The described implementations – including the co-combustion of alternative fuels, modifications in raw material composition, and comprehensive pro-environmental initiatives – are presented in a reliable, well-structured, and analytically sound manner. Importantly, these activities are embedded in a broader strategic context. The authors avoid simplifications and clearly demonstrate that the implementation of Cleaner Production is a complex, long-term process requiring managerial commitment, an appropriate organizational culture, employee competencies, and strategic consistency.

The originality of the monograph lies primarily in its effective integration of theory and practice. Rather than merely reproducing existing concepts, the authors illustrate how Cleaner Production actually functions in a large industrial organization operating under strong regulatory, market, and social pressures. The case study does not serve as a simple illustration, but as an integral analytical component that empirically validates the relevance and feasibility of the proposed approach.

The work is clearly aligned with contemporary research and managerial trends, such as the shift from declarative sustainability towards measurable environmental outcomes, the integration of Cleaner Production with the objectives of the 2030 Agenda and selected Sustainable Development Goals (SDGS), the growing importance of technological innovation, eco-design, and circular economy solutions, as well as the increasing role of stakeholders and institutional pressures in driving pro-environmental transformations.

Special recognition should be given to the way the authors conceptualize Cleaner Production as an element of a new management paradigm, rather than merely a set of technical measures or regulatory requirements. This perspective makes the monograph not only relevant in the current context, but also future-oriented and resistant to rapid obsolescence.

One of the greatest strengths of the reviewed monograph is its practical relevance. The book offers a convincing answer to one of the key questions of contemporary management: how to effectively combine environmental objectives with economic efficiency and social responsibility. The authors successfully challenge the widespread perception of environmental initiatives in industry as cost-generating burdens, presenting Cleaner Production instead as a rationalization tool that reduces losses, improves resource efficiency, and supports sustainable competitive advantage.

The monograph can be regarded as a practical guide for organizations planning or implementing pro-environmental transformations. Numerous examples of good practices, clearly described implementation stages, and a thorough identification of barriers and success factors provide readers with concrete guidance on how Cleaner Production can be applied in real organizational settings. The reader gains not only an understanding of 'what' and 'why,' but also 'how' to implement CP strategies effectively.

At the same time, the publication is strongly embedded in current management and public policy agendas, including industrial decarbonization, ESG frameworks, circular economy models, and responsible production and consumption. As such, it represents a valuable source of knowledge for policymakers, consultants, experts, and students of economics, management, and technical disciplines.

In conclusion, *Implementation of the Cleaner Production Programme on the Example of the Cemex Poland Group* is a well-researched, coherent, and original monograph that makes a meaningful contribution to the body of knowledge on sustainable management and industrial transformation. The publication successfully combines academic rigor with a clear and accessible narrative, avoiding excessive hermeticism while maintaining high scientific standards.

The book not only broadens knowledge but also encourages a shift in thinking about management, innovation, and corporate responsibility. It can be strongly recommended to both academic audiences and business practitioners as an important and insightful contribution to the ongoing debate on the future of industry in the context of green transition.

Dr. Sviatoslav Kniaz

The monograph *Implementation of the Cleaner Production Programme on the example of the Cemex Poland Group* by Wojciech Lutek, Myroslav Malovany and Agnieszka Sitko-Lutek covers challenges related to environmental, economic, and social sustainability, focusing on a particular industry, and aligns well with the stream of publications addressing the ways and strategies in which the general concept of 'sustainable development' can be embedded in practical business activities. The monograph provides a comprehensive and logically structured study of Cleaner Production, demonstrating strong academic rigor and a clear focus on its practical relevance in industrial practice.

The main objective of the presented monograph is to identify and assess the implementation and use of the Cleaner Production concept in the environmental, economic and social dimensions by presenting good practices implemented by the Cemex Poland Group. The research methods employed to achieve it include a comprehensive literature review and a case study analysis. The structure of the monograph supports its main objective, comprising two theoretical chapters and one empirical section.

In general, the authors of the monograph demonstrate a strong understanding of the Cleaner Production concept. As such, the book provides valuable insights into both the theoretical foundations and the practical aspects of its implementation. Additionally, the clear presentation of concepts and practical examples enhances interest in the topic and serves as an additional incentive for all potential stakeholders to engage more deeply with the subject, namely practitioners, researchers, academics, students, workers, and the broader society.

The first theoretical chapter presents a comprehensive overview of the Cleaner Production concept. It begins with a discussion of the genesis and formal definition of the Cleaner Production Programme, outlining its origins and fundamental assumptions. The chapter then examines the key characteristics and core practices associated with Cleaner Production, providing a structured explanation of how the concept operates in practice. Further sections analyse the applicability of Cleaner Production and describe the main phases of its implementation. Particular attention is devoted to the factors influencing the successful adoption of the concept, including the key drivers that stimulate implementation, the barriers that may hinder progress, and the benefits that organisations can obtain from adopting a Cleaner Production strategy. This part of the chapter is of high relevance, as it draws attention to a variety of drivers and barriers, taking a systems theory perspective and addressing the ecosystem in a comprehensive manner. The chapter concludes with a discussion on how sustainability principles can be effectively implemented on the basis of the Cleaner Production concept, highlighting its role as a practical tool for integrating environmental, economic, and social objectives within organisational activities.

The second chapter focuses on practical Cleaner Production activities and instruments that support its implementation. It presents key approaches and tools that enable organizations to integrate environmental considerations into their operations and product development processes. The chapter discusses eco-design as a method of incorporating environmental criteria at the product development stage, as well as the use of environmentally friendly materials (eco-materials). It further examines the role of green technologies in reducing environmental impact and improving production efficiency. Attention is also given to environmental labels and declarations, which enhance transparency and support informed decision-making among stakeholders. The chapter concludes with a discussion of eco-efficiency within the context of Cleaner Production, highlighting the importance of balancing environmental performance with economic effectiveness. By analysing Cleaner Production practices, including eco-design, eco-materials, green technologies, environmental labelling, and eco-efficiency, the authors of the monograph highlight not only the strategic role of Cleaner Production in industrial systems, but also encourage a rethinking of design, manufacturing, logistics, and other core business functions in order to operate in a sustainable manner. Additionally, the need for radical changes and transformation is explicitly stressed, particularly in support of still not widely adopted solutions such as environmental labelling.

The third chapter presents an empirical analysis of the ecological, economic, and social aspects of Cleaner Production implementation, illustrated by the case of Cemex Poland. The chapter begins with a general overview of the cement industry, outlining its specific characteristics and environmental challenges. Further, the chapter also briefly discusses the history and development of the Cemex Group, establishing the organisational context for the case study. The core part of the chapter focuses on the activities undertaken within the framework of Cleaner Production. Overall, the chapter demonstrates how the principles of Cleaner Production can be effectively applied in practice, highlighting their environmental, economic, and social implications within an industrial setting. The empirical analysis provided in the third chapter represents a highly valuable illustration of Cleaner Production implementation in practice and reflects the added value of the monograph itself.

In conclusion, the monograph *Implementation of the Cleaner Production Programme on the Example of the Cemex Poland Group* makes a meaningful contribution to the field of Cleaner Production. It effectively integrates theoretical reflection with practical analysis, providing both a solid conceptual foundation and a carefully developed empirical case.

Taking into consideration its clarity, analytical depth, and applied orientation, the monograph can be confidently recommended as a valuable academic resource for researchers and students, as well as a practical tool for managers, practitioners, and policymakers seeking to take a further step in their sustainability journey.

Dr. Živilė Stankevičiūtė

Wojciech Lutek – PhD in Management. Founder and long-time CEO of KOM-EKO Group in Lublin, long-time president of the Polish Chamber of Waste Management in Warsaw. Active consultant in waste logistics and the development of regional waste treatment plants. Business angel and lecturer at Maria Curie-Skłodowska University in Lublin in the field of logistics. His research interests include sustainable management, circular economy, waste management, and smart cities. He is the author and co-author of twelve scientific monographs.

Myroslav Malovanyy – PhD, Full Professor in Environmental Sciences and Head of the Department of Ecology and Sustainable Use of Natural Resources at Lviv Polytechnic National University. His research focuses on the application of natural sorbents and biological agents in environmental protection technologies, municipal and industrial waste management, and the bio-circular economy. He is the Head of the UNESCO Chair in Sustainable Water and Waste Management and serves as the Chairman of the Lviv Regional Organization of the All-Ukrainian Environmental League.

Agnieszka Sitko-Lutek – PhD, full professor in Management and Head of the Department of Management at Maria Curie-Skłodowska University. Author or co-author of over 190 scientific publications. Her research interests revolve around organizational culture, managerial competencies and development, as well as the circular economy. Member of the Committee on Organization and Management Sciences of the Polish Academy of Sciences.

ToKnowPress
BANGKOK · CELJE · LUBLIN · MALTA
www.toknowpress.net