ENGINEERING THE INDUSTRIAL TRANSFORMATION

Editors:
Polona Domadenik Muren, Matjaž Koman, Tjaša Redek

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Published by

Časnik Finance, d. o. o.

Ljubljana, November 2024

CIP - Kataložni zapis o publikaciji
Narodna in univerzitetna knjižnica, Ljubljana

338.45:005.591.4(082)
661.12(082)

ENGINEERING the industrial transformation / editors Polona Domadenik Muren, Matjaž Koman, Tjaša Redek. - 1st printing. - Ljubljana : Časnik Finance, 2024

ISBN 978-961-6541-65-7
COBISS.SI-ID 212911875

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PREFACE

"Engineering the Industrial Transformation" is a result of a year-long dedicated collaboration by a distinguished group of researchers, including *Andreja Cirman, Barbara Čater, Tomaž Čater, Polona Domadenik Muren, Petra Došenović Bonča, Eva Erjavec, Jurij Giacomelli, Matjaž Koman, Hana Končan, Marko Košak, Mitja Kovač, Barbara Kurbus, Igor Lončarski, Denis Marinšek, Rok Požun, Vasja Rant, Sara Ražman*, and *Tjaša Redek*, along with the students of the 31st generation of the International Master Programme in Business and Organisation (IMB) at the School of Economics and Business, University of Ljubljana. Their unwavering commitment and invaluable insights significantly contributed to the depth and breadth of the research.

We are profoundly grateful to more than 50 executives and professionals from Slovenian companies and institutions who generously contributed their time and expertise during the research conducted in August and September 2024. Their perspectives on the potential for creating ecosystems within selected industries in Slovenia and their insights on navigating the complexities of a brittle, anxious, non-linear and incomprehensible (BANI) environment were pivotal to our study. We are particularly thankful to *Jurij Giacomelli* from META Circularity and *Aleksander Gerbec* from ECUBES Hydrogen and Flexibility for their scholarly contributions and practical knowledge on hydrogen valleys and industrial applications of hydrogen.

The research team acknowledges the financial support from Slovenian research agency grants V5-2349 "*Konvergenca Slovenije napram Avstriji in Nemčiji z ukrepi sodobne razvojne politike*", P5-0128 *"Izzivi vključujočega in trajnostnega razvoja v prevladujoči paradigmi ekonomskih in poslovnih znanosti"* and J7-4540 *"Družbeno-ekonomske posledice rakavih obolenj z vidika posameznika in družbe ter analiza vpliva pandemije covid-19"*.

A heartfelt thank you goes to *Meta Česnik* for her meticulous proofreading, to *Ciril Hrovatin* for his technical editing and design expertise, and to *Jera Jakše* for her creative work on the cover design. We are also deeply appreciative of the technical assistance provided by *Anja Ilić* and the indispensable support from our colleagues at Finance in the final stages of the book's production.

Ljubljana, November 2024

Editors

Polona Domadenik Muren, Matjaž Koman, Tjaša Redek

NAVIGATING THE INDUSTRIAL TRANSFORMATION: SHAPING THE FUTURE ECONOMIES

> *"The difficulty lies, not in the new ideas, but in escaping from the old ones, which ramify, for those brought up as most of us have been, into every corner of our minds"* (Keynes, 1933).

1 Introduction

Formulating appropriate development policies represents a significant challenge for academics and those involved at the implementation level. Since the early 1990s, when the biggest economic experiment in the former socialist and communist countries of Eastern Europe started, the world has faced accelerating trends of globalisation and increased trade, the rise of economic power in East Asian countries, the close intertwining of value chains, and the reduction of the share of manufacturing activities in the overall GDP structure (Stiglitz, 1998).

By the late 1990s, it became apparent that merely increasing GDP per capita as a measure of prosperity was no longer the sole goal. Instead, a broader view was needed, incorporating environment, health, and other determinants of people's well-being into development priorities. Attention also needed to be paid to how the created value is distributed, as income and wealth inequality were increasing (Piketty & Cantante, 2018). Although productivity growth remains important, it is not the only goal of development policies. It is a necessary but not sufficient condition for achieving greater societal well-being.

Fifty years ago, development economics was considered a mechanistic discipline of economics. It emphasised the significant role of the state, as markets alone could not ensure efficient allocation of resources and poorly coordinated different economic entities in the case of missing markets or externalities. Because markets are imperfect, state intervention can almost always lead to a Pareto improvement for certain individuals without worsening it for others (Greenwald & Stiglitz, 1986, 1988; Arnott, Greenwald, & Stiglitz, 1994). On the other side, a significant part of the academic literature in the 1980s warned that the active role of the state in the allocation and coordination process was part of the problem, not the solution. Reducing the state's role in allocation and coordination and giving more space to the private sector and markets to set prices based on market mechanisms would improve allocation, coordination, and, ultimately, economic growth. The (sole) responsibility of the government was to ensure an appropriate macroeconomic environment because interfering in the economy would do more harm than good. This belief led to a neoliberalist approach to economic policy in the 1990s, often referred to as the Washington Consensus, which emphasised increased international trade, macroeconomic stability, and market prices. However, it did not bring as significant contributions to productivity as its proponents had expected.

From today's perspective, the more pragmatic approach of East Asian countries in the past two decades, which appropriately used state interventionist measures, seemed more plausible[1]. Both state interventionism and the market mechanism are important elements of good development policies. Market incentives improve the functioning of the state and its subsystems, and states influence different (better) behaviour of market entities through regulations (Fernandez & Moldogaziev, 2011). Following the concept of the entrepreneurial state (Mazzucato, 2013), the state should be more involved in shaping markets in developing countries, while in developed countries, its role is more of a regulator (co-creator), especially in today's times when facing new potentially very transformative technologies like artificial intelligence. The state's responsibility is mainly to establish and co-create institutions and subsystems (education, health, research) that support the effective functioning of markets. These institutions support and ensure the implementation of effective legislation on property rights, competition, corruption prevention and contract enforcement. Levelling the playing field (equalising rules of the game for all) leads to efficient resource allocation by preventing the appropriation of rents resulting from opportunistic (potentially corruptive) behaviour.

1 Some authors emphasise that Asian countries, often cited as examples of successful state interventionism, would have achieved high rates of economic growth even under different economic policies, as these policies were based on rapid increases in international trade. Similarly, these authors point to examples of Latin American countries where similar interventionist measures did not yield success.

Well-functioning development policy today addresses not only the gap in the availability of production factors but primarily access to knowledge, acceleration of digitalisation, and the use of new technologies. The key emphasis is on building institutional capacity and moving towards a culture of change while questioning whether existing practices are appropriate or if all possible alternatives were reviewed. All this requires knowledge of the specifics of individual countries. Democratically elected governments weigh different alternatives and political consequences. New approaches to industrial strategy also recognise decisions on how to accelerate growth and shape the economy while pursuing social, environmental, and health priorities as important.

Recent development narratives are usually based on a set of recommendations from areas that were not previously combined, such as inequality, access to financing, corruption, the business environment, infrastructure, and public investments (Shiller, 2019; Cherif et al., 2024), usually referred to as the "Washington Constellation"[2]. It captures the story that numerous factors influence growth (achieving a good business environment, investments in infrastructure, ensuring the rule of law, and access to financing, as well as addressing inequality), yet the mechanism, compared to other growth narratives, appears relatively unclear.[3] The Washington Constellation increasingly includes recommendations from the new industrial policy. Therefore this chapter first summarises the development of industrial policy as a constituent component of the development policies of individual countries and continues with a review of practices in three selected powerhouses: the USA, China and the European Union. The contribution concludes with recommendations for a new industrial policy.

2 Industrial policy as a development policy: from "picking" to "shaping" winners

Industrial policy encompasses those government policies that directly target the transformation of the structure of economic activity to achieve certain (public) goals (Juhász, Lane, & Rodrik, 2023). Discussions on the effectiveness of industrial policy, generally defined as a policy program that shapes a country's industrial structure by promoting certain sectors, have been present in the professional literature since the 1960s (see Baldwin, 1969; Rodrik, 2004; Juhász,

2 Creating a new narrative from a series of seemingly unrelated concepts resembles constellations in the sky, which have no objective reason to be grouped together but form patterns and give meaning to the observer (Shiller, 2019).

3 In Slovenia, a similar set of measures is summarised in the Action Plan for Higher Productivity Growth (Mramor et al., 2020) and the Action Plan for Greater Well-Being (Mramor et al., 2022).

Lane, & Rodrik, 2023). Traditionally, industrial policy focused on promoting manufacturing industries such as steel, automotive, shipbuilding, aerospace, and semiconductors - hence the name. Today, this term also refers to support for the service sector and certain types of research and development. Therefore, industrial policies overlap with what could be called regional policies in other contexts (Slattery & Zidar, 2020) or innovation policies (Mazzucato, 2013). In developing countries, industrial policies are called production development policies (Fernández-Arias et al., 2016) or structural policies (Fernández-Arias et al., 2016). These policies are also often referred to as transformational policies because they reflect a broader set of development challenges beyond industrialisation. A comparison of industrial policies from their beginnings in the 1950s is shown in Table 1.

Table 1. Evolution of industrial policies

	Pre-1970	1970– 2000	Post-2000	"New" industrial policy
Key characteristics	Industrialisation	Structural transformation	Stabilisation	Liberalisation
Political goals	Market formation	Diversification	Market-oriented modernisation	Specialisation
Key elements	Import substitution	Protection of new industries	Selective openness to competition	Limited government involvement
Political environment	High political legitimacy for national development strategies	Low political legitimacy for intervention strategies	Political action limitations based on international commitments	Acquired legitimacy for national development strategies

Source: Adapted from Di Pippo et al. (2022).

The economic reasoning for industrial policy, which in most cases is based on market failures, can be summarised in three points (Cherif et al., 2024): (1) the presence of externalities, (2) the failure of the coordination mechanism, and (3) the provision of additional (public) resources for specific economic activities. When economic activity generates positive externalities (i.e., creates benefits elsewhere in society that are not recovered through revenues generated by those conducting the activity), it is appropriate for the state to promote these activities through industrial policy measures. Literature highlights externalities related to learning and skill acquisition, costs, the discovery of rare earth elements, and the creation of good jobs (Rodrik & Sabel, 2022). Coordination failures, as market imperfections, occur when the profitability of an individual producer depends on related actions taken by other economic entities. Related activities may include complementary goods and services in demand, production or activities along the value chain. Coordination failures usually establish an equilibrium that is socially suboptimal[4]. The third argument for implementing industrial policies is based on the premise that the option that brings the greatest social benefit should be chosen in an environment where public resources are limited. For example, public funds for infrastructure development can be allocated to the construction or expansion of a port or road network, benefiting different economic agents (producers and consumers). When deciding to build a port, it could be near a copper mine, steel factory, or a green hydrogen production plant. In such circumstances, governments are essentially "forced to choose" (Hausmann & Rodrik, 2006) which activities need to be supported. These three reasons for action address different problems and require different solutions.

Industrial policy as a concept has often been criticised in terms of "picking winners" by regulatory authorities as being worse than if the market determined the "winners". This policy was justified in the 1950s by the idea that new, unestablished industries and other local traditional activities should be protected from foreign competition and fully exploit domestic demand (Aghion et al., 2015). Countries that followed this principle (Japan, South Korea, and Singapore being the most prominent examples in recent decades) recorded exceptionally high growth rates as it was believed these measures contributed to the state's economic strength . However, in the 1970s, when some poor examples of this policy were recorded, scepticism about the role of industrial policy increased. Two arguments were most highlighted (Spector et al., 2009): (1) Industrial policy is based on the idea that the government, at its discretion, chooses future winners, thus opening the door to particular (self-serving) interests of certain lobbies; (2) Government measures of industrial policy assist struggling companies, leading to the well-known problem of soft budget constraints. Based on the standard argument of market efficiency, opponents of state intervention emphasise that the government does not need to interfere in the sectoral allocation of resources or technology selection at the company level.

In the past decade, the debate on appropriate industrial policy has reignited, mainly driven by growing awareness of climate change and the need to support and promote the development of alternative environmental protection technologies (Aghion et al., 2011). Without state support and only with private financial resources, it is impossible to support innovations in green technologies and their use in production and households because these investments create

4 Consider a scenario where producing good A would be profitable only if good B is also produced, and vice versa. Suppose the same applies symmetrically to good B. In one equilibrium, neither good is produced. In another, both goods are produced. If the social value of producing both goods exceeds their opportunity costs, the economy might be stuck in a suboptimal equilibrium. State interventionism can help encourage producers towards a better equilibrium (Juhász, Lane, & Rodrik, 2023).

high social but low private returns in the short term. Additionally, the global financial crisis from 2008 to 2012 prompted states worldwide to support certain industries or horizontally across all industries with employment subsidies (job retention measures). This action raised a serious question about whether such state aid policies lead to positive outcomes, especially considering high public debt levels and the costs of servicing debt that will burden future generations. The recent Great Financial Crisis (GFC) itself showed that markets are not necessarily efficient and that without strong state intervention – including rescue lines for certain companies and industries – many industries in Europe and the USA might have collapsed (Stiglitz et al., 2014). State subsidy programs are not only meant to address market failures but also to encourage economic agents to engage in socially desirable behaviour to improve the welfare state's equilibrium (solving coordination problems and missing markets). Instead of "picking winners", the new industrial policy promotes the principle of "shaping winners" (Juhász, Lane, & Rodrik, 2023).

Discussions on the effectiveness of industrial policy depend, of course, on the circumstances of a particular country. Domadenik and others (2020) have shown, using the case of Slovenia, that industrial policy, especially state aid policy during financial crises, should be conducted differently than in normal times. The reasons for this are: (1) during financial crises, the criteria for why some companies fail while others do not are distorted (Stiglitz et al., 2014), and (2) some countries (USA, China, and Australia) conducted generous (pragmatic) industrial policies connected to state aid and rescue lines for certain sectors during financial crises. The European Union, on the other hand, responded differently, remaining firm and loyal to its principles and the Maastricht Treaty. Bole and others (2014) emphasise that crisis spending measures in the EU from 2009 to 2010 were almost five times lower compared to the USA and six times lower compared to Australia. This finding might partly explain the considerably poorer macroeconomic performance of the EU post-crisis, particularly compared to the USA and Australia. Empirical studies examining the impact of state aid on productivity growth report that greater sectoral dispersion of subsidies increases productivity growth (Aghion et al., 2015; Domadenik et al., 2018). Therefore, it is unsurprising that the debate on the state's active role and the so-called revival of industrial policy has become more active during geopolitical and environmental challenges that require significant adjustments in the functioning of companies and individuals.

Public discussions on industrial policy often revolve around the short-term and long-term effectiveness of various state support instruments to "shape the winners" and encourage economic agents to engage in socially desirable behaviour to create welfare effects (solving coordination problems). Moreover, the existence of a 21st-century state, which co-creates and shapes markets, is crucial for supporting inventions and innovations that address issues related to increasing inequality, climate change, and population ageing (Mazzucato, 2013). Differences between traditional and new industrial policies are shown in Table 2.

Table 2. Differences between traditional and new industrial policy

	Traditional industrial policy	"New" industrial policy
Action base	Encouraging R&D, innovation, learning-related externalities, improving coordination mechanisms, and underinvestment.	Externalities related to good jobs encourage innovation aimed at solving societal challenges.
Sectors	Tradable sector (manufacturing).	Manufacturing and service sectors.
Companies	Large and globally competitive companies	Small and medium companies (ecosystems).
Assumptions about the role of the state in the economy	The state identifies market failures in advance. The state is fairly isolated from capturing value.	Dispersed knowledge about the location and size of market failures. Governments face considerable uncertainty; the endogenous capacity of the state.
Type of incentives	Tax relief, subsidising loans.	Portfolio of business services (marketing, management, technological assistance), tailored training, infrastructure investments, and access to venture capital or loans for technology development in selected areas of action.
Use of incentives	Fixed set of incentives, except for incentives for large companies, which can be negotiated.	Tailored to the needs of companies and context.
Selection criteria	Defined in advance.	Voluntary participation.
Conditionality	Precisely defined; rigid, predefined criteria.	Soft framework criteria that evolve and adapt to the needs of companies.
Relationship with subsidy recipients	Directed, rigid, predetermined.	Partnership based on collaboration, iterative process, and active project management.

Source: Juhász, Lane, & Rodrik (2023); Di Pippo et al. (2022).

State subsidies have been an important tool of industrial policy since the 1960s, influencing the entry and exit decisions of companies in individual sectors and affecting the Schumpeterian process of creative destruction. In theory, more innovative and productive companies replace those that have not adapted to new market conditions and have outdated business models (Baldwin, 1995; Geroski, 1995; Jovanovic, 1982; Ericson & Pakes, 1998; Asturias et al., 2019). The survival of companies also depends on institutional and regulatory frameworks. Developed economies provide a wide range of services that help start-ups and small companies survive and grow (Gu et al., 2006) despite maintaining a high level of entry and exit of companies. To limit the possibility of misallocation, countries have introduced targeted subsidies conditional on certain behaviour or subsequent changes in behaviour, such as making certain investments or hiring a target number of workers. While most evidence supports horizontal measures aimed at regional development or innovation, some recent studies show that production and investment subsidies can be justified in terms of revenue creation, as they favour large and efficient companies that benefit from economies of scale, while entry subsidies are not effective and attract small producers with high costs (Barwick et al., 2019). Research and development (R&D) subsidies, one of the most common horizontal measures, are intended to encourage private investments in innovation and related technological improvements, which are the main source of productivity growth (see Griliches, 1998) at the national level (Hall, 2011; Crépon et al., 1998). The main argument for R&D subsidies is market imperfections, as companies invest less in R&D than would be optimal from a social perspective (Arrow, 1962).

Table 3. The classification of different types of instruments by areas of action

Area of action	Instruments	
	Market based	Public goods / direct availability
Product market	• Import duties; • Export incentives; • Tax reliefs and exemptions; • Investment allowances (including for R&D).	• Public procurement; • Standardisation; • Localisation requirements; • Investment promotion agencies; • Trade fairs (domestic and international).
Labour market	• Tax reliefs or wage subsidies; • Non-repayable grants for training.	• Training institutions; • Competency councils.
Capital market	• Directed loans; • Interest rate subsidies; • Loan guarantees.	• Development banks; • Sovereign wealth funds; • Export credit agencies.
Land market	• Rent subsidies; • Sale of land at below-market price.	• Infrastructure; • Special economic zones; • Business incubators.
Technology	• Subsidies for R&D&I; • Non-repayable grants; • Co-financing.	• Support for technology transfer; • Public-private partnerships in research; • Public research institutes focused on transferring technology from the research sector to businesses.

Source: Adapted from Di Pippo et al. (2022).

In addition to R&D subsidies, tax incentives and other direct state support for R&D activities (applied and basic research projects) are often used to promote innovation activity. Other important instruments of industrial policy include other types of subsidies, state investment funds (direct state entry into company ownership or financing of venture capital funds), and loans to companies under favourable conditions (development banks, export promotion agencies, etc.) (Di Pippo et al., 2022). The classification of different types of instruments by areas of action is shown in Table 3.

In 2019, China allocated as much as 1.73 percent of its GDP to industrial policy measures, more than four times that of Germany (0.42 percent) and three times that of France (0.55 percent). The USA was even more modest (0.39 percent of GDP), with South Korea standing out among developed countries at 0.67 percent. In China's subsidy structure, nearly a third was in the form of subsidising the costs of loans to state-owned companies, with a quarter in direct incentives and other tax incentives. In France and South Korea, R&D tax incentives and state aid for R&D accounted for 0.47 percent and 0.3 percent of GDP, respectively. In Germany and Japan, the largest share of state aid interestingly amounted to subsidised loans (Di Pippo et al., 2022). During COVID, state aid increased substantially to help citizens and companies mitigate the significant economic impact of the coronavirus pandemic. However, this assistance largely served as a lifeline during the lockdown rather than addressing coordination problems or other state failures (Agnolucci, 2022).

3 "New" industrial policy: China, USA, and Europe

In the post-COVID period, developed countries facing low productivity growth rates have rediscovered industrial policy as a way to create important foundations for future growth. Such an approach, which includes various unrelated measures, is often referred to as productivism (Rodrik, 2022). Moreover, support for industrial policy to overcome coordination problems has also increased to overcome the challenge of green transition. In August 2022, the Biden administration introduced the Inflation Reduction Act (IRA), providing targeted subsidies for sector-specific purposes. In the same spirit, the EU has started discussing how industrial policy and support for certain sectors, crucial for the energy transition, could be utilised to implement the European Green Deal, which commits the EU member states to achieve carbon neutrality by 2050. Consequently, several of them have provided significant subsidies for investments in chip manufacturing and new green and digital technologies. In relation to the green transition and geopolitical challenges, EU member states have begun promoting measures to increase and diversify the EU's supply of critical raw materials by (1) encouraging circularity and (2) supporting research and innovation in efficient resource use and substitution of critical raw materials (Critical Raw Materials Act, 2024). The realisation that different approaches are needed was shaped by China's example, which has made significant economic, technological, and social advances since 2003, when it was accepted into the World Trade Organization (WTO). In continuing, the key elements of the strategic documents of the three largest economic regions in the world are summarised.

3.1 "Made in China 2025": Policy of shaping global winners in strategically important sectors

China is often presented in the literature as a positive example of applying comprehensive industrial policy on carefully selected strategically important sectors (Naughton, 2021). The process, based on ecosystem creation, was multi-staged. In 2006, China adopted the "Medium to Long-term Science and Technology Plan (2006-2020)", which laid the foundations for planned technological self-sufficiency (Naughton & Chen, 2016). Consistent with the directive to support innovation activities, they adopted the "Decision on Accelerating the Development of Strategic Industries" in 2010 and the industrial strategy "Made in China 2025" in 2015, followed by the "SME Development Plan" in 2016 and "10,000 Little Giants" in 2018. The industrial strategy was later supplemented with provincial-level and sector-specific plans, such as the "New Generation Artificial Intelligence Development Plan" in 2017 and the "New Energy Vehicle Industry Development Plan 2021-2035" in 2020. Plans adopted at the provincial level retained the focus from the national plan but were adapted to local specifics (García-Herrero & Krystyanczuk, 2024).

The 2015 industrial strategy, published under the name "Made in China 2025" (MIC2025), aimed to transform China from a global factory of cheap and low-tech products into a global force in high-tech products and services (Li, 2018). The plan highlights ten key sectors in which China aims to become a leading country in production and development: new-generation information technology, high-quality computer-controlled machines and robots, aerospace and aviation equipment, marine equipment and high-tech ships, advanced rail transport equipment, new energy and energy-saving vehicles, electrical equipment, agricultural machinery, new materials and biopharmaceutical products and high-tech medical devices[5] (EUCCC, 2017).

5 http://www.gov.cn/zhuanti/2016/MadeinChina2025-plan/

The strategy's architects outlined a three-stage process: in the first phase, by 2025, they aimed to achieve the same level of production capacity as Germany and Japan during their industrialisation. In the second phase, by 2035, they sought to reach the intermediate level of global manufacturing power, and by 2049, China should become the strongest global manufacturing force. To achieve these breakthroughs, Chinese central and local governments planned to use financial and tax instruments to establish and support manufacturing innovation centres aimed at developing specific industries related to MIC2025. These innovation centres would help Chinese companies co-create international standards (Glaser, 2019), break foreign technology monopolies, and gain control over the most profitable stages of global value chains, also with acquisitions of companies in the USA and Europe[6] (Balderrama & Trejo, 2018). Interestingly, financing priority sectors occurred through the establishment of so-called government guidance funds – large funds that channel public funds and private capital into targeted support for critical sectors (Luong et al., 2021; Wei et al., 2023; Kajitani et al., 2022).

The operational implementation of the MIC2025 industrial policy is based on preparing and executing five-year plans at the national and individual unit levels. Additionally, they adopted an important strategy, "10,000 Little Giants", to support the development of small and medium-sized companies (SMEs) in priority areas to shape value-creating ecosystems. Identification of companies included in the "10,000 Little Giants" program is conducted in two stages: provincial authorities first review applications submitted by companies seeking inclusion in the program. Selected applications are then forwarded to the Ministry of Industry and Information Technology (MIIT), which makes the final selection with the help of randomly selected experts who review the application materials and conduct on-site inspections[7]. Companies seeking to be part of the Little Giants program must not only be "*outstanding among specialised, reformed, and innovative SMEs"* but also "capable of providing key components, parts, and supporting products for large companies or projects, with their leading products having a significant market share in the domestic industry," and be "well-managed with a good reputation and a sense of social responsibility" (MIIT, 2018). From the perspective of understanding industrial policy management, it is interesting that the "10,000 Little Giants" program is based on identifying strategically important industries which slightly differ from those specified in the MIC2025 strategy. Although

6 Because developed countries often viewed these acquisitions as highly politically contentious, they introduced various restrictions on foreign direct investments carried out by Chinese state-owned companies (Zhao & Lee, 2023).

7 Companies are evaluated based on numerous criteria, including financial performance, market position, and the level of expenditures on research and development (R&D). To prevent a slowdown in innovation efforts after enrolment, selected companies retain their status for only three years, after which they must reapply (García-Herrero & Krystyanczuk, 2024).

data on companies included in this program are difficult to obtain because they do not trade on organised capital markets, most operate in the electrical equipment, industrial equipment and machinery parts, electronics and instruments, other commercial products, semiconductors, industrial chemicals, other materials, electronics, computer equipment, aerospace equipment and defence, and diagnostic equipment sectors. In the service sector, only environmental services companies are included (García-Herrero & Schindowski, 2024).

China's industrial policy management differs most from that of the USA and Europe regarding the instruments used. Direct aid has significantly increased in recent years, with 99 percent of all listed companies receiving state aid last year. Between 2015 and 2022, the size of state aid more than doubled, reaching nearly $35 billion (García-Herrero & Schindowski, 2024). On average, the subsidy amounted to slightly less than 2 percent of total company revenues, with a larger share received by companies in the equipment manufacturing, semiconductor, biotechnology, railway transport, and aerospace sectors (García-Herrero & Schindowski, 2024). Besides direct subsidies, since 2017, China has subsidised companies and households in energy consumption (mainly electricity and natural gas), allocating up to 15 percent of GDP in 2022 (Black et al., 2023). The third essential instrument for achieving the goals of China's industrial policy is financing projects through equity capital provided by the state. Government guidance funds (GGFs) are usually established by a government agency, sector-focused, aiming to gather financial resources from government agencies, state-owned banks, state-owned companies, and private investors and invest them through various investment strategies in other funds or directly in companies (Luong et al., 2021). In 2014, there were 96 GGFs; by 2016, the number had risen to 474, with over $240 billion in assets (more than double the amount in 2014). However, many funds did not reach their target asset size, particularly after 2017, attributed to increased competition for investors between locally established and national funds. National funds have generally garnered more media attention, especially the so-called "Big Fund" or "China Integrated Circuit Industry Investment Fund." In 2022, only 15 percent of the funds were national, but they managed 75 percent of all assets. As expected, these funds are highly focused on priority sectors (advanced manufacturing, electronic equipment, biopharmaceuticals, robotics, artificial intelligence, and big data), essentially following the MIC2025 guidelines (China Venture, 2024).

Apart from subsidies and equity funds, bank loans are another key instrument for promoting industrial policy. Data from December 2023 show that 77 percent of corporate financing in China comes from bank loans (PBoC, 2023).

Preferential bank loans support export activities, development, and agriculture, with key institutions being the Export-Import Bank of China, China Development Bank, and Agricultural Development Bank. These selected banks together provide 9 percent of all corporate loans in China. The four large state-owned commercial banks support 27.4 percent of all loans, backed by capital from the People's Bank of China (Liu, 2023). The remainder of corporate financing is supported by provincial state-owned commercial banks.

Since private SMEs have relatively limited access to capital in the Chinese market due to underdeveloped institutions (especially intellectual property rights protection), state certification or inclusion of SMEs in the "10,000 Little Giants" program represents significant leverage for these companies to access organised capital markets. Inclusion in the program acts as a quasi-guarantee of the company's competitiveness and development potential. Due to issues related to intellectual property rights violations, companies do not disclose their actual innovation activities, so this "selective" state certification reveals "hidden champions" to investors. In provinces with weaker intellectual property protection, receiving R&D subsidies facilitates better access to bank loans (Li et al., 2019) or helps obtain listing permission from the China Security and Regulatory Commission. In 2021 and 2022, one-third of companies listed on the stock market were part of the Little Giants program (García-Herrero & Schindowski, 2024).

Other state support mechanisms for individual companies include various tax instruments and preferential access to certain land, which is still state-owned in China. The drawbacks of this mechanism are most visible, as politicians arbitrarily interfere in companies through political appointments, enabling preferential access to resources (regional protectionism). Thus, some studies find that China's development policy has limited success, reflected in stagnating productivity growth since 2011 (García-Herrero & Schindowski, 2024). Significant progress has undoubtedly been made in transportation, especially shipbuilding, railways, and renewable energy production equipment. Similarly, China's recent progress in batteries and electric vehicles will allow for future benefits. Only South Korea achieved a greater increase in the number of robots per 100,000 employees than China between 2016 and 2022 (IFR, 2024). Progress has been less pronounced in other sectors (semiconductors, pharmaceuticals, commercial aviation), and the strong response of key trade partners (Germany, South Korea, USA) has cast doubt on the feasibility of China's industrial strategy. Geopolitical reactions from developed countries have complicated China's plans for economic dominance in selected action areas, making it interesting to observe future adjustments in response to new challenges in the global economy.

3.2 Industrial policy in the USA: Seeking a response to geostrategic challenges

Biden's industrial policy in the USA during the post-COVID period is based on economic incentives adopted under the Inflation Reduction Act (IRA), Creating Helpful Incentives to Produce Semiconductors (CHIPS), and the Bipartisan Infrastructure Law (BIL). The new industrial strategy, financially backed up with nearly $870 billion, supports the expansion of clean energy production and distribution, the transition of the automotive industry from internal combustion engines to electric mobility, reducing energy consumption in buildings, expanding domestic planning, manufacturing, and packaging of semiconductors, while promoting higher value-added sharing by improving workers' wages (Jarsulic, 2023). Instruments to achieve these goals include higher public investments in basic science, research and development, demonstration projects, subsidies for the private sector to reduce production costs in strategic sectors, and subsidies for demand for products that reduce energy consumption and carbon emissions. Access to some subsidies for companies is conditional on meeting specific provisions on wages and job quality.

From the perspective of resource structure, nearly half of the financial resources ($415 billion under BIL) are allocated to basic infrastructural projects at the local community level supporting the green transition: clean energy production, investments in the electrical grid, raw material extraction and battery production, investments in railway infrastructure, public transport, and infrastructure supporting electric mobility (charging stations). Despite the ambitious plans, the current implementation shows that the infrastructure enhancement plan supports selected smaller projects (highways, bridges, airports, water systems, toxic waste clean-ups, broadband expansion, and electrical grid expansion) in more than 40,000 local communities (Yang & Walters, 2024; Nichols, 2024).

In contrast to BIL, which dispersedly promoted decentralisation and local community projects, the Inflation Reduction Act (IRA) designed instruments to promote the growth of renewable energy sources and their use. The IRA, as the second support pillar of the new industrial policy with a scope of $370 billion, supports renewable energy production and transmission, subsidises the purchase of electric vehicles, and encourages investments in reducing energy consumption through building renovations for private and business purposes. The main instrument comprises tax incentives for business investments in renewable energy sources and a tax credit ($7,500) for purchasing electric cars and devices like batteries and solar panels. These benefits are limited to companies that conduct a significant portion of their activities in the USA, especially the final assembly of cars.[8]

Tax subsidies promoting the expansion of electricity production from solar and wind energy revealed the necessity of significant infrastructure investments in grid renewal, upgrading, and expansion. Moreover, large renewable energy projects anticipated by the IRA are long-term and capital-intensive; they require large initial investments hoping to operate for decades with low variable costs due to free solar energy. Their economic justification, therefore, depends on the cost of capital, which is influenced by interest rates. High growth in base interest rates in recent years has contributed to many companies withdrawing from such projects despite subsidies, as renewable energy must compete in price with fossil fuel-based energy (Jarsulic, 2023). Since energy is a completely homogeneous good for the consumer, price is the sole factor of choice. The margins expected from these investments are relatively low and do not outweigh the risks of such investments. All this does not instil optimism in achieving the planned investments in renewable energy production and reducing greenhouse gas emissions in the future.

The main purpose of the CHIPS Act – the third pillar of the new industrial strategy in the USA, providing $79 billion in investments in the semiconductor industry and basic research – is to restore the US manufacturing capabilities in this sector, partially at the expense of the currently dominant global plants in Taiwan, to avoid excessive dependence on China. Semiconductor capabilities are also considered essential for military purposes and national security related to reconnaissance, surveillance, information processing, command, and other functions.[9] The development phase is expected to establish a national technology center (National Semiconductor Technology Center) and support a national program for advanced semiconductor packaging manufacturing (National Advanced Packaging Manufacturing Program) with public funds (Jarsulic, 2023). Besides promoting semiconductor production, the USA has also introduced a trade ban with China for American companies collaborating with Chinese firms within the

8 Promoting the production of electric vehicles does not guarantee profits for American companies. According to their own data, Ford lost $4.7 billion on electric vehicles in 2023, or just under $65,000 per vehicle (Bryce 2024). Tesla has significantly lowered prices due to Chinese competition, and Hertz has discontinued electric vehicle rentals. Because of high limitations in range, charging station networks, and high investment costs of new vehicles, electric mobility is available to households with above-average incomes. Despite subsidies from the IRA program, electric vehicle manufacturers outside the US are not price competitive with Chinese companies, which have a cost advantage due to economies of scale and highly automated production processes.

9 Interestingly, the Taiwan Semiconductor Manufacturing Company (TSMC) has committed to building factories in Arizona; the work is progressing, albeit not without delays and challenges (Lee & Wu, 2024; Ting-Fang & Li, 2024).

value chain in this industry. Such a policy of promoting semiconductor production in the USA and preventing access to the latest chip manufacturing technologies used in semiconductor production could provoke certain short-term measures on China's part (accelerated research and development in strategic technologies needed for the semiconductor industry), redirect Taiwan, whose semiconductor industry is undermined by this US policy, towards China, and increase the cost of semiconductor-based products in the American market. As a retaliatory measure, China banned the export of rare metals gallium and germanium,[10] used in mobile and satellite communications, laser diodes, LED displays, sensors in aerospace and defence systems, optical fibres, infrared optics, and catalysts for plastic polymerisation (Critical Raw Materials Alliance, 2024).

Although the laws were passed to enable quick and decisive action, critics argue that the democratic operation in the USA, which prioritises storytelling over realisation, prevents the effective allocation of funds. So far, relatively few funds have been spent, and those distributed very sparsely, in stark contrast to the concentrated promotion of semiconductor industry ecosystems in Taiwan.

It is noteworthy that, besides vertical measures, horizontal measures were also adopted to promote the creation of quality jobs in manufacturing, construction, and related fields. All projects envisaging the construction of new manufacturing capacities and supported by public funds from the CHIPS Act and most projects from the BIL must meet job quality standards named "Good Jobs Principles" [11]. US economic policymakers anticipate this will lead to wage increases and more on-the-job training. There should also be spillover effects on neighbouring labour markets where companies not subject to these conditions compete for workers with those industries supported by public funds. Moreover, higher wages will contribute to higher levels of aggregate demand, leading to greater production and employment.

3.3 European industrial strategy

For three decades, the EU has strived to eliminate national subsidies for industry to level the playing field for businesses within the EU's internal market and eliminate any market "distortions". A strong EU Directorate-General for

10 Gallium and germanium do not occur independently in nature but are obtained as by-products of bauxite processing into aluminium and zinc processing. A significantly greater problem for the EU and the US would be trade restrictions on graphite and aluminium, as it is hard to imagine battery production without graphite (Home, 2023). Column: China flexes critical metals muscles with export curbs - MINING.COM

11 Good Jobs Principles (dol.gov)

Competition was established to curb anti-competitive practices of companies through antitrust investigations and fines, reduce state aid, prohibit mergers that would diminish competition, and monitor regulations and practices favouring local businesses. However, industrial policy, focusing on particular industries, has regained momentum with the European 2020 New Industrial Strategy and has become an important tool for promoting growth at the EU institutional level. After 2020, the Chip Act, Net-Zero Industry Act, and a relaxation of state aid rules followed, enabling member states to support important projects of common European interest (Important Projects of Common European Interest – IPCEI) at the supra-national level or among groups of member states.

In 2020, the European Commission introduced a new package of measures forming the basis of a new, more ambitious industrial policy to make manufacturing activities in EU countries more sustainable, competitive, and environmentally friendly (European Commission, 2020). Estimates suggest that the global market value of net-zero technologies will reach €600 billion annually by 2030, with an expected threefold increase in key serially produced net-zero technologies. The EU set an ambitious goal for its ecosystems to generate €100 billion annually from this field by 2030 (European Commission, 2024). The main driver of innovations in various ecosystems is expected to be small and medium-sized companies (SMEs), which need help reducing regulatory burdens, addressing payment delays, enhancing solvency, and increasing resilience. Additionally, investment attraction will be strengthened through the European platform for net-zero industry and the European Hydrogen Bank, and access to markets will be facilitated by promoting demand for renewable energy sources through implementing sustainability and resilience criteria in public procurement. Since the introduction of new technologies will increase the demand for new skills, special attention will be given to enhancing skills and competencies (establishment of academic programmes supporting Net-Zero Industry jobs creation). Measures thus address government regulation failures. In terms of correcting the coordination mechanism failures (market failures), the European Commission proposed supporting projects for carbon capture and storage, establishing regulatory toolboxes to help develop and test innovative net-zero technologies, and creating encouraging conditions for innovation.

At the end of May 2021, the European Commission updated the industrial strategy guidelines based on COVID-19 period experiences, focusing on the following key areas: (1) strengthening the resilience of the single market, (2) addressing EU's strategic dependencies, and (3) accelerating the green and digital transition. To strengthen the resilience of the internal market, structural solutions were proposed to ensure the availability and free movement of people, goods, and services during emergencies, harmonise standards for business services, and other measures to deepen the single market and annually monitor 14 key sectoral ecosystems in the EU: aerospace and defence industry, agri-food sector, construction, cultural and creative sectors, digital services, electronic industry, energy-intensive industries, renewable energy, healthcare, mobility, transport and automotive industry, local social economy and civil security, retail, textile industry, and tourism (European Commission, 2021).

The new industrial strategy, named the Net-Zero Industry Act, proposed by the European Commission in 2023 and adopted by the EU Council in February 2024, identified eight strategic net-zero technologies available for commercial use with the potential for rapid expansion in both the short and long term: (1) solar photovoltaic and solar thermal technologies; (2) onshore and offshore wind power; (3) batteries and storage; (4) heat pumps and geothermal energy; (5) electrolysers and fuel cells; (6) sustainable biogas and biomethane; (7) hydrogen capture and storage technologies and (8) grid technologies.

Projects related to these strategic sectors are also expected to receive assistance in administrative procedures, which should shorten the permit acquisition and limit public interest related to environmental protection, a move already condemned by certain environmental organisations. Measures mentioned in the Act also support other net-zero technologies, including sustainable alternative fuel technologies, advanced energy production technologies from nuclear processes with minimal waste from the nuclear fuel cycle, small modular reactors, and related best-in-class fuels. Sectors rapidly adopting net-zero technologies will also receive state support under relaxed criteria (Net-Zero Industry Act, 2023).

The Net-Zero Industry Act is one of the three key legislative initiatives of the industrial plan, alongside the Critical Raw Materials Act (CRMA) and the reform of the electricity market design, enhancing the competitiveness of European industry to achieve a 55 percent reduction in greenhouse gas emissions by 2030 compared to 1990 levels (European Council, 2023). The CRMA is based on four pillars. The first pillar aims to create a regulatory environment that simplifies and streamlines permitting for new technologies defined in the eight strategic sectors. The second pillar of the plan is to increase investments and funding for net-zero technology by creating the Strategic Technologies for Europe Platform (STEP) to maintain the EU's edge in critical and emerging technologies crucial for the green and digital transition. The third pillar focuses on developing the skills needed for the transition and increasing the number of skilled workers in the clean energy technology sector. The fourth pillar concentrates on trade and diversifying the supply chain of critical raw materials, based on forming a club of like-minded countries (partners) and reducing dependency on a single supplier. These four pillars would underpin the creation of net-zero acceleration valleys. With a relatively narrow technological and geographical scope, these would enable industrial symbiosis, minimise environmental impact from various activities, and enhance the efficiency of different industrial partners' operations[12]. The primary goal of this instrument is to create clusters of net-zero industrial activities, making the EU an attractive location for manufacturing activities by streamlining administrative processes and increasing the EU's appeal as a manufacturing location.

The change in market formation goals within the EU resulted in the adoption of a new set of intervention tools and industrial policy mechanisms. In general, EU policy tools can be divided into those that are more oriented towards the internal market and those primarily targeting global markets. However, similar to goals, both categories significantly overlap and intersect. Internal market-oriented industrial policy tools developed by the EU include fiscal innovations, new coordination activities led by the European Commission, and regulatory changes and reinterpretations of EU legislation. The most significant fiscal innovation is the possibility of joint borrowing within the EU. The "Next Generation EU" program, adopted in July 2020, established the possibility of issuing joint European debt within the EU, raising €360 billion in loans and €390 billion in grants, tightly linked to strategic interests defined by the European Commission within the new European industrial policy (Schramm et al., 2022).

Another significant example of expanded fiscal interventions is the European Investment Bank and its partnership with national development banks, issuing bonds on international capital markets and becoming the world's largest lender of green financing (Mertens et al., 2021). A new European Sovereignty Fund was proposed to provide a strategic response to the Inflation Reduction Act (USA) in terms of subsidies Still, a certain group of European countries (so-called frugal states) do not support it (Lynch, 2022).

12 When defining the scope, Member States could consider prioritising areas that could ensure expansion, reindustrialisation, or the creation of new jobs. The formation of European net-zero technology industrial clusters must be based on a vision and the availability of relevant information on how transportation and network infrastructures, storage, and other infrastructures (including education and the availability of a skilled workforce) will develop in line with the needs of industrial partners. The valleys should be designated by Member States, and each designation should be accompanied by a plan with concrete national measures to enhance the valley's attractiveness as a location for manufacturing activities. Valleys are suitable for the formation and strengthening of net-zero emission industrial activities, particularly in coal transition regions (European Council, 2024).

Another major tool of the new industrial policy in the EU is the initiative for Important Projects of Common European Interest (IPCEI), supporting large cross-border innovation and infrastructure projects in strategic areas. Between 2018 and 2024, ten multinational IPCEI projects were approved[13]. Initially, three IPCEI projects in research, development, and innovation (one in microelectronics and two in batteries) were approved. Large IPCEI projects in health, hydrogen, cloud computing, microelectronics, and ICT followed in 2022, 2023, and 2024. These projects involve 22 member states, the UK, and Norway, including 283 companies developing 334 projects with an estimated public co-financing of €37.2 billion and an additional €66 billion from private financing. Unfortunately, Slovenia has not been involved in any of these initiatives by 2024, while Hungary and Slovakia have been very active among the "new" EU members.

The second major category of EU incentives is tools targeting the global market, using trade and investment mechanisms to achieve EU strategic goals, representing a shift from previous decades of liberal EU operations in global markets (Haroche, 2023). Like in the domestic economic area, the EU is moving towards structuring its involvement in the global economy to ensure ambitious climate and digital transformation goals, protect against vulnerabilities in transnational supply chains, and leverage Europe's dominant position in global markets to protect and project European interests and values abroad. This recalculated globalisation is reflected in a new willingness to deviate from previous commitments to free trade within the WTO contractual system, as in the case of the proposed EU Carbon Border Adjustment Mechanism (CBAM).

The new geopolitics are also evident in revised bilateral trade and investment agreements prepared to increase the resilience of EU supply chains. Overall, the EU is moving towards a much more measured version of global trade, prioritising climate and other shared European interests and values. However, differences in vision exist among various EU countries.[14]

13 Although the IPCEI provision has been in the European treaty since 1957, it was scarcely used until 2018. Before 2017, only two infrastructure projects were approved as IPCEIs – the Øresund Bridge between Denmark and Sweden and the fixed rail link Fehmarn Belt between Denmark and Germany (Poitiers & Well, 2022).

14 The latest development in the EU's approach to global markets is found in the proposal for the European Anti-Coercion Instrument (Hackenbroich, 2020). Originally developed in response to concerns about the anti-European agenda of U.S. President Trump's administration, it was expedited due to Russia's exploitation of the EU's energy vulnerability and perceived economic intimidation by China. The Anti-Coercion Instrument officially outlines the rationale for imposing tariffs, restricting services such as foreign banking and trade in intellectual property, and denying access to foreign direct investments in the EU single market if economic intimidation harmful to the EU's interests and values is detected (European Commission, 2021).

Table 4. New economic policy in EU, USA and China

	EU	USA	China
Action plan	• New Generation EU • EU Chips Act • Net Zero Industry Act • Critical Raw Material Act (CRMA)	• Inflation Reduction Act (IRA) • Creating Helpful Incentives to Produce Semiconductors (CHIPS) • Bipartisan Infrastructure Law (BIL)	• SME Development Plan • Made in China 2025 (MIC2025) • 10,000 Little Giants • New Generation Artificial Intelligence Development Plan • New Energy Vehicle Industry Development Plan 2021-2035
Key sectors	• Semiconductors • Batteries • Health and pharmaceuticals • Hydrogen • Cloud computing • Microelectronics • Information technology • Focus on supporting the development and commercialisation of net-zero technologies	• Electricity production from renewable sources • Production of electric vehicles • Semiconductors • Construction (energy efficient solutions)	• New-generation information technology • High-quality computer-controlled machines and robots • Aerospace and aviation equipment • Marine equipment and high-tech ships • Advanced rail transport equipment • New energy and energy-saving vehicles • Electrical equipment • Agricultural machinery • New materials • Biopharmaceutical products and high-tech medical devices
Companies	• Large and globally competitive companies • Companies forming ecosystems in net-zero technologies	• Companies operating in strategic sectors, infrastructure companies.	• Large and medium-sized companies with the potential to become industry leaders.
Assumptions about the role of the state in the economy	• The state addresses regulatory and market failures	• The state identifies strategic sectors and promotes sharing higher added value with employees (creating good jobs)	• The state plays an active role in the economy
Types of subsidies	**Internal market:** • Fiscal innovations • Coordination subsidies (like Net Zero Acceleration Valleys) • Regulatory changes • Reinterpretations of EU legislation **External market:** • Introduction of additional restrictions on the import of environmentally harmful products, such as the EU's Carbon Border Adjustment Mechanism (CBAM) • Tariffs on products from manufacturers that compete with predatory pricing in the EU internal market due to extensive state support	• Subsidies for businesses and individuals • Tax incentives for business investments in renewable energy sources • Subsidies ($7,500) for the purchase of electric vehicles and equipment, batteries, and solar panels, • Subsidies for investments in building renovations • Investments in infrastructure • Funding for fundamental science and its practical application (especially in the field of semiconductors) • Projects • Guarantees	• Direct state aid • Investments in infrastructure • Subsidised access to venture capital or loans • Tax instruments • Priority access to land

Source: García-Herrero & Schindowski (2024), European Commission (2024), Jarsulic (2023).

3.4 Concluding remarks: In search for country-specific True Industrial Policy (TIP)

Various industrial policies of developed countries show that approaches vary and depend on the specifics of each country and economic cycle. While China and the USA have clearly defined strategic industries for the future, EU countries are more cautious. While Germany highlights ten future industries[15] (BMWi, 2019), Austria, for example, still relies on applying horizontal measures of research, technology and innovation[16] (Federal Government of the Republic of Austria, 2020). The first challenge for those responsible for vertical industrial policies is, thus, identifying industries with growth potential in the future. Identification is based on the comparative advantages that the national economy shows in certain areas and on future opportunities (new industries). Industrial policy can be mission-oriented, technology-focused, or support the rapid development of specific industries or locations. The chosen strategy justifies the selection of instruments and is designed to achieve defined goals. Selected instruments are bundled with specific target values, with different methods operating either through the supply side (promoting dynamics at the company or industry level) or through demand.

The principles of modern industrial policy focus on technological advancement, export orientation, intense competition, accountability, and a balance between state intervention and market signals. The policy emphasises five essential principles (Cherif & Hasanov, 2019): **(1) Technological advancement and innovations** focusing on advanced industries. True industrial policy (TIP) encourages the development of domestic manufacturers in industries that go beyond initial comparative advantages, which means focusing not only on existing strong sectors but also on new, technologically advanced ones. The state must invest in R&D and promote innovations for technological advancement. This action includes financial support for companies and research institutions working on advanced technologies. **(2) Export orientation** in terms of promotion of exports and international competitiveness. TIP emphasis es the importance of exports as a key factor for economic success. The state must support companies in entering international markets, which may include subsidies, favourable loans, and trade assistance. A successful industrial policy must ensure that domestic companies are competitive globally, which requires continuous improvement in the quality and innovation of products. **(3) Intense competition and accountability.** TIP encourages intense competition among domestic com-

15 Schlaglichter der Wirtschaftspolitik – Monatsbericht März 2019 (bmwk.de)

16 RTI Strategy 2030 – Strategy for Research, Technology and Innovation of the Austrian Federal Government

panies, leading to greater efficiency and innovation. Companies should not be shielded from competition but operate in a competitive environment. The state must establish mechanisms for measuring the performance of companies and policies (Accountability and Performance Measurement). These mechanisms should include setting clear goals, monitoring progress, and adjusting policies based on results achieved. **(4) The role of the state** in the form of state intervention and finding a balance between market and state. The state is crucial in directing labour and capital to strategic sectors. This includes setting priorities, allocating resources, and creating a favourable business environment. TIP requires a balance between state intervention and market signals. The state must intervene where the market alone cannot achieve optimal results, but it must also consider market signals and adapt accordingly. **(5) The AAA approach to industrial policy (Ambition, Accountability, Adaptability)**. TIP requires highly ambitious goals for economic development. The state must have ambitious plans and a vision for the future. Consistent monitoring and evaluation of achievements are crucial. The state must be accountable for the results of its policies and have mechanisms for tracking progress. TIP must be adaptable and respond quickly to changes in the economic environment, which means the state must continuously adjust its policies in response to new challenges and opportunities.

Despite good intentions and the desire to actively address market and government regulation anomalies with measures promoting economic growth, concerns are growing that granting large sums of aid increases corruption risks[17]. In principle, the discretionary right to allocate large amounts of state aid to industrial projects should be accompanied by strict management and transparency to prevent bribery and negative effects on the single market. There are warnings that the IPCEI program in the EU lacks both and even encourages EU countries to compete in granting industrial subsidies (Poitiers & Well, 2022), which is exactly what the state aid rules sought to avoid.

17 The ICPEI tool represents a partial reversal in competition policy, with the European Commission justifying this based on state aid exceptions under Article 107 of the EU Treaty, which permits "aid to promote the execution of an important project of common European interest" (Evroux, 2022).

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IMPACT OF RESEARCH, DEVELOPMENT AND INNOVATION ON ECONOMIC PERFORMANCE

1 Introduction

In today's rapidly evolving global economy, innovation is a key driver of growth and competitiveness. Nations prioritising technology and research are securing long-term success as the global economic balance shifts from resource-based to knowledge-driven models. China's GDP per capita grew fivefold from 2000 to 2022, and R&D investment increased from 0.9 percent of GDP to over 2.4 percent. This rapid rise illustrates how innovation helps countries catch up with advanced economies (World Bank, 2024). China has shifted from acquiring foreign technologies to pursuing innovation-led growth, allowing it to challenge the United States and European Union in high-tech industries. Smaller economies, like Slovenia, have similarly used innovation to drive growth, showcasing how technology-driven strategies can benefit nations across different economic contexts (Brinza et al., 2024).

This chapter explores the relationship between innovation and economic growth, focusing on how countries leverage technology to increase competitiveness. Drawing on data from the Observatory of Economic Complexity (OEC), the World Bank, and relevant literature, it examines growth strategies while highlighting the role of research and development and innovation (R&D&I) and technology in major economies like the EU, USA, and China, as well as smaller nations like Slovenia. The chapter begins by examining the link between innovation and growth, compares the innovation strategies of the EU, USA, and China, and concludes with how Slovenia navigates the challenges of a tech-driven global market, offering insights into how countries can adapt and thrive in an innovation-centric economy.

2 Technology and knowledge as the key sources of productivity growth

Since World War II, global economic development has sharply contrasted the advanced economies of the USA and Europe with rapidly evolving economies like China. For much of the post-war era, the USA and Europe symbolised economic success driven by strong industrial bases, institutions, and technological leadership. Their growth initially relied on extensive resource use and industrial expansion, gradually transitioning to knowledge-intensive models. This shift marks mature economies, where progress now hinges on innovation, advanced technologies, and a highly educated workforce (Rodrik, 2014).

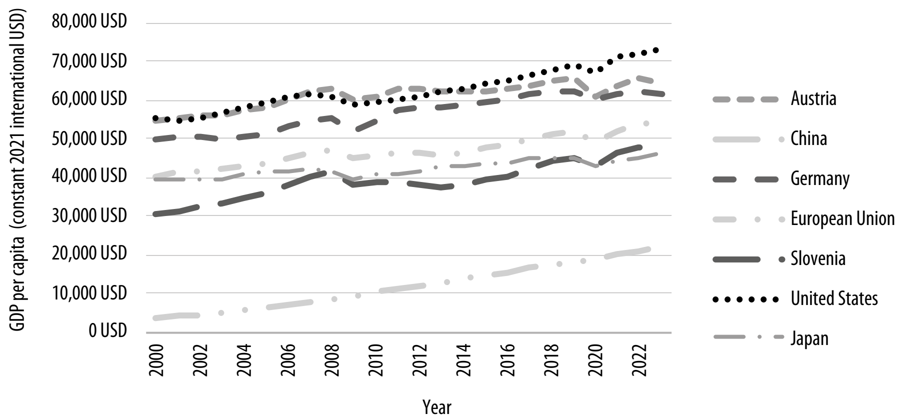
Emerging economies like China utilised their labour force and resources for rapid industrialisation and growth, initially driven by labour-intensive manufacturing and technology adoption, helping close the gap with the West (Wu et al., 2018). However, China's limited attention to intellectual property caused tensions over intellectual property (IP) enforcement (Athreye, 2020). Now, at the economic frontier, China faces the challenge of sustaining growth through innovation. Trade tensions, particularly in sectors like semiconductors, exposed the risks of relying on foreign technologies, prompting increased research and development (R&D) investment (Adams, 2021). China is at a pivotal stage in transitioning to a knowledge-based, high-value economy (Wu et al., 2018).

Shifts in the relative power of China, the USA, and European countries are reflected in key metrics like GDP composition, R&D spending, and high-tech exports. As the USA and Europe see declines in manufacturing and high-tech sectors, China has rapidly boosted R&D (Figure 2) and technology spending to close the gap (Figure 1).

By 2000, the USA and Europe were dominant economic powers with high output driven by advanced industrial and service sectors (Figure 1). Their growth has been steady but moderate, typical of mature economies, with fluctuations, especially during the 2008 financial crisis, resulting in slower growth and even contraction (Romer & Romer, 2017). Though the USA and EU recovered, their growth has been slower than in past decades (Figure 1), showing the difficulties of being at the forefront of development.

In contrast, China's economy has surged since 2000 from a lower base, driven by rapid industrialisation, large infrastructure projects, and a robust export sector. Unlike the USA and EU, which were hit by global downturns like the 2008 financial crisis, China continued growing due to government support and steady investment (Womack, 2017). By 2023, though the USA still leads, the gap between China and the EU has closed, highlighting China's effective strategy and sustained growth despite global challenges (Figure 1).

Figure 1. GDP per capita by region from 2000 to 2022 (constant 2021 international USD)

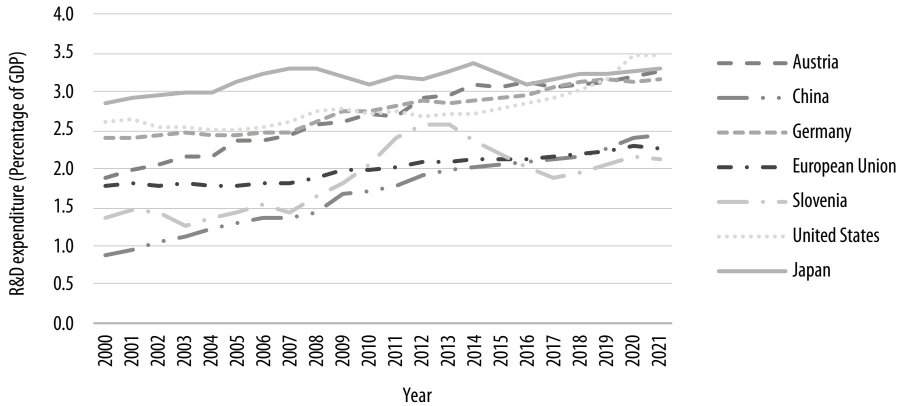


Source: World Bank (2024).

A critical element of China's development strategy has been its increasing focus on R&D (Yiming, 2023). China used to spend little on R&D, focusing more on manufacturing and infrastructure, but now it is shifting to innovation and high-tech areas. R&D expenditure rose from 0.9 percent in 2000 to about 2.4 percent by 2021, though still lower than in the USA (Figure 2). With gross fixed capital formation at 41.9 percent of GDP, China invests heavily in physical assets, supporting technological progress, yet its R&D investment remains limited. The gap in R&D spending compared to the USA and many EU nations, except Slovenia, underscores China's challenge in closing the innovation gap (Figure 2).

The United States has consistently increased its R&D expenditure, rising from around 2.5 percent of GDP in 2000 to 3.5 percent by 2021 (Figure 2). With gross fixed capital formation at 21.3 percent of GDP (World Bank, 2024), the USA maintains a strong focus on innovation and physical investment, ensuring infrastructure and manufacturing capabilities to scale innovations. In contrast, the EU's R&D spending rose slowly, from 1.7 percent in 2000 to 2.3 percent by 2021, possibly affecting its global competitiveness. While the USA leads, the narrowing gap between China and the EU suggests China is positioning itself as a major global innovator (Chen et al., 2021).

Figure 2. R&D expenditure as a percentage of GDP by region from 2000 to 2021



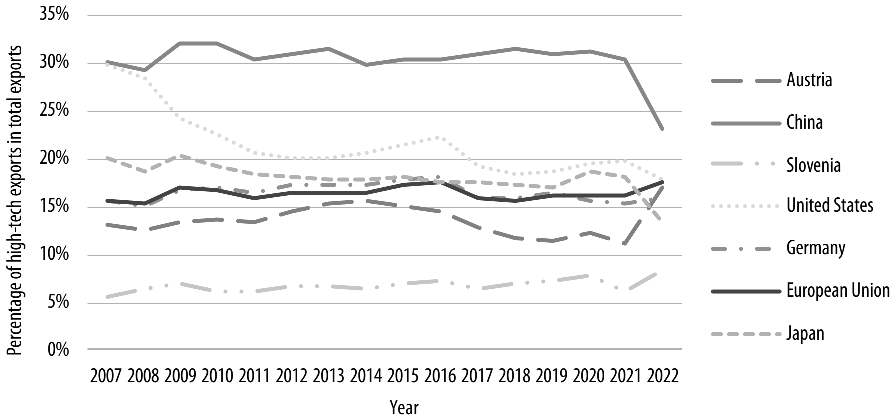
Source: World Bank (2024).

High-tech exports, as a percentage of manufactured goods, are a key indicator of a country's technological advancement and global competitiveness (Kabaklarli et al., 2018). China has maintained a significant share of high-tech exports, emphasising its focus on high-tech industries. However, this stability was disrupted by the COVID-19 pandemic, which caused supply chain issues, including factory shutdowns and semiconductor shortages (Meier & Pinto, 2020). Lockdowns in key manufacturing areas slowed production and reduced export volumes (Lin et al., 2021). Since 2022, rising geopolitical tensions have worsened these issues, with US and EU sanctions on semiconductors limiting China's high-tech exports and access to key technologies (Shilov, 2024). These sanctions have led European countries, including Slovenia, to rethink their reliance on Chinese technology and increase protections for critical infrastructure (Poitiers & Sekut, 2024).

The United States has experienced a decline in its share of high-tech exports (Figure 3), reflecting structural changes in its economy, particularly the loss of manufacturing power. Many regions, such as the "middle belt", have faced economic dislocation due to job losses as industries moved abroad, mainly to China (Charles et al., 2018). This decline in high-tech exports mirrors the broader trend of deindustrialisation, with high-tech industries becoming less central to the US economy. This shift has had economic and political repercussions, contributing to the rise of populist movements (Autor et al., 2020).

The European Union has maintained a relatively stable share of high-tech exports, though it consistently lags behind China. This stability reflects a more measured approach, with the EU focusing on preserving its strengths rather than expanding its high-tech sector. China surpassing the USA and EU in high-tech exports as a share of manufactured goods showcases its strategic success and rising status as a global tech leader (Figure 3).

Figure 3. High-tech exports as a percentage of manufactured exports by region from 2007 to 2021

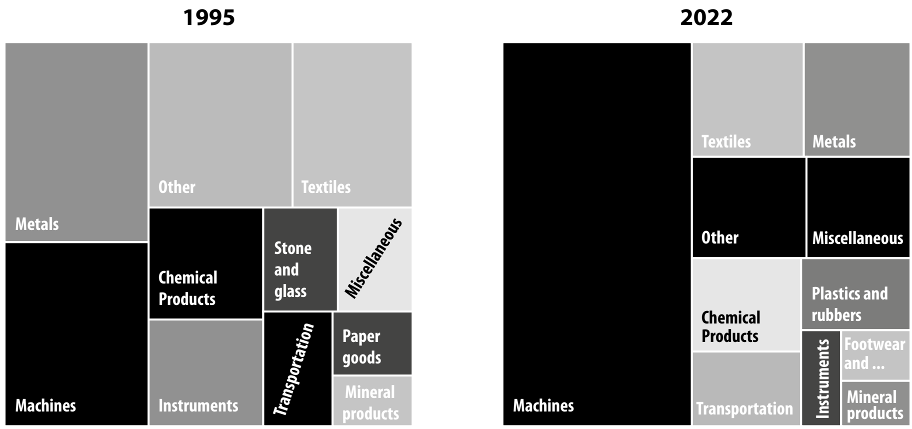


Source: World Bank (2024).

Between 1995 and 2022, China's export data shows a major shift. In 1995, sectors like textiles and paper goods were key parts of China's exports, reflecting its position as a producer of low-cost goods. By 2022, the picture had changed completely. Machinery and chemical products grew sharply, with machinery making up a large share of total exports. This change highlights China's move from traditional, labour-intensive industries to high-tech and advanced manufacturing (Figure 4).

What is particularly interesting is how quickly China managed to make this shift. The rapid growth in its high-tech exports shows not just industrial expansion but a clear focus on taking part in increasing global demands for advanced products. In just a few decades, China has gone from being a low-cost manufacturing centre to a major player in technology and global trade. This shift illustrates China's move from low-tech, labour-intensive industries toward high-tech, value-added sectors, aligning with its strategic focus on becoming a global leader in advanced manufacturing and technology (Zhou et al., 2021). As China continues to grow in these areas, the global balance of economic power is being reshaped, with implications for future economic leadership, technological advancement, and innovation.

Figure 4. China's export structure as a percentage of total exports in 1995 and 2022



Note 1: Other 1995: Plastics and Rubbers (2.37 percent); Wood Products (1.80 percent); Footwear and Headwear (1.89 percent); Precious Metals (1.86 percent); Foodstuffs (1.69 percent); Animal Hides (1.32 percent); Vegetable Products (1.22 percent); Weapons (1.04 percent); Arts and Antiques (0.98 percent); Animal and Vegetable Bi-Products (0.49 percent); Animal Products (0.37 percent)

Note 2: Other 2022: Stone and Glass (1.69 percent); Paper Goods (1.06 percent); Animal Hides (1.04 percent); Foodstuffs (1.03 percent); Precious Metals (0.83 percent); Vegetable Products (0.74 percent); Wood Products (0.55 percent); Animal Products (0.42 percent); Animal and Vegetable Bi-Products (0.10 percent); Arts and Antiques (0.07 percent); Weapons (0.01 percent)

Source: Observatory of Economic Complexity (2024).

3 The relationship between innovation and economic performance

The relationship between innovation and economic performance is a key driver of growth and competitiveness. As economies shift toward knowledge-intensive models, technological innovation, research, and complexity are crucial for sustaining long-term development (Wu et al., 2018). Innovation boosts productivity, creates higher-quality jobs, and diversifies economies through advanced products and services. These processes are essential for navigating the challenges of globalisation and technological change, making innovation-driven growth a central focus of economic policy (Furman & Hayes, 2004).

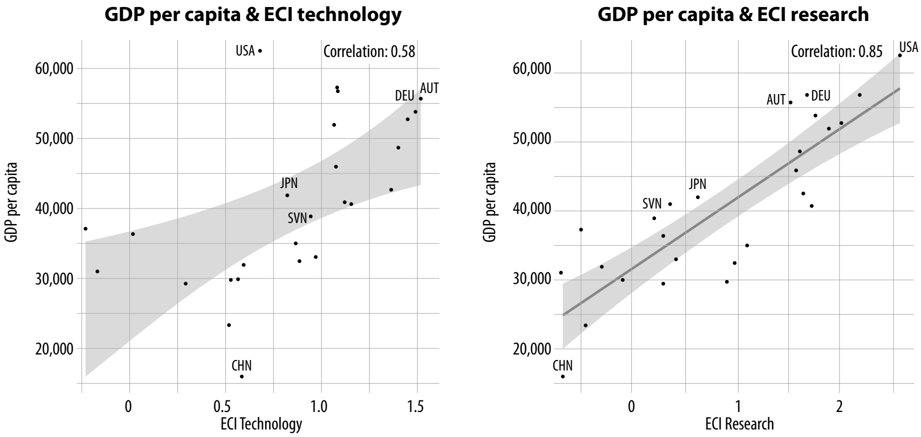
This analysis explores how trade, technology, research complexity, and human capital contribute to GDP per capita growth, highlighting different development paths in a shifting global economy. Focusing on data from the USA, China, Japan, and the EU, particularly Slovenia, Austria, and Germany, the analysis provides a comprehensive view of the economic complexity index (ECI). Trade complexity is assessed by export diversity and sophistication, while technology and research are measured by patents and scientific publications (OEC, 2023).

Figure 5 focuses on ECI Technology and ECI Research. Both display positive correlations, with technological complexity moderately correlated (0.58) and research complexity showing a stronger correlation (0.85). The higher correlation for research complexity suggests that research investment may drive economic output more than technology alone, highlighting the importance of innovation ecosystems. Austria and Germany excel in technological and research advancements, aligning their high GDP per capita with strong innovation policies. Their success highlights the importance of supporting research and technology as key growth drivers. Japan also performs well but ranks slightly below Austria and Germany, indicating a balanced approach with perhaps less intensity in research or technological leadership (Figure 5).

Slovenia holds a more moderate position in technological and research complexity, suggesting that while it has some economic complexity, there is room for growth, particularly in research. China, in comparison, shows a significantly lower position in technological and research complexity despite its relatively high GDP per capita. Its lower scores in both ECI dimensions suggest that China's economic strength is less reliant on advanced technological and research capabilities than other countries. This positions China at a different stage of development, where improving technological complexity and research investments could drive further economic growth. Countries with moderate complexity can boost their economic output by strategically investing in research and diversifying their knowledge base (Hausmann et al., 2014).

The USA shows a contrast between technological and research complexity. Its high GDP per capita contrasts with a relatively lower ECI Technology score (Figure 5), suggesting that non-technological factors, like dominance in service industries or financial markets, contribute to its economic strength. The high complexity of research aligns with GDP per capita, as research-driven economies tend to perform better over time (Mazzucato, 2018). The USA's strong research infrastructure and ability to commercialise research support this view (OSTP, 2024).

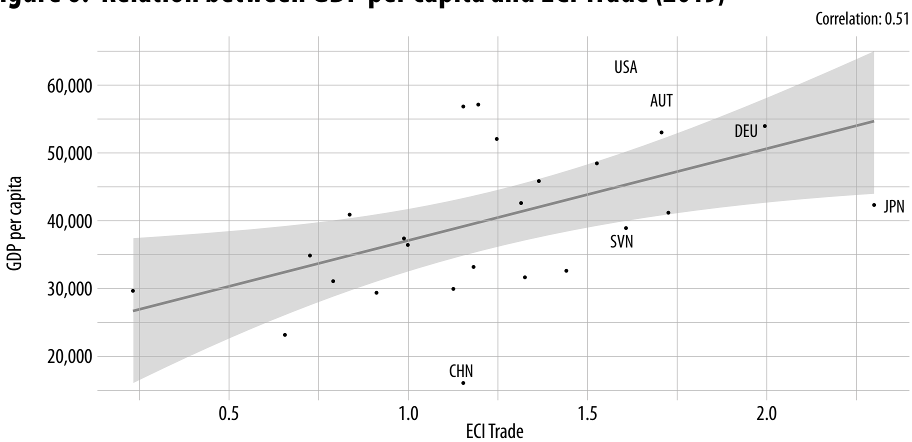
Figure 5. Relationship between GDP per capita and ECI Technology & ECI Research (2019)



Note: China (CHN), Austria (AUT), Germany (DEU), Slovenia (SVN), Japan (JPN), United States of America (USA)

Source: OEC (2023).

Figure 6. Relation between GDP per capita and ECI Trade (2019)

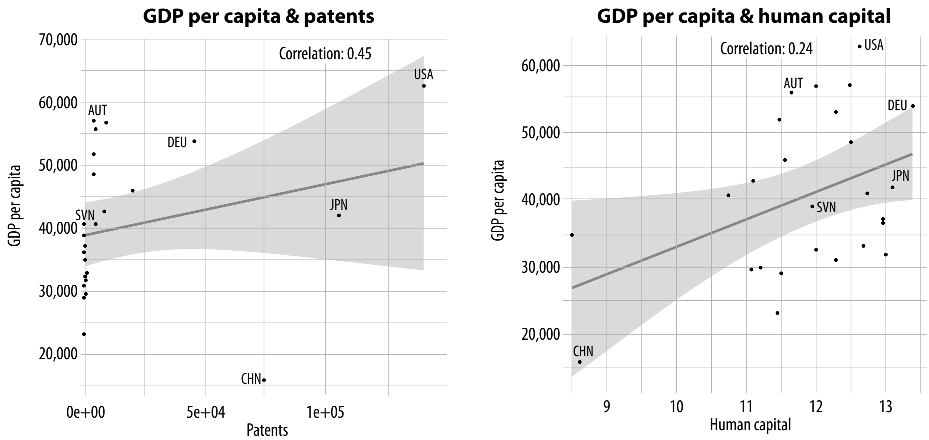


Note: China (CHN), Austria (AUT), Germany (DEU), Slovenia (SVN), Japan (JPN), United States of America (USA)

Source: OEC (2023).

Figure 6 shows the relationship between GDP per capita and the ECI for trade in 2019, with a moderate correlation of 0.55. The trend line suggests that higher ECI generally corresponds with higher GDP per capita. The USA, Austria, and Germany have higher GDP per capita and ECI, showing a stronger correlation between complexity and prosperity. Slovenia has a lower GDP per capita despite a similar ECI, hinting at structural issues in converting complexity into wealth. With lower GDP per capita, China also has a lower ECI Trade score than the more advanced economies. This placement suggests that China's trade complexity, while growing, is not yet on par with countries like Germany or Japan, limiting its current potential to achieve higher GDP per capita. Japan displays high ECI but lower GDP per capita, suggesting external factors may influence its performance.

Figure 7. Relation between GDP per capita and Patents (2019) and Human Capital (2019)



Note: China (CHN), Austria (AUT), Germany (DEU), Slovenia (SVN), Japan (JPN), United States of America (USA)

Source: OEC (2023).

Figure 7 (left panel), examining patents, shows a moderate correlation of 0.45 between GDP per capita and patents. Countries like the USA and Germany exhibit high GDP per capita alongside a significant number of patents, underscoring the critical role of innovation and intellectual property in driving economic prosperity. Austria also demonstrates a solid position, though somewhat lower in both metrics, highlighting the importance of a balanced innovation strategy. In contrast, despite having a high patent count, Japan lags in GDP per capita, suggesting that while patents are vital, other factors, such as the commercialisation of innovation or broader economic policies, may limit their full economic potential. In this context, China shows both low patent activity and lower GDP per capita, indicating that its innovation ecosystem is still developing and there is potential for growth in leveraging patents to drive economic gains.

Figure 7 (right panel) depicts a weaker correlation (0.24) between GDP per capita and human capital, with Austria maintaining strong economic outputs despite only moderate human capital scores. Slovenia, while lower in patents and human capital, illustrates the need for countries with moderate economic complexity to invest in innovation and human capital development to enhance their economic potential.

4 Reviving EU competitiveness and the role of innovation: Strategies for ongoing and future success

The European Union (EU) has developed a comprehensive strategy to foster innovation, sustainability, and competitiveness, supported by substantial public funding and programs to boost economic growth. The foundation of this strategy lies in the public funding allocated to drive innovation and support key sectors. Central to this strategy is Horizon Europe, which has a €95.5 billion budget for the years between 2021 and 2027, reflecting the EU's commitment to tackling societal challenges, promoting industrial competitiveness, and advancing sustainable development (European Commission, 2021a). The EU aligns public and private sectors through these funding mechanisms and supports programs to mobilise resources across the EU.

The EU's strategic focus on fostering public-private partnerships (PPPs), which promote collaboration between governments, industry, and academia, is evident through different initiatives. These programs are designed to stimulate innovation by utilising public sector support to address societal challenges, reflecting Mazzucato's Mission Economy framework through goals that foster transformative change and position Europe in global markets (European Commission: Directorate-General for Research and Innovation & Mazzucato, 2018). This effort is complemented by the European Technology Platforms and Joint Technology Initiatives, which facilitate cooperation between the public and private sectors to advance critical technologies (European Commission, n.d.). Furthermore, the Global Gateway initiative enhances the EU's geopolitical stance by improving global connectivity and infrastructure, positioning Europe as a counterbalance to China's Belt and Road Initiative (Feingold, 2023).

Innovation is at the core of these strategies, though each region pursues it through different frameworks. The European Innovation Council (EIC), with a budget of €10.1 billion, supports groundbreaking innovations from early research to start-up scaling (European Commission, n.d.). Furthermore, the EU dedicates 30 percent of its long-term budget to climate change and 20 percent to digital transformation (European Commission, 2021b), contrasting with

China's use of state-owned funds, such as the $21 billion National Integrated Circuit Fund (ISDP, 2018), and the USA's focus on infrastructure and energy.

The EU's Important Projects of Common European Interest (IPCEI) framework supports large-scale, cross-border innovation in key sectors like microelectronics, hydrogen, and digital technologies. Since 2018, it has combined over €91 billion in state aid and private investment, effectively scaling new technologies and addressing industrial needs. Unlike other innovation programs, IPCEI pairs technological progress with capital investment, promoting cross-border knowledge-sharing, SME participation, and sustainable growth (European Commission, 2023b).

Talent development is a central focus of the EU, with Horizon Europe and initiatives like the European Research Area (ERA) prioritising the top scientific talent and ensuring career stability (European Commission, 2023a). Additionally, programs like the Marie Skłodowska-Curie Actions (MSCA) provide opportunities for international mobility and access to leading research facilities, enhancing researchers' career prospects (European Commission, 2024). The US strategy emphasises workforce development through public-private partnerships in sectors like advanced manufacturing and clean energy, with significant funding for training programs, STEM integration, and strengthened industry collaborations (Office of Science and Technology Policy & National Science and Technology Council, 2022). China's "Initiative for Cultivating Top Talent in Basic Disciplines" uses AI methods to enhance its scientific base, supporting its goal of building a talent pool for technological ambitions (Zhang, 2024).

Financial incentives vary by region. The EU emphasises climate action and digital transformation, increasing energy subsidies from €216 billion in 2021 to €390 billion in 2022 due to the energy crisis (European Commission, 2023c). Alongside direct subsidies, tax incentives and credits for research and innovation reduce the tax burden on companies (OECD, 2023). In the USA, tax incentives include a 25 percent credit for semiconductor manufacturing under the CHIPS Act (McNeece, 2023) and a $35 per kilowatt-hour credit for US-made electric vehicle batteries as part of the Inflation Reduction Act (IRA) (Murlless & Sagatelova, 2024). China's approach features preferential tax rates for high-tech enterprises and state-owned bank subsidies, supported by funds like the National Integrated Circuit Fund (ISDP, 2018).

The management of IP distinguishes these economies. Through the European Union Intellectual Property Office, the EU requires Horizon Europe projects to report IP ownership and ensure the commercialisation of research outcomes (European Commission: European Innovation Council and SMEs Executive Agency, 2022). The USA enforces IP rights via laws like the Digital Millennium Copyright Act and the Lanham Act, with the US Patent and Trademark Office playing a key role (Intellectual Property Enforcement, n.d.). The USA also leads global IP enforcement, collaborating with the World Intellectual Property Organization to protect innovation (Intellectual Property Enforcement, n.d.). Meanwhile, China has become a leader in patent filings, submitting 921,000 patents in 2023, highlighting its commitment to technological advancement and IP management (Chen, 2024).

Geopolitical considerations also play a role in shaping each region's public-private partnerships. Through its Data Strategy and AI Act, the EU aims to enhance digital sovereignty and set global standards for emerging technologies, making significant investments in AI and infrastructure to boost its international influence (Csernatoni, 2024). The USA counters global tensions by leveraging trade policies and investing in defence technologies to maintain its technological advantage and secure critical infrastructure (Murlless & Sagatelova, 2024). China, focusing on technological decoupling and techno-nationalism, is working to build an independent technological ecosystem while exerting control over key resources (Esade, 2024). Although the EU supports innovation and collaboration, dependence on public funding and slow decision-making limit its global competitiveness, especially in fast-evolving areas like AI and biotechnology. Through significant funding and cross-border cooperation, the Important Projects of Common European Interest (IPCEI) program enhances industrial competitiveness and aligns with global demands (European Commission, 2023b).

In contrast, the US strategy, reflected in the CHIPS Act and Inflation Reduction Act, is more direct, aiming to secure technological leadership and national security by investing in key industries. However, concentrating on certain industries could limit broader innovation (Scheinert, 2023). China's state-led model, exemplified by the "Made in China 2025" initiative, has accelerated technological advancement, primarily through government support. However, this approach may cause inefficiencies and hinder creativity by reducing competition and market dynamics, which are essential for long-term innovation. These inefficiencies arise because reliance on state intervention can create dependency, reducing the incentive for firms to optimise processes and respond to consumer demands effectively (Branstetter & Li, 2022). China's effort to reduce dependence on foreign technology could intensify geopolitical tensions. Still, in industries like automotive, China is already setting global standards, surpassing the USA and Europe in some areas (Breznitz, 2021). China's relatively low ranking in human capital could be a crucial factor hindering its next development phase. To maintain its technological leadership and global competitiveness, China should enhance human capital by improving education, fostering creativity and critical thinking, and adopting more flexible approaches alongside its state-led model (Hu & Jefferson, 2018).

5 Implications for Slovenia

Slovenia's economic progress demonstrates its ability to navigate the complexities of a small, open economy. Its stable growth, backed by a focus on innovation and EU integration, has built a strong foundation, but moving forward, Slovenia faces challenges. To reach its full potential, it must strengthen its innovation ecosystem and expand high-tech sectors, which are essential for competing in the increasingly tech-driven global market.

While global powers like China, the USA, and the EU leverage innovation for growth, smaller nations like Slovenia face unique challenges. Slovenia's GDP per capita places it between China's rapid rise and the mature economies of the USA and EU (Figure 1). Joining the EU in 2004 boosted trade and investment, but the 2008 financial crisis led to a severe banking crisis, slowing its recovery. Unlike larger economies, Slovenia's growth resumed cautiously due to necessary reforms, and its small, export-dependent economy remains vulnerable to EU market conditions (United States Department of State, 2023).

Despite these challenges, Slovenia maintains a relatively high GDP per capita, supported by its advanced industrial base and global supply chain integration. Although growth is slower compared to emerging economies, Slovenia's resilience offers potential for long-term development. R&D spending increased after EU accession, peaking in 2013 at over 2.6 percent of GDP, reflecting a shift towards a knowledge-based economy (Figure 2). By 2021, R&D spending stabilised at 2.3 percent, above the EU average, with key industries like pharmaceuticals, IT, and manufacturing driving innovation (Figure 2). High-tech exports, though relatively low, fluctuate between 5 and 8 percent of total manufactured goods (Figure 3), showing Slovenia's efforts to expand in sectors like pharmaceuticals and electronics.

Slovenia's strength lies in its specialised knowledge and technical expertise, particularly in high-value sectors like pharmaceuticals, machine engineering, IT, and electronics (Domadenik Muren et al., 2024). Despite its small size, the Slovenia Development Strategy 2030 highlights the country's potential to lead in knowledge-intensive industries (Chateau et al., 2019). With the reindustrialisation strategy, Slovenia has a unique opportunity to expand in high-value-added manufacturing and services (Chateau et al., 2019). Despite limited mass production, Slovenia's advanced tech and engineering make it a key player in Europe, but it needs to boost its innovation and high-tech sectors to stay competitive. Its stable growth, backed by EU integration and a focus on R&D, provides a strong foundation, but further efforts are needed to fully realise its potential in a technology-driven economy.

6 Conclusion

As the global landscape shifts, countries must move beyond traditional methods of growth and adopt more flexible strategies focused on technological innovation. The key to long-term success lies in utilising advancements, fostering new industries, and preparing for future uncertainties. It is not just about increasing R&D spending; the challenge is converting these investments into sustainable growth, competitive industries, and economies that can adapt to global market changes and geopolitical dynamics.

In an increasingly interconnected world, collaboration across borders is critical. Countries that build innovation ecosystems, promoting knowledge-sharing, public-private partnerships, and international cooperation will have a distinct advantage. Economic leadership will no longer be defined by size or historical achievements but by how effectively nations navigate modern technological complexities. The countries striking the right balance between innovation, policy, and global collaboration will lead the next phase of global development.

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A COMPARATIVE ANALYSIS OF THE PRODUCTIVITY OF SLOVENIAN INDUSTRIES

1 Introduction

Empirical studies show that the concept of average firm productivity is a poor economic indicator, as the distribution of productivity within each industry is strongly asymmetrical to the right: in every industry, there are a small number of very successful firms and many others (Altomonte & di Mauro, 2022). Although the productivity of firms is influenced by factors at both the macroeconomic level (e.g., infrastructure, logistical links, institutions, market regulation and politics) and the industry-specific level (e.g., know-how advantage provided by the local research institutes), firm-specific factors (innovative capacity, management skills, brand, etc.) also play an important role. The task of economic policymakers is, therefore, to find the right balance between general measures to increase the productivity of all firms and an appropriate reallocation of resources to more efficient firms within industries, as well as to identify the most promising industries where synergies are most likely to be found and ecosystems created.

The chapter is divided into two main parts. In the first part, an industry analysis is conducted, highlighting the productivity of Slovenian firms within individual industries, focusing on the distribution of total factor productivity in the period from 2012 to 2022, and also showing the difference in productivity for predominantly export-oriented firms, while also presenting the shares of growing and zombie firms. The second part presents a between-industry analysis, comparing the industries and trying to identify those which could be the most promising in the future. A quantified indicator was constructed based on the firm's financial performance data, which was used to compare the industries.

In addition, the relative importance of the industry within the economy is considered based on the contribution to value added and the number of employees, as well as the potential for synergies and creating ecosystems.

Empirical analyses of the performance of firms in different European countries have shown that only a handful of firms tend to play a dominant role in economic activity, including the share of exports and foreign direct investment (Altomonte & di Mauro, 2022). Similar results were obtained by researchers comparing industries in the USA according to the SIC (Standard Industrial Classification) classification (see Syverson, 2004), where results showed that a firm in the 90th percentile is, on average, twice as productive as a firm in the 10th percentile. Syverson (2011) notes that the differences within industries are significantly greater than the differences between industries. Mayer and Ottaviano (2007) have empirically proven for the EU that only 1 percent of the most successful firms generate up to 75 percent of the GDP and international trade. Hsieh and Klenow (2009) showed that for China and India, the productivity ratio within the industries between the 10th and 90th percentiles is as high as 1 to 5. Such findings are important for policymakers, as in the US economy, for example, the 100 most successful firms generate up to a third of GDP (Gabaix, 2011), and this phenomenon is even more pronounced in smaller economies.

Melitz (2003) notes that, generally, only the most productive firms are involved in international trade. In an average economy, about 20 percent of firms are export-oriented, generating up to 80 percent of total economic activity. Low-productive to medium-productive firms tend to offer their services or products only in the domestic market as competing on a global level is more difficult. Similarly, in their study of France and Germany, Mayer and Ottaviano (2007) find that in most industries, only a handful of firms are export-oriented, and these tend to be the firms that create the most added value and have a better-educated workforce on average. However, empirical research has yet to clarify whether a high level of engagement in international activities is the cause or the result of higher productivity, but the causality most likely goes both ways.

Finally, empirical research (see Bartelsman et al. (2013), Hopenhayn (2014), Gopinath et al. (2017)) has shown that a large part of the productivity differences between firms can be explained by the inefficient allocation of labour and capital between firms within industries. Bartelsman and others (2013) showed that a more efficient allocation of labour and capital between firms within industries would increase production by more than 30 percent. The European Central Bank (ECB) came to similar conclusions: "Total factor productivity increases substantially through the reallocation of assets from less productive to more productive firms, which is particularly pronounced in the euro area, as the differences between the least productive and the most productive firms are extremely large" (Draghi, 2015).

2 Goals and methodology

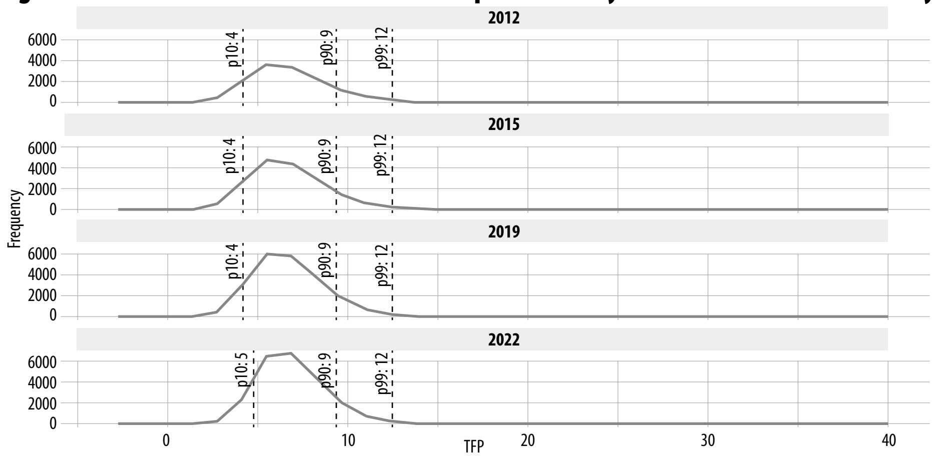
The first part of the analysis focuses on the prominence of the differences in productivity within industries, i.e. between the least and the most productive firms within an individual industry. In the second part, the differences between the industries are analysed. Productivity is measured using the total factor productivity (hereafter TFP), which is the residual between the actual and the expected value added, based on how much capital and labour the firm employs. It measures the efficiency of transforming production factors into final products and is a frequently used measure of productivity in financial studies. TFP was estimated using the econometric model, following Wooldridge's (2009) approach. This residual can be attributed to the firm's innovative capacity, investment activities, management skills, brands, etc. For each industry separately, defined by the Standard Classification of Activities of Slovenian firms (NACE Rev. 2), the firm's TFP was estimated, based on their financial statements, reported to the Agency of the Republic of Slovenia for Public Legal Registers and Services (AJPES). The data analysed cover the period from 2012 to 2022 and includes all Slovenian firms that:

- were actively operating in the year 2022 but were founded before the year 2021 (at least three years of financial data),
- had a balance sheet value of at least €10,000 in the year 2022,
- had a total turnover of at least €10,000 in the year 2022,
- had at least two employees in the year 2022, and
- employed at least one employee each year during which the firm was active.

3 Productivity within the industry

Figure 1 shows the distribution of total factor productivity for the Slovenian economy. The pattern observed for the total economy (high right skewness) can be observed within each industry. The firm in the 90th percentile (p90) is about twice as productive as the firm in the 10th percentile (p10), even though both firms operate in the same industry and face a similar business environment.

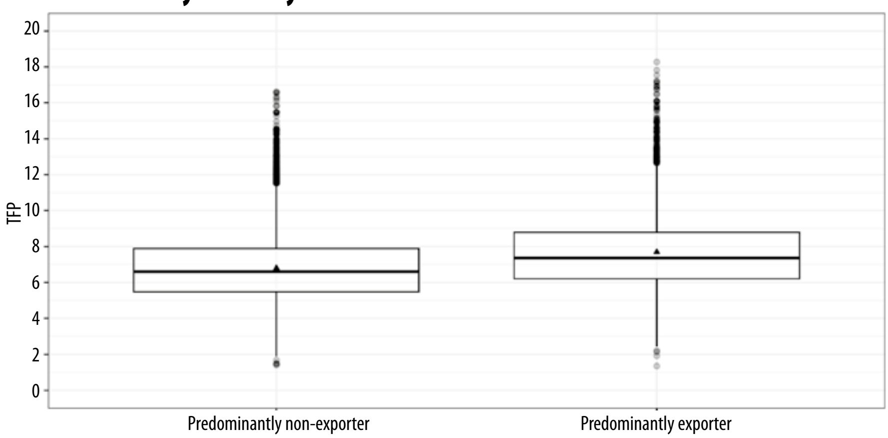
Figure 1. The distribution of total factor productivity for the Slovenian economy



Source: AJPES (2024).

The distribution of TFP of exporters (at least half of total revenue is generated in foreign markets) was also compared with that of non-exporters. Figure 2 shows that exporters have a higher average and median TFP, as is the case in the majority of all Slovenian industries.

Figure 2. The distribution of total factor productivity for predominantly non-exporters vs predominantly exporters for the Slovenian economy for the year 2022



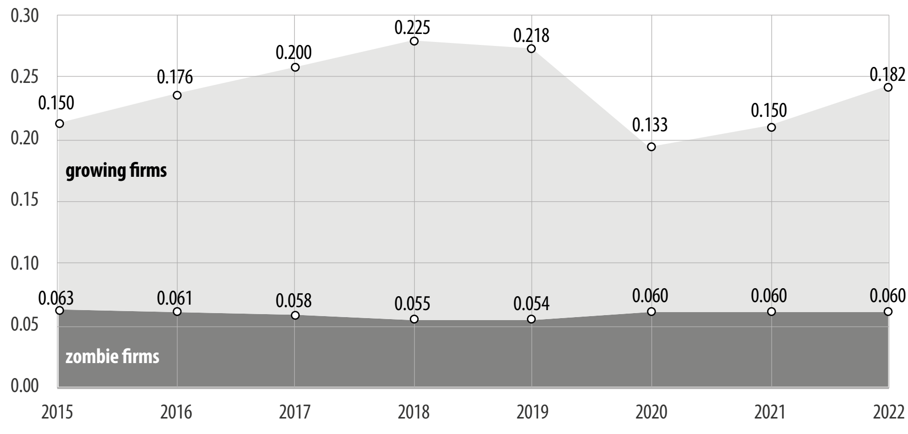
Note: a firm is classified as predominantlz exporter if it generates at least half of its revenue in a foreign market. Distribution is shown with boxplot. Triangle shows the average.

Source: AJPES (2024).

Finally, the proportion of growing firms (firms with at least 3 percent annual sales growth for three consecutive years) and zombie firms (firms that make losses for three consecutive years and are not growing firms) in Slovenian industries were analysed. Empirical studies have shown that policy must not only promote the internal growth of firms (e.g., through subsidies for research and development) but must also support the reallocation of resources from less productive to more productive firms within industries. As a rule, such reallocations can only take place if less productive firms fail. Empirical results show (e.g., Altomonte & di Mauro, 2022) that low-productive firms accumulate debt, leading to the emergence of so-called zombie firms. The constant financial support of such firms harms the economy, as they inhibit innovation and invest too little. In addition, the high proportion of such firms makes it difficult for the more productive firms in the sector to access external funding. The phenomenon of zombie firms is particularly evident in southern European countries (Altomonte & di Mauro, 2022). It should be noted that when less productive firms collapse, it is mainly the less qualified workers who lose out, as it is more difficult for them to find a job in more productive firms. Economic policies should, therefore, encourage the training of less educated workers.

In addition, fast-growing firms are also extremely important for the economy, as only they create new, well-paid jobs (so-called "good jobs" – see Rodrik, 2022), w hich is why analysing fast-growing firms is crucial for formulating appropriate policy measures.

Figure 3. The proportion of growing and zombie firms in the Slovenian economy

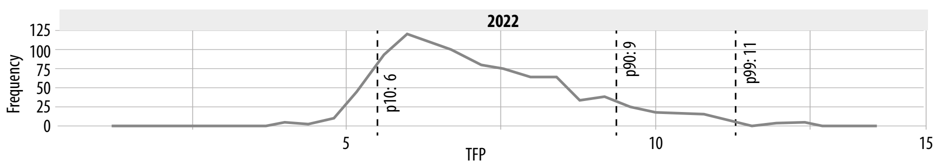


Source: AJPES (2024).

A firm was classified as a growing firm in year *t* if it recorded nominal sales growth of at least 3 percent in years *t*, *t-1* and *t-2* (i.e., three consecutive years). A firm was defined as a zombie firm in year t if it recorded a loss in years *t*, *t-1* and *t-2* (i.e., three consecutive years) but was not a growing firm (for both definitions, definitions of Altomonte and di Mauro, 2022, were followed). Figure 3 shows the proportion of growing (light grey) and zombie firms (dark grey) for all Slovenian firms. The results show that the share of zombie firms was relatively constant at around 6 percent in the period from 2015 to 2022, while the proportion of growing firms fell significantly in the year 2020 due to the COVID-19 crisis, while it was as high as 22 percent in the years 2018 and 2019.

As empirical studies have shown for foreign economies, the results confirm that the distribution of productivity within industry is skewed to the right among Slovenian firms. For example, 1,022 firms are operating in industries J62 and J63 (data processing and databases), of which 10 percent of the most successful firms in terms of total value added generate 65 percent of total value added, 56 percent of total turnover and employ 53 percent of the workforce in that industry. The difference between the least productive and the most productive firms in this sector is shown in Figure 4.

Figure 4. Distribution of total factor productivity in industries J62 and J63 in the year 2022



Source: AJPES (2024).

4 Productivity between industries

There are large differences in productivity between firms operating in the same industry –differences within the industry. As other empirical studies have shown, these differences are greater than the differences between industries. However, the differences between Slovenian industries were analysed to show in which industries firms are more successful on average. A quantified indicator was developed based on the Z-score for this analysis.

Since many financial indicators influence industry performance and especially its prospects, the analysis included evaluations of all industries defined by a five-digit SKD number (NACE Rev. 2) with at least five operating firms in the year 2022, according to the values of median value added per employee, median total factor productivity, median investment rate, share of exports, share of growing firms and share of zombie firms. These are some of the most frequently used financial indicators in productivity analyses - see Altomonte and di Mauro (2022).

First, industries were compared based on individual financial indicators. By comparing the total factor productivity (TFP), the most perspective industries were C27.200 (Manufacture of batteries and accumulators), C27.510 (Manufacture of electric domestic appliances) and C28.110 (Manufacture of engines and turbines, except aircraft, vehicle and cycle engines). By analysing the investment activities, the industries M72.110 (Research and experimental development on biotechnology), C13.950 (Manufacture of non-wovens and articles made from non-wovens, except apparel) and C28.140 (Manufacture of other taps and valves) showed the highest median values. Looking at shares of exports, the industries J58.210 (Publishing of computer games), C13.950 (Manufacture of non-wovens and articles made from non-wovens, except apparel), C20.590 (Manufacture of other chemical products) and C28.300 (Manufacture of agricultural and forestry machinery) are the most promising. Lastly, by analysing the share of growing firms, industries C14.120 (Manufacture of workwear), C28.130 (Manufacture of other pumps and compressors), and C26.120 (Manufacture of loaded electronic boards) have the highest potential.

Table 1. Z-score indicator for industry comparison

Industry indicator (5-digit SKD code)	Transformation of values into Z-scores
Median value added per employee	Z-score1
Median total factor productivity	Z-score2
Median investment rate	Z-score3
Median share of exports	Z-score4
Share of growing firms	Z-score5
Share of zombie firms	Z-score6
Sum	Quantified indicator based on Z-score

Note: Z-score values are winsorized at the interval between -3.5 and 3.5; Z-score6 is multiplied by -1.

Furthermore, the values of all six financial indicators mentioned above were considered, so a single quantified indicator was constructed. As shown in Table 1, for each 5-digit SKD code defined industry (NACE Rev.2), values of all indicators were standardised to Z-score and winsorized at the interval between -3.5 and 3.5 (values below -3.5 were replaced by value -3.5, while values above 3.5 were replaced by value 3.5). Z-scores were then summed to create a quantified indicator.

Based on the empirical results, eight potentially prospective industries and corresponding sub-industries scored the highest Z-scores. These are:

- Manufacture of textiles (C13)
  - Preparation and spinning of textile fibres (C13.100)
  - Manufacture of non-wovens and articles made from non-wovens, except apparel (C13.950)
- Manufacture of workwear (C14.120)
  - Manufacture of chemicals and chemical products (C20)
  - Manufacture of industrial gases (C20.110)
  - Manufacture of paints, varnishes and similar coatings, printing ink and mastics (C20.300)
  - Manufacture of glues (C20.520)
  - Manufacture of other chemical products (C20.590)
- Manufacture of pharmaceutical preparations (C21.200)
- Manufacture of rubber and plastic products (C22)
  - Manufacture of plastic plates, sheets, tubes and profiles (C22.210)
  - Manufacture of plastic packing goods (C22.220)
  - Manufacture of builders' ware of plastic (C22.230)
  - Manufacture of other plastic products (C22.290)
- Manufacture of computer, electronic and optical products (C26)
  - Manufacture of electronic components (C26.110)
  - Manufacture of loaded electronic boards (C26.120)
- Manufacture of electrical equipment (C27)
  - Manufacture of electric motors, generators and transformers (C27.110)
  - Manufacture of electricity distribution and control apparatus (C27.120)
  - Manufacture of wiring devices (C27.330)
  - Manufacture of electric domestic appliances (C27.510)
- Manufacture of machinery and equipment (C28)
  - Manufacture of fluid power equipment (C28.120)
  - Manufacture of other pumps and compressors (C28.130)
  - Manufacture of other taps and valves (C28.140)
  - Manufacture of bearings, gears, gearing and driving elements (C28.150)

- Manufacture of ovens, furnaces and furnace burners (C28.210)
- Manufacture of agricultural and forestry machinery (C28.300)
- Manufacture of other machine tools (C28.490)

- Wholesale of pharmaceutical goods (G46.460)
- Scientific research and development (M72)
  - Research and experimental development on biotechnology (M72.110)
  - Other research and experimental development on natural sciences and engineering (M72.190)

5 Statistical analysis of selected industries with possible potential for synergies and creating ecosystems

Three of the most successful and prosperous industries identified by the empirical analysis of financial statements are the manufacture of basic pharmaceutical products and pharmaceutical preparations (C21), the manufacture of electrical equipment (C27), and the manufacture of machinery and equipment (C28). Furthermore, based on the strategic importance, tradition, technological competencies, and the number of employees, the importance of the automotive industry (C29 and C30) has to be highlighted. Finally, the wood processing industries (A02, C16 and C31) could also play an important role in the Slovenian economy, mainly due to the large number of employees working along the vertical chain, the large availability of resources, tradition, and high technological and product competencies. All selected industries are analysed in later chapters of this book to evaluate their true potential for synergies and creating ecosystems.

5.1 Manufacture of basic pharmaceutical products and pharmaceutical preparations (C21)

In 2022, only 14 firms were active in the pharmaceutical industry, contributing 5 percent to the value added of the overall Slovenian economy. The average firm had a value added per employee of €85,471, while the median value was just under €50,000. Both figures have risen significantly since 2017. On average, the firms employed 820 employees (median value was 6). The proportion of growing firms was 14 percent, while the proportion of zombie firms was twice lower (see Table 2). Comparing the productivity of these firms, the firm in the 80th percentile (€143,500) had four times higher value added per employee than the firm in the 20th percentile (€36,150).

Table 2. Description of industry C21

	2012	2017	2022
Total number of firms	10	13	14
Total number of employees	7,087	8,387	11,486
Average number of employees	709	645	820
Median number of employees	5	9	6
Total sales in €	1,704,851,697	2,156,237,735	3,119,955,703
Value added per employee in € (average)	66,470	51,301	85,471
Value added per employee in € (median)	50,457	41,293	49,651
Proportion of value added in the total economy (in percent)	5.0	4.7	5.0
Investments/Value added (average, in percent)	/	24.7	27.9
Proportion of growing firms (in percent)	/	30.8	14.3
Proportion of zombie firms (in percent)	/	23.1	7.1

Source: AJPES (2024).

For a more detailed analysis of the pharmaceutical sector in Slovenia, see Cirman et al. (2024) and Kovač et al. (2024).

5.2 Manufacture of electrical equipment (C27) and manufacture of machinery and equipment (C28)

In 2022, the industries C27 and C28 contributed 6.7 percent to the value added of the entire Slovenian economy and employed 34,952 people. The average firm had a value added per employee of €50,738, while the median value was €6,600 lower. On average, the firms employed 69 employees (the median value was 12). The share of growing firms was 16 percent, while the share of zombie firms was slightly less than 6 percent (see Table 3).

Figure 5 shows that the distribution of total factor productivity is skewed to the right, with a few firms having very high productivity. In contrast, more than half of the firms have below-average productivity. Comparing value added per employee, the firm in the 80th percentile had twice the value added per employee in 2022 (€62,000) than the firm in the 20th percentile (€31,350).

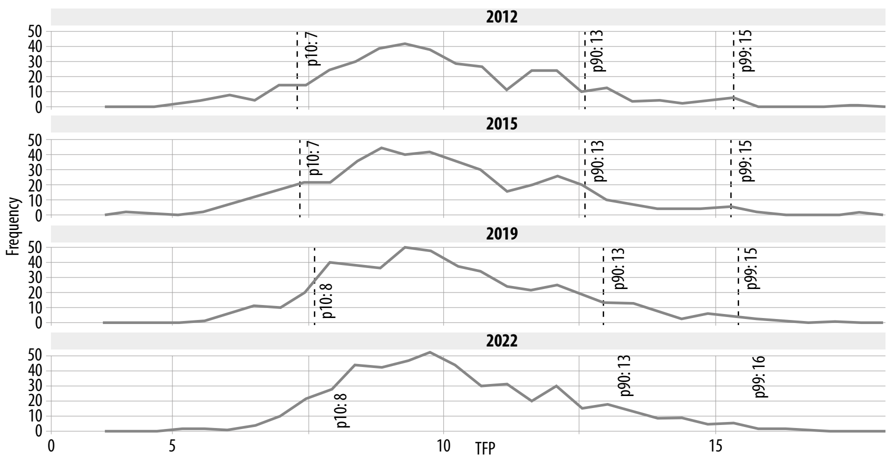
The share of growing firms (see Figure 6) fluctuated between 22 percent (2018) and 10 percent (2020). On the other hand, the proportion of zombie firms remained constant at 5 percent.

Table 3. Description of industries C27 and C28

	2012	2017	2022
Total number of firms	418	478	504
Total number of employees	28,581	32,324	34,952
Average number of employees	68	68	69
Median number of employees	11	10	12
Total sales in €	3,819,897,795	5,071,358,967	8,332,073,057
Value added per employee in € (average)	38,664	44,087	50,738
Value added per employee in € (median)	31,530	35,589	43,435
Proportion of value added in the total economy (in percent)	7.7	7.4	6.7
Investments per value added (average, in percent)	/	19.1	19.9
Proportion of growing firms (in percent)	/	21.5	16.1
Proportion of zombie firms (in percent)	/	4.8	5.8

Source: AJPES (2024).

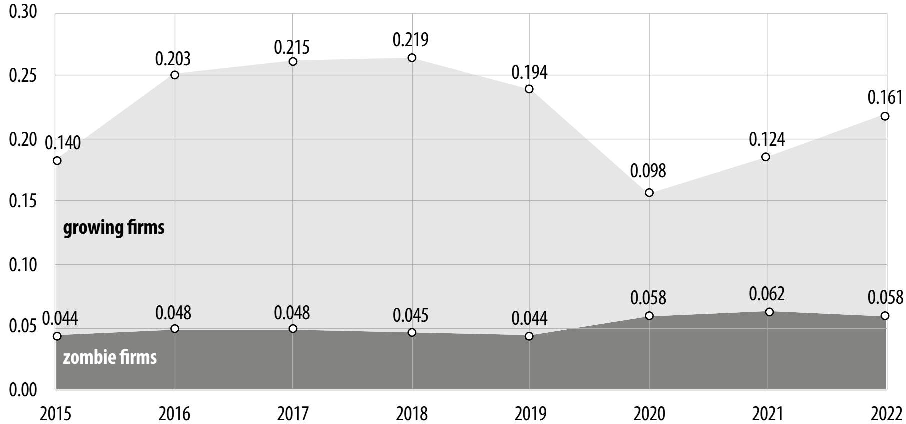
Figure 5. The distribution of total factor productivity within industries C27 and C28



Source: AJPES (2024).

For a more detailed analysis of the C27 and C28 industries, see Domadenik Muren et al. (2024).

Figure 6. The proportion of growing and zombie firms for the industries C27 and C28



Source: AJPES (2024).

5.3 Automotive industry (C29 and C30)

In 2022, the automotive industry, which includes the manufacture of motor vehicles, trailers and semi-trailers (C29) and the manufacture of other transport equipment (C30), contributed 2.8 percent to the value added of the overall economy (down from 3.6 percent in 2017) and employed 14,627 people. On average, firms generated value added per employee of €48,009, while the median value was €38,510. On average, the firms employed 107 employees (the median value was 10). The proportion of growing firms was 18 percent, while the proportion of zombie firms was 12 percent (see Table 4).

Figure 7 shows the distribution of total factor productivity in the automotive industry. When comparing the distribution in 2012, 2015, 2019 and 2022, an interesting pattern can be observed – the distribution is skewed more and more to the right, which means there are fewer and fewer very productive firms, while the median firm is losing its relative position. Looking at the value added per employee in 2022, the firm in the 80th percentile had twice the value added per employee (€58,300) than the firm in the 20th percentile (€27,880).

The share of zombie firms in the automotive industry shows a growing trend between 2015 and 2022, ranging from 3.4 percent in 2015 to almost 12 percent in 2022 (see Figure 8). Similarly, the share of growing firms was around 28 percent between 2015 and 2018, followed by a sharp decline to 12 percent from 2019 to 2020.

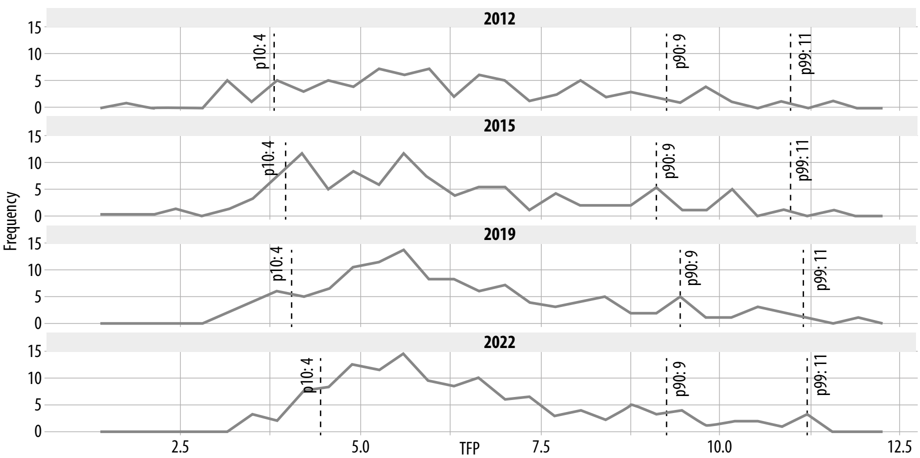
For a more detailed analysis of the automotive industry in Slovenia, see Končan et al. (2024).

Table 4: Description of industries C29 and C30

	2012	2017	2022
Total number of firms	100	127	137
Total number of employees	9,829	13,610	14,627
Average number of employees	98	107	107
Median number of employees	7	10	10
Total sales in €	2,070,742,204	3,497,122,293	3,562,750,436
Value added per employee in € (average)	27,836	33,869	48,009
Value added per employee in € (median)	27,103	31,705	38,510
Proportion of value added in total economy (in percent)	2.9	3.6	2.8
Investments per value added (average, in percent)	/	24.5	21.5
Proportion of growing firms (in percent)	/	28.3	17.5
Proportion of zombie firms (in percent)	/	5.5	11.7

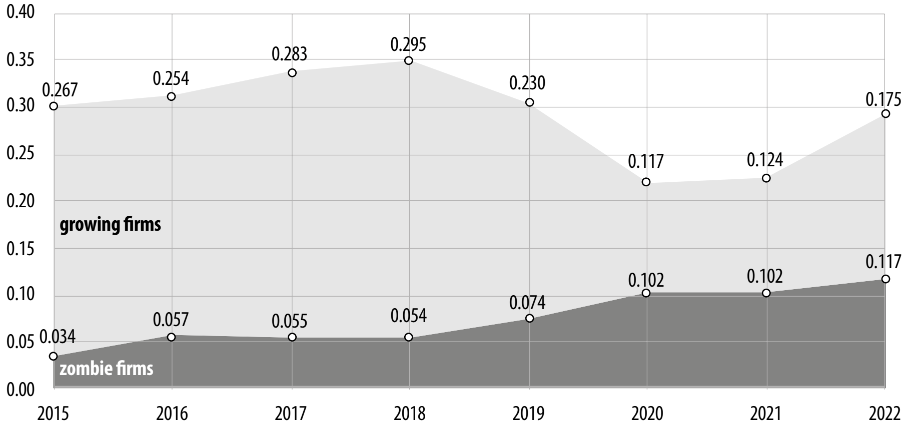
Source: AJPES (2024).

Figure 7. The distribution of total factor productivity within industries C29 and C30



Source: AJPES (2024).

Figure 8. The proportion of growing and zombie firms for the industries C29 and C30



Source: AJPES (2024).

5.4 Wood processing industries (A02, C16 and C31)

The wood processing industries comprise the activities defined under NACE Rev.2 codes A02 (Forestry and logging), C16 (Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials) and C31 (Manufacture of furniture). This definition covers the entire value chain, from the cultivation and harvesting of wood raw materials to the manufacture of wood products and furniture.

In 2022, the wood processing industries contributed 2.2 percent to the value added of the overall Slovenian economy and employed more than 12,500 people. On average, the firms generated value added of €42,861 per employee and had 20 employees, with a median value of 7 (see Table 5).

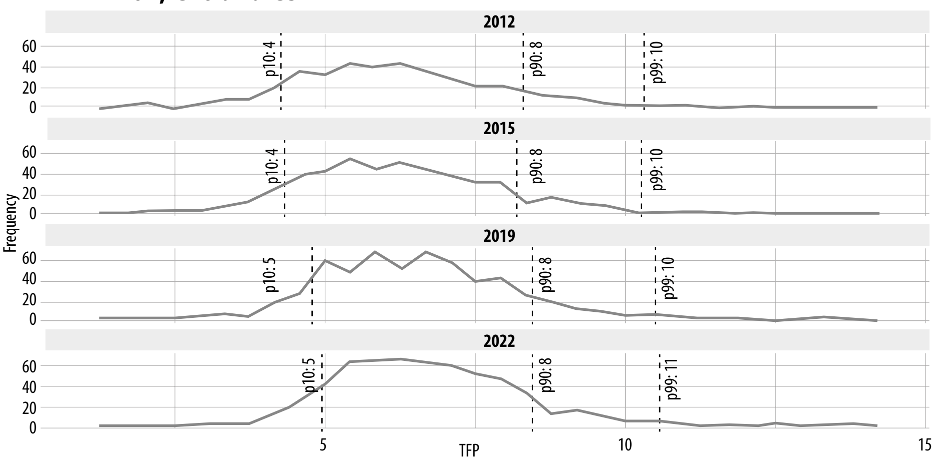
The distribution of total factor productivity in the wood processing industries follows the general pattern that can also be observed elsewhere – a high degree of skewness to the right, which becomes even more pronounced in the later periods (see Figure 9). Comparing the value added per employee in 2022, the firm in the 80th percentile had twice the value added per employee (€51,500) than the firm in the 20th percentile (€25,300).

Table 5. Description of industries A02, C16 and C31

	2012	2017	2022
Total number of firms	462	563	619
Total number of employees	8,490	10,603	12,533
Average number of employees	18	19	20
Median number of employees	5	7	7
Total sales in €	807,434,131	1,283,321,867	2,030,654,847
Value added per employee in € (average)	28,008	32,364	42,861
Value added per employee in € (median)	23,786	26,166	34,196
Proportion of value added in total economy (in percent)	1.8	2.0	2.2
Investments per value added (average, in percent)	/	20.3	19.2
Proportion of growing firms (in percent)	/	21.7	19.5
Proportion of zombie firms (in percent)	/	5.2	4.2

Source: AJPES (2024).

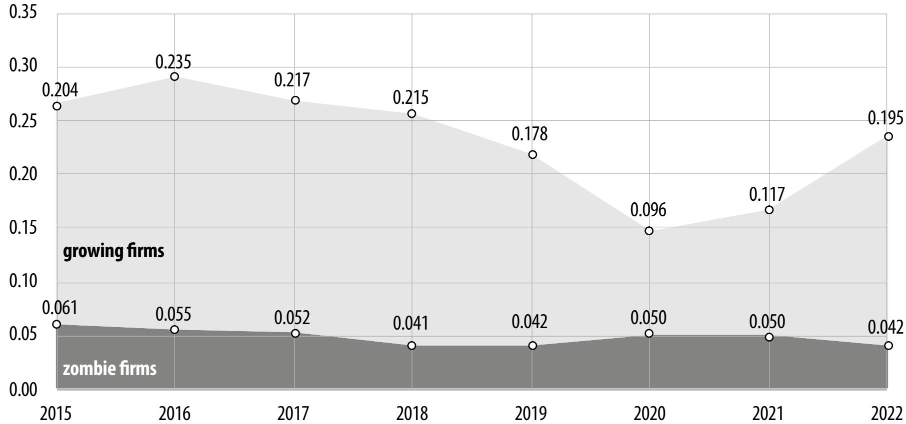
Figure 9: The distribution of total factor productivity within industries A02, C16 and C31



Source: AJPES (2024).

The share of growing firms fell significantly in 2019 and 2020, when it reached only 10 percent, and has risen again rapidly in the last two years. Positively, the share of zombie firms is declining. In 2022, it reached its lowest level of 4 percent (see Figure 10). For a more detailed analysis of the wood processing industry in Slovenia, see Čater et al. (2024).

Figure 10. The proportion of growing and zombie firms for the industries A02, C16 and C31



Source: AJPES (2024).

6 Conclusion

The empirical analysis showed that the distribution of productivity in most Slovenian industries is highly skewed to the right, as is also the case in foreign economies. By creating quantified indicators, the prospects of Slovenian industries, defined by NACE Rev. 2 classification, were assessed in terms of value added per employee, total factor productivity, investment rate, export share, share of growing firms and zombie firms. Finally, the potential for synergies and the creation of ecosystems were also considered.

Three sectors have been identified – the manufacture of basic pharmaceutical products and pharmaceutical preparations (C21), the manufacture of electrical equipment (C27) and the manufacture of machinery and equipment (C28). In addition, the importance of the automotive industry (C29 and C30) was emphasised due to its strategic importance and the number of employees. Finally, the wood processing industries (A02, C16 and C31) could also play an important role in the Slovenian economy. Further analyses of the proposed industries are presented in later chapters of this book, focusing on the results of qualitative research obtained by visiting the most important firms in each listed industry.

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PHARMACEUTICAL SECTOR IN SLOVENIA: ECOSYSTEM IN THE GENERIC PHARMA SECTOR

1 Introduction

The pharmaceutical industry plays an important role globally in the development, production, and commercialisation of medicines. It is structured around three primary types of products covering original medications, which are newly developed drugs protected by patents; biosimilars, which are highly similar versions of biologic drugs that have lost patent protection; and generics, which replicate the active ingredients of original drugs at a lower cost once patents expire (OECD, 2023). In Slovenia, the pharmaceutical sector is a key component of the national economy, reflecting the country's commitment to both innovation and healthcare. Slovenia is home to a well-established pharmaceutical ecosystem that includes the production of generic drugs, biosimilars, as well as original small and large molecule medications. Major companies like Krka and Lek (a subsidiary of Sandoz) contribute significantly to this landscape, manufacturing generics and biosimilars that serve domestic and international markets. Novartis focuses solely on original medications. The country's pharmaceutical industry is well-integrated into global supply chains, making Slovenia a growing hub for pharmaceutical development and production. This position is further emphasised considering the recent Biotech Hills initiative, which supports strong biotechnological and pharmaceutical development and establishes Slovenia as a top location for biotech investments (STA, 2024).

Slovenia's pharmaceutical industry, covering originals and generics, is well-known for its substantial foreign direct investments (FDI) and robust export results. The most significant investment is a €500 million biosimilars production project by Sandoz in Lendava (Lek, 2023), which is by far the biggest investment ever received by the country. With a few other investment activities, they highlight Slovenia's appeal to foreign direct investment and its function in raising output levels to keep up with the rising global demand. However, a key competitive advantage of the Slovenian market lies in the qualified workforce, where Slovenia achieved a high ranking in the number of PhD degrees earned each year, with an average of around 500 new doctorates each year (Stat.si, 2019; World Population Review, 2024), which means 250 doctorates per one million inhabitants. In perspective, the average number of doctorates in the USA was around 55,500 in the previous years, translating to approximately 167 doctorates per one million inhabitants (Falkenheim, 2021).

This chapter aims to provide an overview of the Slovenian pharmaceutical sector, highlighting its current standing in the global market. It then evaluates the position of generic and biosimilar pharmaceuticals in Slovenia, identifying the competitive advantages that can be leveraged for future growth in the industry.

2 Overview of the pharmaceutical industry

The pharmaceutical industry, classified under NACE code C21, which pertains to the manufacturing of basic pharmaceutical products and preparations, plays an important role in the Slovenian economy. The industry categorises medicines into generics, biosimilars, and originators, further explored by Došenovič Bonča and others (2024).

In Slovenia, the leading companies in the generic sector are Krka and Lek, with Lek increasingly shifting its focus toward the production of biosimilar medicines. Recently, as Slovenia's strategic response to improve Europe's economic resilience, sustainability, and innovation, the Slovenia Biotech Hills initiative and the Government of the Republic of Slovenia have signed a letter of intent for a joint commitment to the development of a complex ecosystem in the field of biotechnology and pharmaceuticals. The Slovenia Biotech Hills initiative aims to become the most attractive destination for biotech investments, development, production and education (to promote knowledge-sharing and build supportive legislation). Its central European location and strong security provide an ideal growth environment. As Slovenia's first initiative of this kind, Biotech Hills focuses on strategic partnerships, global recognition, and continuous innovation (STA, 2024).

From the latest data (see Table 1), the Slovenian pharmaceutical industry generated approximately €3.4 billion in revenue in 2023 (EFPIA, 2023). The latest data shows Slovenia allocated 0.45 percent of its GDP for pharmaceutical research and development (R&D) in 2021. In comparison, Germany and Austria both allocated less than one percent of GDP to the pharmaceutical industry R&D directly (Table 1).

Table 1. Comparison of the Slovenian, Austrian and German pharmaceutical industries in 2023

Country	Slovenia	Austria	Germany
Sales in 2023, in billion €	3.4	7.2	47.53
Production value of the industry in relation to GDP, in percent (2021)	5.42	1.03	1.67
R&D expenditures, in million € (percentage of contribution to GDP, 2021)	230 (0.45)	283 (0.06)	8,540 (0.20)
Number of employees (percentage of all employees)	13,090 (1.40)	19,000 (0.42)	123,475 (0.27)
CAGR (2024-2029), in percent	3.75	4.36	4.77
Trade balance relative to GDP, in percent	4.21	0.12	0.82

Source: EFPIA (2023); Migration.gv.at (2023); SiStat (2023); Statista (2021a, 2021b, 2024a, 2024b).

Slovenia's pharmaceutical industry contributed 2.5 percent to the national GDP in 2023 in terms of value added (SiStat, 2024) and is projected to grow at a compound annual growth rate (CAGR) of 4 percent between 2024 and 2029 (Statista, 2024b). This growth rate will exceed the overall economic growth rate, which is expected to increase more slowly, at 1.5 percent over the next two years (UMAR, 2024). Similarly, the pharmaceutical sector in the European Union is expected to grow at a comparable rate, driven by increasing healthcare demand, rising costs, an ageing population, and ongoing innovation in drug research and development (EFPIA, 2023). In relative terms (production per capita), Slovenia is one of the five largest drug-manufacturing countries in Europe (EFPIA, 2023). The high productivity level reflects the advanced state of Slovenia's pharmaceutical manufacturing capabilities, likely driven by a well-educated workforce, the use of advanced production technologies, a focus on high-value generic drug production, and successful expansion into biotechnology with the production of biosimilar medical products (Lek, 2023). As seen from Table 1, in 2021, the pharmaceutical industry in Slovenia contributed more to the GDP than Austria and Germany in terms of its production value relative to the GDP – indicating the importance of the industry in Slovenia.

The Slovenian pharmaceutical industry employed 13,090 people, which is approximately 1.40 percent of the country's total employment (Table 1). Over the last ten years, employment in this industry has shown resilience and a significant increase of 40 percent (Dun & Bradstreet, n. d.), indicating the industry's stability and continued expansion efforts. Austria and Germany have less than one percent of the population employed in the pharmaceutical industry (Table 1).

The pharmaceutical trade balance in Slovenia remained positive, with €2.6 billion, or 4.21 percent relative to the national GDP, and exceeding the trade balance of the Austrian pharmaceutical industry (€550 million), with 0.12 percent relative to the country's GDP. The trade balance for the pharmaceutical industry in Germany accounted for €33 billion, which corresponds to 0.82 percent relative to the country's GDP in 2023 (EFPIA, 2023). The strong export performance in Slovenia is primarily driven by the three largest corporations (Krka, Lek as part of Sandoz, and Novartis), which are also significant players in the global pharmaceutical industry. Lek and Krka mainly represent generics, Lek is also a key player in biosimilars and Novartis specialises in innovative pharmaceuticals (Krka, 2023; Lek, 2022). Originators like Novartis lead the market in drug innovation with substantial investments in R&D and patent-protected exclusivity. Generics like Lek and Krka also invest in R&D but to a lesser extent, as they focus more on the cost-efficient production of established drugs, making healthcare more accessible. Biosimilars, like those from Lek, offer an emerging middle ground, addressing the high costs of biologics by providing near-identical, affordable alternatives once patents on original biologics expire (OECD, 2023).

Slovenia's entire pharmaceutical industry, encompassing generics, biosimilars and originators, has established itself as a significant destination for foreign direct investment (FDI). It has been identified as one of Slovenia's most attractive industries for FDI (Slovenia Business, 2024). Sandoz's €500 million investment over the next three years in a new facility in Lendava, dedicated to producing biosimilar medicines, will generate 300 new jobs. They also announced a $90 million investment in a new biosimilar technical development centre in Ljubljana (Lek, 2023). Furthermore, in 2022, Novartis invested €111 million to expand its production facilities in Ljubljana and develop its Biocampus in Mengeš. As a result of this action, Slovenia will be Novartis' and Sandoz's largest regional location for manufacturing biological medicine products. These investment patterns are essential to keep Slovenia's competitive advantage in the international pharmaceutical industry. Such investments support Slovenia's ongoing growth by increasing production capacity and meeting the rising demand for pharmaceutical products (Novartis, 2023). Global corporations such as Novartis and Sandoz have played a critical role in advancing the industry by transferring technology innovation and creating jobs. The Biocampus expansion alone is expected to generate around 100 new job opportunities. Between 2022 and 2025, more than €1 billion will be invested in Slovenia's pharmaceutical industry, further expanding both originator and biosimilar output and innovation (Slovenia Business, 2023).

3 Value chain in the generic pharmaceutical industry

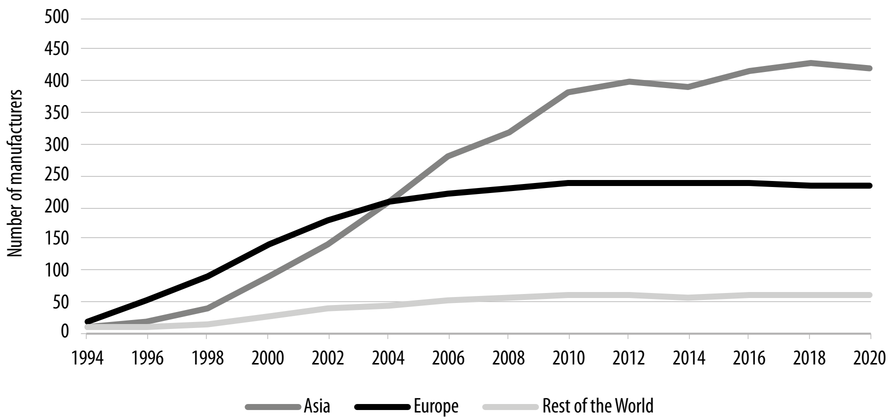
Generally, the pharmaceutical value chain has three main components: manufacturing, distribution, and dispensing. Manufacturing includes the initial R&D phase, regulatory approval, and product commercialisation. Distribution covers transportation from manufacturer to the end user. The last step is dispensing, which ensures the correct dosage to the right patient in a timely manner. Depending on the type of medicine, the distribution channel, reimbursement regulation, or geographic region, the components of the value chain can differ between and within markets (Aitken, 2016).

Generic value chains are shorter and simpler than those for innovative medicines due to a less extensive R&D phase. This simplification leads to fewer steps and external dependencies, making the process more streamlined and cost-effective, posing its own challenges (Antaloczyt et al., 2019). As medicines become generic, market entrants and competition increase, leading to decreased prices and eroded profit margins. This "commoditisation loop" often pushes production to lower-cost locations, creating vulnerability to shortages and susceptibility to low reinvestment (Sardella, 2023).

On the other hand, the value chain for biosimilars is similar to that of generics but with additional complexities due to their biological nature. Biosimilars are similar but not identical to their reference biological, complicating the manufacturing process. This complexity stems from the need for extensive clinical studies to demonstrate bioequivalence, safety, potency, and efficacy, which takes longer and costs more than traditional generics. Regulatory approval for biosimilars is stricter than for small-molecule generics, requiring proof that the biosimilar has no clinically significant differences from the reference biological. Distribution presents additional challenges because biosimilars require careful handling and storage to maintain stability, which adds to the logistical complexity of their value chain. Overall, the biosimilar value chain is similar to that of generics, but it faces additional challenges in manufacturing, regulatory approval, and distribution, resulting in higher costs and longer timelines (Schneckel & Rajkumar, 2021).

The pharmaceutical industry is highly globalised, which complicates the value chain. The reliance on international or global value chains (GVCs) means that multiple actors in different parts of the world are involved in producing a single ingredient. This global distribution can affect the resilience of pharmaceutical manufacturing chains and contribute to their fragility (Antaloczyt et al., 2019). The fragility of global supply chains was highlighted during the COVID-19. As a result, major global players in the pharmaceutical industry, including the European Union, the United States and China, were forced to reconsider their policies and strategies.

Figure 1. Development of the number of active manufacturers of active pharmaceutical ingredients (API)



Source: Adapted from Progenerika (2020).

In general, the pharmaceutical sector in the European Union contributes significantly to the EU's economy by producing highly skilled jobs and investing in innovation. Therefore, the European Commission (2020) launched the Pharmaceutical strategy to strengthen the industry. The plan is to provide a stable and adaptable regulatory environment that ensures legal certainty for investors, adapts to technological trends, and promotes competition, particularly in the generic and biosimilar medicines industry. Such drugs play a vital role in providing patients with affordable treatments while also creating cost savings for health systems due to their positive effect on pricing competitiveness (European Commission, 2022). However, in the last two decades, the EU's capacity to produce large volumes of off-patent medicines and active pharmaceutical ingredients (APIs) has stagnated, and its global production share has declined (Figure 1). That is why some stakeholders suggest that the EU should strengthen its industrial capability to contribute to the diversity of global supply chains while also ensuring supply continuity and security (European Commission, 2022).

The EU Directorate-General for Health and Food Safety proposed a reform in 2023 to ensure that patients across the EU have timely and equitable access to safe, effective, and affordable medicines. The proposal focuses on improving the security of supply, eliminating shortages, and making the pharmaceutical industry more competitive and innovative. Key measures include stronger obligations on marketing authorisation holders to notify potential or actual shortages as well as marketing withdrawals, cessations, and suspensions, which will improve supply chain resilience, especially given the EU's reliance on Asian API producers (Directorate-General for Health and Food Safety, 2023). The reform also includes initiatives to simplify regulatory procedures and boost digitalisation, which include provisions related to the electronic submission of applications for marketing authorisation and electronic product information (ePI) on authorised medicinal products. These actions are expected to reduce the regulatory burden on companies and support innovation in the pharmaceutical sector (Directorate-General for Health and Food Safety, 2023). These directions also offer opportunities for Slovenia's pharmaceutical industry to strengthen its position in the European market.

Similarly, the US government recognises the risks of relying on foreign sources, notably from China, for APIs. Mandatory reporting on the location, production volumes, and dependency on API manufacturers has been implemented alongside requirements for reporting projected shortages (since 2007, drug shortages have been a recurring issue, with over a hundred medicines being reported annually). This data would allow the Food and Drug Administration (FDA) to develop a dynamic map to track potential shortages or quality concerns (Webb Kosloff, 2024).

Despite expectations that the prices of innovative medicines will decline after their patent runs out and they are approved by the FDA to go on the market as generic drugs in the USA, generic drug prices have risen over the last decade due to increased costs and shortages (Gupta et al., 2019). Governmental interventions like prioritising essential generics, developing national inventories, and forming nonprofit public-private partnerships are recommended to maintain supply stability. These efforts may involve domestic production of prioritised generics to reduce geographical risks (Jarsulic, 2024). The FDA's Drug Competition Action Plan (DCAP), launched in 2017, intends to streamline regulations for complex generics, reducing development time and costs (FDA, 2024). As part of these efforts, the Office of Generic Drugs collaborates with international regulatory bodies to unify scientifically driven worldwide standards, reducing duplication of research and testing. In 2023, the FDA released unified guidance for generics on bioequivalence for immediate-release solid oral dosage forms, further supporting the efficient approval and distribution of generics (Murphu, 2024).

Not only are overseas pharmaceutical companies incorporating China into their global registration strategies, but local companies are also seeking to expand their presence in international markets. China is rapidly updating its drug regulations to accelerate medication reviews and approvals in line with the rapidly growing scientific innovation and R&D (Liu et al., 2022). One of the regulatory innovations in China is the Generic Consistency Evaluation (GCE), introduced in 2015, which mandates bioequivalence tests to enhance the quality of domestic generic drugs (Gov.cn, 2018). These efforts align with the State Council's Circular No. 20, which encourages the development and quality of generics. The policy supports the generic drug industry by offering preferential treatment of high-quality generics in public hospital tenders and encourages patentees to grant licenses to Chinese manufacturers. It also incentivises the development of high-priority generics, such as those for orphan or pandemic diseases, through research grants and tax benefits while tightening approval standards to ensure generics match the quality of originator products (Wang, 2018).

4 Slovenian pharmaceutical ecosystem

4.1 Krka and Lek as the leaders in generics in Slovenia

Slovenia has a relatively long history of a successful pharmaceutical industry. The sector is dominated by generic pharmaceuticals, with Lek and Krka being the leading players. These companies have ensured the country's strong presence in international markets and made substantial contributions to Slovenia's GDP and employment. Lek was established in 1946, immediately after World War II (Lek, 2024). Krka followed eight years later, and both companies remain highly successful to this day (Krka, 2024). In 2002, Novartis acquired Lek, which was a strategic acquisition, as Novartis wanted to enhance Lek's strength in this part of the world. In 2023, Sandoz was spun off from Novartis, shifting exclusively to generics and biosimilars, while Novartis continues to focus on original, innovative medicines. As part of Sandoz, Lek remains dedicated to developing and producing generics and biosimilars (Lek, 2024).

Lek is a leading manufacturer of generic and similar biological drugs, with a particular focus on the development of biosimilars. The company has a portfolio of 11 biosimilars, contributing to its success in the global market. Biosimilars involve higher costs but also offer higher margins than traditional generics, which generally have smaller market potentials. The products manufactured at Lek in 2023 were destined for the European market (71 percent), the Asian market (11 percent), North America (8 percent), and other regions of the world (10 percent). Lek once again generated the majority of its sales with pharmaceutical products (86.2 percent of product sales), while the remaining 13.8 percent came from other products (active ingredients and biopharmaceutical products). Lek is a Sandoz company and Sandoz provides treatments for over 500 million people worldwide per year (Sandoz group, 2023). In 2023, Lek began constructing a high-tech centre for biosimilar production in Lendava. A new biosimilar development centre will also be built in Ljubljana (Lek, 2023).

On the other hand, Krka is a leading generic pharmaceutical company based in Novo mesto, Slovenia, with production sites in Slovenia, Croatia, Poland, Germany and Russia. Its medicines are available in over 70 markets worldwide, serving over 100 million people. Their portfolio includes a wide range of medicines, covering treatments for cardiovascular diseases, diabetes, the central nervous system, gastrointestinal conditions, and oncology. Krka also manufactures veterinary medicines and self-care products. It has a strong presence in Eastern European markets, generating most of its revenue there, including Russia and Ukraine. It also records growth in Central and Western Europe as well as Southeast Europe, where sales increased by more than 10 percent in 2023. Despite challenges in global markets, Krka continues to report steady sales and profit growth, which is positive for investors. They export 94 percent of products, positioning Krka as a global player in the generic pharmaceutical market. It forecasts continued growth and expansion, with planned investments of €150 million in 2024 (Krka, 2023).

In comparing the financial performance of Krka and Lek, distinct patterns emerge that highlight their differing strategic focuses and operational efficiencies.

Table 2. Financial and operational performance of Krka and Lek in 2023

	Krka	Lek
Sales (in billion €)	1.674	1.595
Number of employees	11,667	2,895
Return on assets (ROA, in percent)	11.3	11.8
Return on equity (ROE, in percent)	11.3	17.5
Net profit margin (in percent)	17.59	8.51
Value added per employee (in €)	128,145	114,445
CAGR 5Y Sales (in percent)	6.33	8.49
CAGR 10Y Sales (in percent)	1.69	4.11

Source: Dun & Bradstreet (n.d.).

In Table 2, Krka, with annual sales of €1.67 billion and a workforce of 11,667 employees, demonstrates strong profitability, evidenced by a net profit margin of 17.59 percent and value added per employee of €128,146. These indicators reflect Krka's operational scale and efficiency in turning revenue into profit. However, despite having fewer employees (2,895) and slightly lower sales (€1.59 billion), Lek surpasses Krka in key efficiency metrics, such as return on assets (ROA) of 11.8 percent and return on equity (ROE) of 17.5 percent. Lek's 5-year CAGR (compound annual growth rate) of 8.49 percent and 10-year CAGR of 4.11 percent underscore its stronger growth trajectory, likely driven by its focus on high-value segments like biosimilars under the Sandoz umbrella. This comparison highlights Krka's superiority in profitability and operational scale, while Lek excels in growth potential and asset utilisation, positioning both companies uniquely in the competitive pharmaceutical landscape.

4.2 Methodology of empirical research

The empirical analysis is based on in-depth interviews in four companies, conducted between 29 August and 5 September 2024, with six selected executives. Interviews covered different parts of the pharmaceutical value chain, focusing on generics and biosimilars. Some of the best-performing companies under the C21 classification were selected, as well as those working closely with the companies in C21. Table 3 provides an overview of these companies and the interviewees. While the core questions remained consistent across all companies, some were customised to address specific aspects of each company's operations.

Table 3. Sample characteristics

Company	Type of company	Interviewees	Interviewee's code
Company 1	Private ownership	General manager	GENERICS1-1
		Sales program manager	GENERICS1-2
Company 2	Start-up	Organisational unit head	GENERICS2
Company 3	Multinational subsidiary	General manager	GENERICS3-1
		Organisational unit head	GENERICS3-2
Company 4	Private ownership	General manager	GENERICS4

Source: Own work (2024).

4.3 Findings

What makes Slovenia and its pharmaceutical industry particularly appealing to foreign investors is not low taxes or a vast market. *"Tradition, the people and the knowledge they gathered and the history they built in the last 60 years. You see, it is not the market size, low costs, or taxes that make Slovenia interesting. What adds the most value are the people"* (GENERICS3-1).

The strength of a brand of both large pharmaceutical companies in this region can significantly motivate employees and foster a sense of pride in belonging to a recognised and respected company. Despite this, many companies face challenges in maintaining competitiveness due to tax burdens, especially in higher tax brackets where key professionals work, e.g., in development teams. Compared to countries like Austria and Germany, where employees receive higher net salaries, this can make it difficult to retain talent. To address this, companies often form strategic partnerships with educational institutions to promote their work and attract young talent. *"Slovenia is very good precisely because of pharmacists and 50 years of tradition in natural sciences, chemistry, pharmacy, and biotechnology. One half went to Lek and Krka, and the other half to something else"* (GENERICS2). They offer students the option of working as students, intending to employ them later. *"Usually, we have students with us working for a few months, or up to a year if they are extending their studies, with the goal of employing them afterwards. A significant part of our newly hired engineers come directly from universities"* (GENERICS1-1). In addition, they may encourage professionals who have gained experience abroad to return by offering attractive employment packages and growth opportunities. This environment is especially appealing to young families, as these companies offer favourable working conditions for both personal and professional development. *"Firstly, this is a safe work environment. Safety is the top priority. Secondly, we want to include everyone in our environment. We aim to provide every individual with the opportunity to feel good and develop the best version of themselves"* (GENERICS3-2). Foreign experts are often recruited to fill specialised roles, especially from countries where the necessary skills are more readily available. Companies also prioritise linguistic diversity and adapt work processes to create multilingual environments accessible to employees from different cultural backgrounds. While regional cooperation (e.g., attracting talent from neighbouring countries) can be effective, there are challenges in integrating workers from more distant regions due to language and cultural differences.

One of Slovenia's main investment advantages is the concentration of knowledge, expertise, and equipment in a single location. This ecosystem connects established industries, universities, scientific institutes, and centres of excellence and provides fertile ground for spin-off companies, start-ups, and successful fast-growing global companies. The three most important scientific institutions in Slovenia, the Jožef Stefan Institute, the National Institute of Chemistry and the National Institute of Biology, are all involved in basic research in areas connected to pharmacy (Slovenia Business, 2020). In the years 2023 and 2024, multinational pharmaceutical companies with subsidiaries present in Slovenia announced big investments in the biotechnological sector, including a new high-tech production centre for biosimilars in Lendava and development in Ljubljana (Lek, 2023) and a Center for Biologic Technical Development in Mengeš (Novartis, 2023). The mentioned ecosystem allows at least 50 percent of planned investments to remain within the country. *"While certain specialised services or machinery may only be sourced globally, much of the construction, engineering work and automation is handled by Slovenian companies. In projects like the one in Lendava, many local companies typically contribute to building the infrastructure, covering everything from plant design, construction works, electrical and mechanical installations, automation to validation. This local support, infrastructure, and expertise allow for efficient project execution, enabling rapid response and collaboration"* (GENERICS1-1). This development creates an advantageous environment for workers and pharmacists within the Slovenian pharmaceutical ecosystem.

The Lendava investment by Sandoz, where they will build a new biosimilar API production plant, is most related to the production of generics. After the split with Novartis, Sandoz's investments focused on quickly developing their capacities. A thorough due diligence process was conducted globally, and Slovenia was chosen over other strategically important locations. Several factors contributed to this decision. Firstly, Slovenia's political environment was appealing, providing state-level support to investors rather than just regional support. Slovenia's responsive politics, similar to Singapore, contrasted with the slower processes in larger countries like Germany. Slovenia's system, while not without issues, was very investment-friendly, with strong support from the Ministry of Economy in this case. *"Slovenia, as a small country, offers support to investors at the national level, not in the area of a federal land or an area or a region, but basically in the area of the country. Slovenian politics is also very responsive. Things can change very quickly. Germany, for example, needed much longer for various agreements than here in Slovenia. Singapore is also an example of a very small country that is very responsive. There, you can talk to the prime minister of the government overnight"* (GENERICS3-1).

One of the main reasons why Lendava attracted the largest investment in Slovenian history from private investors was due to its strategic location at the intersection of Austria, Hungary, Croatia, and Slovenia. *"It will be the Silicon Valley of Slovenia"* (GENERICS4). This location provides strong access to skilled personnel and university networks, including Graz, Budapest, Maribor, and Zagreb. The local community support in Lendava was critical, with the mayor initially finding such a large investment surprising. These factors, including Slovenia's open system and strong legislative support, played a significant role in the successful investment strategy. Slovenia's system allows for direct and responsive communication between ministers and the prime minister, which contrasts sharply with other countries. This responsiveness and legislative support were crucial in securing and facilitating these investments (Lek, 2023; Portal GOV.SI, 2023).

With the continued development of biosimilar pharmaceutical industry in Slovenia, new positions will emerge, with at least 300 new ones planned, requiring updated and specialised knowledge (Lek, 2023). *"The Slovenian government has shown strong openness to foreign investments, demonstrating responsiveness and adaptability. One key advantage of Slovenia's smaller system is its ability to quickly implement educational adaptations, particularly in pharmacy programs, ensuring that professionals are equipped with the necessary skills"* (GENERICS3-2). This adaptability is a crucial factor in the ecosystem, where not only the government but all stakeholders, including educational institutions and industry partners, contribute to fostering a supportive environment for growth. As Lek and Krka developed and evolved, so did the pharmaceutical industry in Slovenia and everyone around them. As the need for R&D and production within these two companies grew, other Slovenian companies offering equipment, optimisation processes, transport, and other things needed for pharmaceutical production grew. Employees within this ecosystem have continuously learned from one another, collaborating to find solutions to create new companies, roles, and departments within existing companies.

As Slovenia aspires to become a leading biotech hub, the support of its ecosystem will be crucial. The joint efforts aim to position Slovenia as the most attractive destination in Europe for research and development, production, and investment in start-ups as well as small, medium, and large companies in biotechnology and pharmaceuticals. These fields present a unique opportunity to connect stakeholders within Slovenia and across Europe, highlighting the country's excellent geographical location, natural resources, and safety as key advantages for companies looking to invest. This transformation aligns with investor interests and Slovenia's green transition policies, as biotechnology plays a pivotal role in enabling sustainable practices. *"From all of this, looking at pharmaceuticals and biotechnology, I do not think the green transition will change biotechnology, but that biotechnology will make it possible"* (GENERICS2).

Biosimilars and generics offer significant savings for healthcare systems, however biosimilars are allowing funds to be redirected toward innovative treatments that improve patient outcomes. "*Most of the pharmaceutical industry will go into biosimilars, so biopharmaceuticals are changing how we treat people. And so many new products will come on the market in the next couple of years, maybe 5 to 10 years. It will also totally change how the health system works and the quality of treating people. The quality of life of people will be changed significantly"* (GENERICS4). Some pharmaceutical companies even require their contractors to align with their green practices. *"Before we signed a contract with them, they said, if we would like to work for them, we have to be we have to be compliant [with ESG standards], with at least 80 percent of the business "* (GENERICS4). In 2004, Lek opened the first biopharmaceutical production site in Mengeš, Slovenia, and in 2007, the development centre for biopharmaceuticals followed (Lek, 2024). With the upcoming investment in both Ljubljana and Lendava, Lek will expand its biosimilar manufacturing capabilities, adding substantial value to an industry primarily focused on the research and development of generic drugs (Portal GOV.SI., 2024). Table 4 summarises the key findings of the research.

Table 4. Summary of key empirical findings on generic and biosimilar pharmaceuticals

Topic	Findings
Value added by tradition	• Several decades of tradition, knowledge, and skilled workforce. • The majority of new hires come from university partnerships and student programs. • Technological and production competence.
Development of the biotechnological ecosystem	• Collaboration between pharmaceutical companies, universities, and research institutes results in a solid innovation ecosystem. • Sandoz is investing in biosimilars, including a high-tech plant in Lendava and R&D centre in Ljubljana. • 50 percent of planned investments remaining in Slovenia. • Inclusion of local businesses in the biotechnological ecosystem.
Talent retention and development	• Higher tax burdens on salaries compared to Austria and Germany. • Low employee turnover rate in the pharmaceutical industry. • Foreign experts filling specialised roles. • Young families benefit from safe and inclusive workplaces that promote personal and professional development.
Policy and government support	• Responsive Slovenian government. • Ministry of Economy promotes quick investment processes through strong foreign investment support. • Education programs adapted to meet industry needs in pharmaceuticals and biotechnology.

Source: Own work (2024).

5 Conclusion

Slovenia's pharmaceutical industry stands as a key pillar of its economy, contributing significantly to its GDP, employment, and trade balance. Compared to Austria and Germany, Slovenia's pharmaceutical sector plays a much more prominent role in the national economy. It contributes a higher percentage to the GDP and employs a larger portion of the workforce. Additionally, Slovenia's pharmaceutical trade balance, as a percentage of the GDP, is notably stronger than that of Austria and Germany. Leading companies such as Krka and Lek are at the forefront of production and export, with Lek increasingly focusing on biosimilars. Recent strategic initiatives, like the Slovenia Biotech Hills, and significant foreign direct investments from global players like Novartis and Sandoz, highlight Slovenia's commitment to becoming a biotech innovation hub. These factors, combined with robust R&D investment and ongoing expansion, position Slovenia's pharmaceutical industry for continued growth and a competitive edge in the global market. In Slovenia, Krka is a key player in generics alongside Lek, which is also a pioneer in biosimilars. Krka is noted for its large scale and strong profitability, while Lek focuses on high-value biosimilars and has shown impressive growth. Financially, Krka excels in profitability and scale, while Lek's growth and efficiency stand out.

Interviews with industry experts reveal that Slovenia's strong tradition, skilled workforce, and supportive political environment make it an attractive location for pharmaceutical investment. The country's collaboration between established companies, research institutions, and start-ups fosters innovation and growth. Slovenia is emerging as a biotech hub, with significant investments in high-tech facilities and research centres.

Global supply chain issues, highlighted during the COVID-19 pandemic, have led regions like the EU and the USA to rethink their strategies to boost resilience and competitiveness in pharma production.

Overall, Slovenia's pharmaceutical industry, supported by its leading companies and a growing ecosystem, is well-positioned for future advancements and global impact. Its blend of tradition, expertise, and innovation highlights its strategic role in the evolving world of pharmaceuticals and biotechnology.

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SUSTAINABILITY IN PHARMACEUTICAL COMPANIES: A COMPARATIVE ANALYSIS

1 Introduction

Sustainability has emerged as a critical concern worldwide, and the pharmaceutical industry is no exception. Stakeholders are increasingly demanding transparency and accountability from companies. They expect them to focus not only on financial performance but also on contributing positively to society and the environment. The integration of ESG (Environmental, Social, and Governance) principles has gained importance, particularly as a consequence of the COVID-19 pandemic, which highlighted the critical role of pharmaceutical companies in health crises. ESG ratings, which capture the commitment to sustainability, comprise three pillars. The Environmental (E) pillar relates to the importance of pharmaceutical companies' management of environmental impacts like emissions and waste. The Social (S) pillar focuses on ethical practices, patient safety, and access to drugs, which are critical for maintaining public trust. The Governance (G) pillar ensures ethical management and regulatory compliance, which are essential for sustaining investor confidence and avoiding legal issues (Chime, 2024).

Because business operations in the pharmaceutical industry revolve around the well-being of its stakeholders, exploring sustainability is crucial. This chapter explores whether measures of sustainability signal solely genuine commitments in the industry. It analyses how pharmaceutical companies of different characteristics vary in their ESG ratings and approaches to sustainability. By doing so, it aims to better understand how to monitor the level to which ESG factors remain present among pharmaceutical companies, laying the groundwork for future considerations of strategy and compliance.

First, the chapter discusses sustainability in the pharmaceutical industry. Then, the literature on ESG ratings is reviewed to define research questions, followed by a discussion of findings on ESG ratings and company performance. The chapter concludes by summarising the findings and their implications.

2 Overview of sustainability in the pharmaceutical industry

Production and use of pharmaceuticals lead to active pharmaceutical ingredients entering the environment through manufacturing emissions, wastewater, and improper disposal of drugs (Bartolo et al., 2021). To address these issues, pharmaceutical companies are increasingly integrating sustainability strategies into their operations (Milanesi et al., 2020). Despite the consequent importance of ESG ratings within the industry, comparison remains complicated as each pillar addresses a specific area of sustainability.

The environmental pillar focuses on the industry's contribution to climate change, pollution, biodiversity, and depletion of the world's natural resources (Datwyler Group, 2022). The chief reason for its importance is the perception that the pharmaceutical industry is insufficiently contributing to environmental sustainability, as indicated by 70 percent of 343 pharmaceutical industry professionals in a GlobalData survey. Environmental issues were viewed as the most important sustainability area for the pharmaceutical industry to address (GlobalData, 2021). Nonetheless, regulatory standards vary across regions, making standardisation and comparison difficult (Mihaiu et al., 2021).

The social aspect of sustainability in the industry enhances access to medicines, promotes ethical labour practices, and supports communal health, directly impacting the lives of the stakeholders (Dănescu & Popa, 2020). The pillar encompasses the complexities surrounding human rights, diversity and inclusion, health and safety, and communal impact. Maintaining reputation in these areas is crucial for pharmaceutical companies because failure to do so can damage profitability and incur penalties (Datwyler Group, 2022). McKinsey & Company (2022) emphasise that approaches to the social aspect of ESG have shifted toward proactive and resilient frameworks. Companies are moving from cost-focused reactive solutions to agile approaches that enhance employee safety and workplace diversity. Digital transformation supports solutions for tracking social metrics, while talent management has evolved to emphasise strategic workforce planning and reskilling. Nonetheless, social aspects remain hard to measure consistently due to differing cultural and legal contexts (Mihaiu et al., 2021).

The governance pillar considers how pharmaceutical companies use policies and controls to inform business decisions, comply with the law, and fulfil their obligations to the stakeholders. Examples of failure include tax avoidance, corruption, excessive executive pay, and intensive lobbying. The industry is often criticised for price fixing and unlawful promotion of drugs, which can severely harm the trust it enjoys (Datwyler Group, 2022). As the pillar deals with the complexity and variability of governance practices across companies and countries, inconsistencies arise when ensuring transparency and accountability (Mihaiu et al., 2021).

Further obstacles to universal standardisation arise because the implementation of ESG principles is measured by various providers with different rating systems. Some of the most recognised are MSCI ESG Research, S&P Global, Sustainalytics, Bloomberg, and LSEG Workspace. To evaluate the ESG practices of companies, they collect data from company disclosures, regulatory filings, news reports, various organisations, and third parties. However, none of the providers account for certain company characteristics (see Section 2.1), such as the type of pharmaceuticals produced or the development of the country where the company operates (Bloomberg, 2024; LSEG, 2024). Moreover, there are no uniform compliance mechanisms to standardise the ESG rating market worldwide, complicating comparisons between different providers.

This issue creates inconsistencies in how companies are assessed, leading to confusion among stakeholders about the comparability and reliability of the ratings. Although many countries are adopting regulations that require companies to disclose ESG information, these disclosure standards are not yet internationally unified, in contrast to the globally recognised International Accounting Standards. The lack of standardisation in disclosure practices and rating assessments increases the risk of greenwashing through modified disclosures and limits comparability between different rating providers (Mihaiu et al., 2021).

3 Characteristics of pharmaceutical companies and their impact on ESG ratings

Relying on companies' public disclosures, the rating providers fail to consider certain company characteristics that could impact a company's ESG rating in the pharmaceutical industry. Consequently, this section explores existing literature to denote the most notable characteristics that can impact how a company in the pharmaceutical industry is evaluated (Bloomberg, 2020; Bloomberg, 2024).

3.1 The impact of the nature of produced drugs on ESG ratings

Drugs can be classified as generic and originator drugs, which primarily differ in their development process, cost, and regulatory requirements (Dunne et al., 2013). This classification influences the ESG profiles of their producers. **Originator drugs** are developed by innovator companies and are protected by patents, allowing exclusive sales by the patent-holding company. This exclusivity and the high research and development (R&D) costs associated with bringing a new drug to the market make them more expensive. As their costs can limit availability, originator producers face challenges related to drug pricing and access. For safety and efficacy, they must comply with stringent regulatory standards and ethical marketing practices (Dunne et al., 2013).

Generic drugs, produced after the expiration of originator patents, must demonstrate bioequivalence, meaning they are pharmaceutically equivalent to the originator in dosage form, strength, and therapeutic effect. Generic drugs are generally much cheaper due to lower development costs and increased competition, enhancing their accessibility and playing a crucial role in public health. However, governance issues can be more pronounced in developing markets with less stringent regulations, potentially affecting the quality and safety of generic drugs. Thus, while generics have a lower environmental impact and offer broader access to medications, they must maintain robust quality control and adhere to ethical business practices to ensure trust and safety in the pharmaceutical supply chain (Dunne et al., 2013).

3.2 ESG in the pharmaceutical industry

Environmental sustainability practices within the pharmaceutical industry face significant challenges due to varying levels of regulatory enforcement and environmental awareness among companies. Originator companies, which typically operate under stricter regulatory environments, are more likely to adopt advanced environmental strategies, such as sustainable drug production and waste management practices. On the other hand, generic pharmaceutical companies face varying levels of acceptance and trust among healthcare providers and patients, impacting their sustainability efforts. They prioritise cost efficiency and accessibility, which often leads to sustainability strategies aimed at reducing production costs and optimising supply chains (Riikonen et al., 2024).

Originator producers appear to have higher ESG ratings, as innovation and R&D are crucial parts of their operations and are vital components of long-term sustainability in the pharmaceutical industry (Tölke et al., 2022). The notion is not a new one. McWilliams and Siegel (2000) have shown that R&D positively contributes to social impact, given that many of its elements consist of product and process innovation. Finally, Dicuonzo and others (2022) analytically proved that companies that invest more in innovation show better ESG performance than their competition. Consequently, it could just so happen that ratings partly reflect the business models of pharmaceutical companies, where those that favour innovation enjoy an advantage.

3.3 The impact of the country's development on ESG ratings

The second notable distinction differentiates between pharmaceutical companies in **developed** and **developing** countries. These exhibit notable differences in sustainability practices and ESG ratings based on country development. Compared to companies in developed countries, those in developing markets often enjoy lower levels of regulatory enforcement. Meanwhile, they struggle with underdeveloped infrastructure and financial constraints, leading to lower ESG ratings. Nonetheless, they still develop and implement sustainability strategies to keep up with their competition. When doing so, they may face fewer controversies due to less stringent regulations and lower media scrutiny. Those in developed countries, on the other hand, are subject to stricter regulations and greater media attention, making ESG controversies, which can significantly impact their financial performance, more likely (Nascimento Jucá et al., 2024; Beckmann & Rogmann, 2024).

3.4 The impact of financial indicators on ESG ratings

The third notable distinction is due to **the relationships between ESG ratings and the financial performance of companies**. Friede, Busch, and Bassen (2015) found strong evidence that the two positively correlate. This positive relationship is especially notable in North American and emerging markets and across various asset classes. While some studies show neutral or mixed results, the overall trend supports the business case for integrating ESG into corporate strategy to enhance long-term value. The data presented by Barbieri and Pellegrini (2022) reveals that the relationship between ESG ratings and financial performance in pharmaceutical companies is complex and not uniformly positive across all ESG dimensions. The study shows that while overall ESG ratings do not have a statistically significant relationship with company profitability, specific components do. This finding suggests that while sustainability efforts can coincide with financial success, the impact varies depending on the specific ESG actions undertaken by the company.

Moreover, ESG ratings are positively correlated with company size (Toader & Ciobanu, 2021) and the financial performance of pharmaceutical companies (López-Toro et al., 2021). Zhou (2023) extrapolates these relationships as a positive influence of ESG ratings on sales revenue, contributing to company size and financial performance.

Zumente and Lāce (2020) show that larger size makes it easier for companies to be awarded ESG scores by allowing them to allocate more resources towards sustainability implementation and reporting. This size bias is further confirmed by Boffo and Patalano (2020), who also show that, consequently, smaller companies with fewer resources to devote to sustainability efforts receive less attention, further alienating potential investment attention. The latter effect is especially prevalent in developing countries, where the limits in company size and financial market development hinder external ESG rating availability and, consequently, the emergence of developing countries as potential targets for sustainability-orientated investors.

The chapter introduces three research questions to further explore the impacts of company characteristics on ESG ratings. The **first research question** addresses the differences in ESG ratings and approaches to sustainability between originator and generic producers. The **second research question** addresses these differences between companies operating in developed and developing countries. The **third research question** explores whether more sustainably oriented companies also happen to be larger and more financially successful.

4 Sustainability – compliance or a competitive front? A comparative analysis

4.1 Data and methodology

The analysis was based on data from 53 publicly listed pharmaceutical companies from 21 countries. The data contained ESG ratings and financial indicators sourced from Bloomberg Terminal and LSEG Workspace (Bloomberg, 2024; LSEG Workspace, 2024). In line with the chapter's goals, companies were categorised based on the drug types they produced and the development of the country where they have headquarters. Given the discrepancies between rating providers, the chapter relies solely on Bloomberg's ESG ratings to maintain a consistent analysis. The ratings range between zero and ten, with higher ratings indicating better sustainability performance. Its methodology joins the three pillars into a total ESG rating by assigning weights based on intelligence and fundamental research of issue priorities (Bloomberg, 2023).

The distinction by drug type is considered a company's core business in order to differentiate between producers of originator and generic drugs. If a company was primarily a producer of generic drugs but happened to have developed and patented some of its own, it remained in the former category. The distinction by country development followed World Bank classifications, denoting high-income countries as developed and middle- and low-income countries as developing. As such, Spain was classified as developed and India as developing (The World Bank, 2024). The sample composition by company characteristics and medians and standard deviations of total ESG ratings are shown in Table 1.

Table 1. Sample composition by company and ESG rating characteristics

Country	Number of countries	Number of companies	Originators	Generics	ESG median	ESG stand. deviation
Developed	18	45	34	11	4.17	1.29
Developing	3	8	1	7	4.06	0.52
Total	21	53	35	18	4.16	1.21

Source: Bloomberg (2024); The World Bank (2024).

Differences also appear in how the sample of companies performs on various ESG pillars. This may have occurred partially due to the low number of companies in the sample from developing countries. Table 2 displays medians and standard deviations of total ESG ratings and pillars.

Table 2. Medians and standard deviations of ESG ratings and pillars for the sample

	ESG rating	E score	S score	G score
Median	4.16	5.82	2.99	6.72
Standard deviation	1.21	2.18	1.37	1.23
Minimum value	1.48	0.00	0.39	3.18
Maximum value	6.78	9.12	5.76	8.45

Source: Bloomberg (2024).

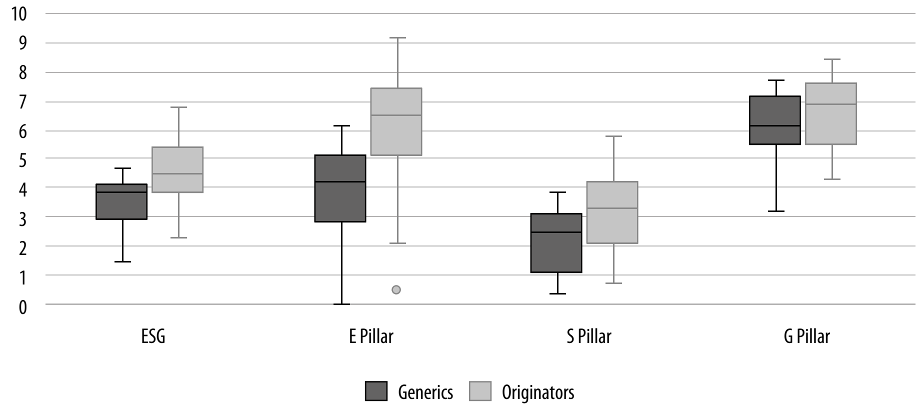
The medians of the Governance and the Environmental pillars were notably higher than those of the Social pillar. And while a standard deviation of 1.21 suggests that the total ESG ratings of the companies in the sample present moderate variability, the standard deviation of the Environmental pillar at 2.16 is 80 percent higher. This finding suggests that the pharmaceutical companies in the sample achieve the most divergent results regarding environmental issues. Assuming that ESG ratings reflect a genuine commitment to sustainability, this signals that, on average, pharmaceutical companies perform well in environmental concerns relative to the other pillars of ESG. Still, their success differs drastically from one company to another. Without that assumption, we might suspect a lack of standardisation in disclosure practices and rating assessments (Mihaiu et al., 2021). The sample included contrasting pharmaceutical companies with different characteristics, which may be able to explain the divergence between the pillars to some extent.

4.2 Originator vs generic producers – addressing sustainability

Literature suggests that producers of originator and generic drugs are subject to different conditions that impact their ESG ratings. In line with the first research question, this section compares both types of producers to discern any potential trends in ESG ratings. In addition to a quantitative analysis of the ratings – sustainability outcomes – it includes a qualitative analysis of companies' policies – sustainability approaches – to discern whether higher ratings reflect genuine commitment.

On average, originator companies are pulling ahead in all three ESG pillars separately, constituting a higher total ESG rating than generic companies (Figure 1). The largest differences can be observed within the Environmental pillar, while they remain minimal within the Governance pillar. However, this may not be entirely attributable to a genuine commitment to sustainability but rather the differences in business environments and models of different producers. Riikonen, Timonen, and Sikanen (2024) show that originator producers operating under stricter regulations are more likely to adopt advanced sustainable strategies. Generic producers, however, prioritise cost efficiency and accessibility, as the levels of their acceptance and trust among healthcare providers and patients vary (Dunne et al., 2013). Originator producers, whose business models revolve around R&D and innovation, are also more favoured by ESG ratings (Tölke et al., 2022; McWilliams & Siegel, 2000; Dicuonzo et al., 2022).

Figure 1. ESG ratings and their components by company type

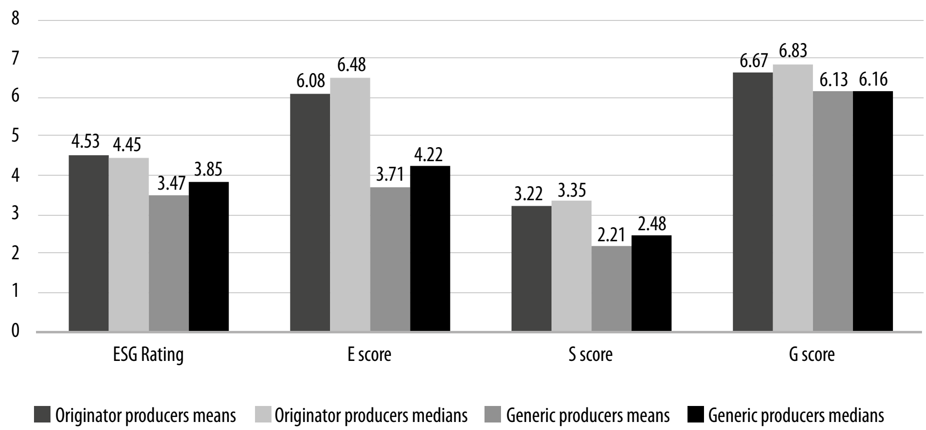


Note: each boxplot conveys some characteristics of the respective variable. The borders of a boxplot represent the first (lower border) and the third (upper border) quartile. The difference between the first and the third quartile – the coloured rectangle of a boxplot – represents the interquartile range. The bold line inside a boxplot represents the median (the second quartile). The lines extending above and below a boxplot's borders indicate variability outside the upper and lower quartiles. If outliers are present, they are denoted by black dots below or above the whiskers.

Source: Own work (2024).

The most notable difference in scores between originator and generic producers can be observed within the Environmental pillar (Figure 2).

Figure 2. Arithmetic means and medians of ESG ratings and pillars by drug type



Source: Bloomberg (2024).

To better discern sustainability commitments in originator and generic producers, a qualitative analysis of their approaches to sustainability follows. It compares two originator producers with the lowest ESG ratings – Faes Farma and Indivior – and two with the highest – Johnson & Johnson and GlaxoSmithKline. The same is done for two generics producers with the lowest ESG ratings – Celltrion Pharm and Zentiva – as well as two with the highest – Teva Pharmaceutical Industries and Krka. Table 3 presents the key findings.

Table 3. Comparison of sustainability approaches of originator and generic producers

Classifications	Company	Focus area	Approach	Strategic scope
Originator, low ESG ratings	Faes Farma	Environmental sustainability	Ambitious environmental goals	Limited to environmental aspects
	Indivior	Social initiatives and governance through innovation	Focused on social initiatives and ethics	Limited to social and governance aspects
Originators, high ESG ratings	Johnson & Johnson	Long-term sustainability across pillars, innovation	Proactive and transparent with ambitious targets	Broad and ambitious
	GlaxoSmithKline			
Generics, low ESG ratings	Celltrion Pharm	Basic ESG principles, focus on operational growth	Reactive, limited integration	Underdeveloped
	Zentiva			
Generics, high ESG ratings	Teva Pharmaceutical	Comprehensive ESG integration	Clear, detailed targets and reporting	Integrated into strategy and across operations
	Krka			

Sources: Faes Farma (2024); Indivior (2024); Johnson & Johnson (2024); GSK (2024); Celltrion (2023, 2024); Zentiva (2023, 2024); Teva (2024); Krka (2024).

Within both originator and generic producers, the most notable difference that justifies the discrepancies between ESG ratings appears within the scope of sustainability strategy. Companies with the lowest ESG ratings, regardless of the type of drugs they produce, present an underdeveloped or limited scope of strategy. Faes Farma, for example, appears very committed to environmental sustainability and has ambitious goals. However, its disclosures seldom touch upon the other pillars. Similarly, Indivior appears to sacrifice some scope for the sake of social initiatives and ethics. On the other hand, those with the highest ESG ratings implement broader and more ambitious strategies and integrate them into operations. Taking Johnson & Johnson and GlaxoSmithKline as examples, not only is their reporting transparent, but it also has clear targets across pillars. Their approach appears proactive and driven beyond legislator requirements. ESG ratings thus appear reflective of the sustainability strategies of the observed pharmaceutical companies.

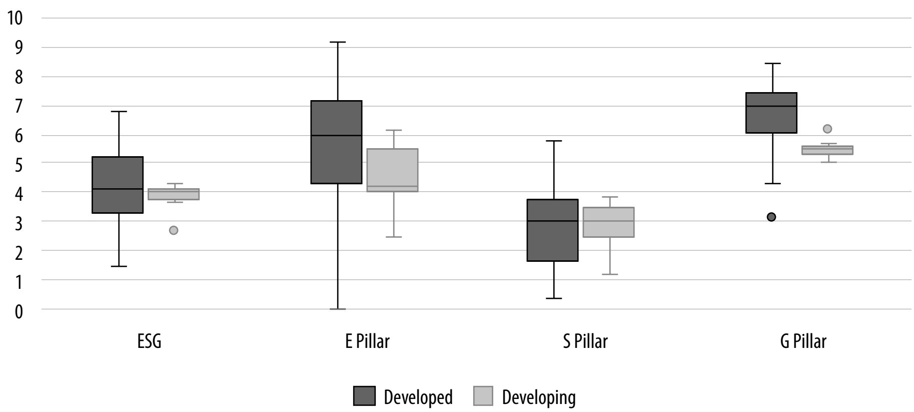
However, other discrepancies between the producers should not be overlooked. Riikonen and others (2024) show that originator producers typically operate under stricter regulatory environments and are consequently more likely to adopt advanced sustainability strategies (as demonstrated in Figure

1), such as sustainable drug production and waste management, emphasising sustainability as part of their brand and product. On the other hand, while detailed in reporting, generics also appear reactive. Their strategies tend to be more operational and revolve around meeting industry standards, less so around innovations, leading to lower ESG ratings, as attested to by literature (Tölke et al., 2022; McWilliams & Siegel, 2000; Dicuonzo et al., 2022). The higher ESG ratings observed with originator producers may not solely be reflectors of genuine sustainability commitments; rather, they appear to, in part, also be a consequence of the differences between production models.

4.3 Comparing sustainability in pharmaceutical companies in developed and developing countries

In line with the second research question, this section compares pharmaceutical companies in developed and developing countries to examine how a country's status impacts its ESG ratings (Nascimento Jucá et al., 2024; Beckmann & Rogmann, 2024). It begins with a quantitative analysis of ESG ratings, which is later reinforced with a qualitative analysis of companies' approaches to sustainability.

Figure 3. ESG ratings and their components by country status

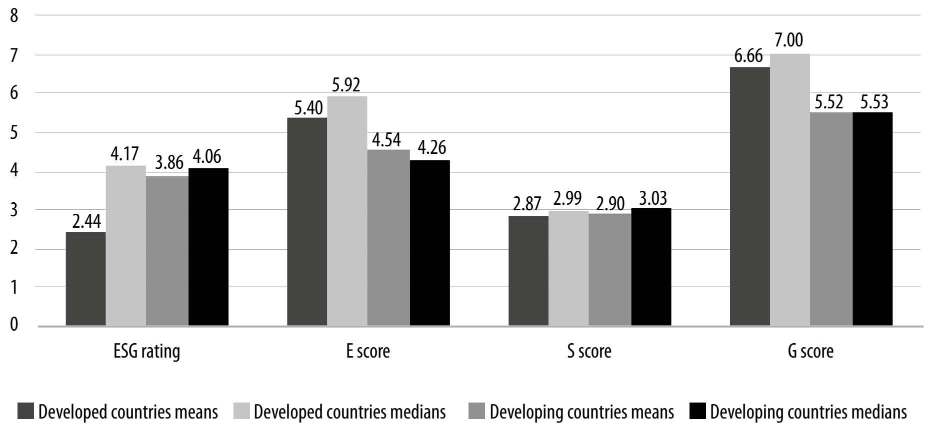


Source: The World Bank (2024).

Figure 3 shows that the companies in developed countries tend to feature much larger variability in their ESG ratings – their ratings differ more than those between companies in developing countries. When observing the ESG pillars separately, the companies in developed countries also feature higher Environmental and Governance scores. Barring extreme values, 75 percent of the best-rated companies in developed countries score higher on the Governance pillar than all the companies in developing countries together.

This finding may not necessarily mean that companies in developed countries are more committed to sustainability – especially as they appear more divergent in results. It may, however, partially signal that their sustainability pursuits are better incentivised by the type of drugs they produce. Their counterparts in developing countries often remain subject to less regulatory enforcement but struggle with financial constraints and underdeveloped infrastructure (Nascimento Jucá et al., 2024; Beckmann & Rogmann, 2024; Dunne et al., 2013). The former can explain why they score lower in ESG ratings (Boffo & Patalano, 2020). The latter can explain their notably higher Social scores. In addition to less stringent regulation, companies in developing countries also face lower media scrutiny. A lower fear of repercussions could drive them to engage in sustainability strategies more aggressively – especially if they try to keep up with their competitors operating in developed countries – even when those may be poorly developed or implemented. Moreover, low variability in ESG ratings of developing countries occurs because they are not subject to greater disclosure requirements, which promotes greater disagreements among rating agencies and metrics in developed countries (Christensen et al., 2022). Figure 4 shows that, by country development, companies' scores differ most within the Environmental and Governance pillars.

Figure 4. Arithmetic means and medians of ESG ratings and pillars for companies in developed and developing countries



Source: The World Bank (2024).

The differences in ESG ratings may not be entirely due to genuine commitment to sustainability – country development could play a significant role. To better discern sustainability commitments between companies operating in countries of different levels of development, a qualitative analysis of approaches to sustainability follows. It compares two producers in developed countries with the lowest ESG ratings – Celltrion Pharm and Zentiva – as well as two with the highest – Johnson & Johnson and GlaxoSmithKline. The same was done for two producers in developing countries with the lowest ESG ratings – Sun Pharmaceutical Industries and Aurobindo Pharma – as well as two with the highest – Kalbe Farma and Cipla. Table 4 displays the key findings obtained by investigating companies' reports and strategies.

Table 4. Comparison of companies' sustainability approaches by country development

Classifications	Company (country of origin)	Focus area	Approach	Strategic scope
Developed country, low ESG ratings	Celltrion Pharm (Czech Republic)	Specific goals, targets, and achievements	Limited disclosures, specific areas	Less developed in strategic and operational focus
	Zentiva (South Korea)			
Developed country, high ESG ratings	Johnson & Johnson (USA)	Long-term sustainability across pillars, innovation	Proactive and transparent with ambitious targets	Broad and ambitious
	GlaxoSmithKline (Great Britain)			
Developing country, low ESG ratings	Sun Pharmaceutical Industries (India)	Energy efficiency and reducing emissions	Clear disclosures, but in specific areas	Challenges in implementation across all operations
	Aurobindo Pharma (India)			
Developing country, high ESG ratings	Kalbe Farma (Indonesia)	Operational targets along supply chains	Clear and transparent operational targets	Structured goals integrated into business operations
	Cipla (India)			

Source: Celltrion (2023, 2024); Zentiva (2023, 2024); Johnson & Johnson (2024); GSK (2024); Sun Pharmaceutical Industries Limited (2024); Aurobindo (2023); Kalbe (2023); Cipla (2024).

With companies operating in developed and developing countries, the strategic scope of sustainability initiatives appears to justify discrepancies between their ESG ratings. Regardless of country development, companies with the lowest ESG ratings present less developed strategies or challenges in broad implementation. Those with the highest ESG ratings present more broad, ambitious, and well-structured strategies. ESG ratings again appear reflective of the sustainability strategies of the observed pharmaceutical companies.

However, the dilemma remains: good sustainability strategies may originate not solely from genuine commitment but also partially from country development. The explanation remains plausible as the rating providers do not universally account for country development; companies in developed countries face stricter regulations and media attention (Nascimento Jucá et al., 2024; Beckmann & Rogmann, 2024; Dunne et al., 2013). This circumstance incentivises them to pursue sustainability strategies meaningfully so as not to face scrutiny. Meanwhile, the ESG ratings among companies in developing countries, while lower, appear to be more consistent from one company to another (Christensen et al., 2022). Unlike their competitors in developed countries, they can engage in sustainability strategies more aggressively due to lower regulatory and media pressures. They do, however, appear to engage mostly so far as operational consequences are concerned – the desire to keep up with the competition may push them to meet standards but go no further where innovation is concerned (Nascimento Jucá et al., 2024; Beckmann & Rogmann, 2024; Dunne et al., 2013). All the while, the limits in their company size and financial market development hinder their ability to obtain high external ESG ratings, further deferring potential sustainability-minded investors (Boffo & Patalano, 2020).

4.4 Financial performance and ESG ratings

ESG ratings show mixed results regarding financial performance (Friede et al., 2015). Rather than the overall ESG ratings and controversies, specific rating components present a notable impact. Sustainability efforts can correspond with financial success, but the effect varies (Barbieri & Pellegrini, 2022).

Table 5. Correlations and p-values of ESG ratings and pillars with financial indicators

	EBIT margin	Return on assets	Return on equity	Net income	Revenue	Net profit margin
ESG	0.50***	0.50***	-0.06	0.52***	0.70***	0.01
E pillar	0.46***	0.40***	-0.10	0.47***	0.43***	0.07
S pillar	0.44***	0.44***	-0.10	0.42***	0.61***	0.03
G pillar	0.29**	0.34**	0.11	0.42***	0.59***	-0.09

Note: *The significance levels of p-values are denoted by stars next to a correlation coefficient; ** p-value < 0.1; ** p-value < 0.05; *** p-value < 0.01

Source: Bloomberg (2024); LSEG Workspace (2024).

ESG ratings feature a semi-strong positive correlation with EBIT margin (0.50), ROA (0.50), and net income (0.52) (Table 5). Like total ESG ratings, all separate ESG pillars feature positive correlations of different strengths with EBIT margin, ROA, net income, and revenue. Finally, the size of a company (proxied by revenue) features an even higher correlation with an ESG rating (0.70). These results coincide with the findings of previous studies, which show that larger companies tend to have higher ESG ratings (Zumente & Lāce, 2020; Boffo & Patalano, 2020).

Finally, revenue and net income present a positive and semi-strong correlation (0.68), signalling that larger companies also happen to be more profitable ($p<0.001$). Given the correlation between company size and ESG ratings (0.70) in Table 5, it could be that the ratings do not merely reflect sustainability commitment but also a company's financial capability – a notion that also resonates with the literature. As ESG ratings present a competitive front for companies, the non-uniform rating system may favour larger companies with sufficient financial resources to achieve higher ratings. On the other hand, even if the lower financial resources of small companies allow for sustainability measures, they can limit them severely. Consequently, although their commitment to sustainability may be genuine and reflect their best efforts, small companies can go unnoticed (Boffo & Patalano, 2020; Zumente & Lāce, 2020; López-Toro et al., 2021; Toader & Ciobanu, 2021).

5 Conclusion

The chapter analyses relationships between ESG ratings and some of the prevalent company characteristics denoted in literature – drug type, country development, and company size – in the pharmaceutical industry. It observes whether high ESG ratings solely reflect a genuine commitment to sustainability or remain impacted by company characteristics.

The findings reveal that originator companies tend to have higher ESG ratings than generic producers, driven by their focus on innovation and R&D (Tölke et al., 2022; McWilliams & Siegel, 2000; Dicuonzo et al., 2022). As ESG rating providers do not account for such company characteristics, the ratings may not solely reflect the commitment to sustainability but also operational dissimilarities. Companies in developed countries often score higher due to stricter regulations. While presenting lower ratings, companies in developing countries appear much less variable from one company to another due to lower pressure from regulators and the media (Christensen et al., 2022; Nascimento Jucá et al., 2024). Finally, larger companies may be able to attain higher ESG ratings, possibly due to their size and financial capacity. Consequently, smaller companies with resource constraints that may otherwise be more committed to sustainability can go overlooked (Boffo & Patalano, 2020; López-Toro et al., 2021). These effects of company characteristics on ESG ratings pose questions about the universal fairness and consistency of current ESG frameworks within the pharmaceutical industry.

The defined levels of country development rely on the World Bank's income classifications of countries (The World Bank, 2024). They present a limited perspective on the actual development of a country in a broader context, which remains a notable limitation of this chapter. Similarly, the choice of the rating provider impacts the results, as the chapter focuses solely on Bloomberg's ESG ratings. Another limitation pertains to Section 3.4, which fails to explain causality by only analysing correlations; all interpretations remain only possible explanations of the observed results by leaning on prior literature.

Pharmaceutical companies should consider the impact their characteristics have on ESG ratings when deciding on a strategy. Those producing generic drugs and operating in developing countries should recognise their inherent disadvantages under current ESG frameworks and strive to adopt more proactive and innovation-driven sustainability strategies to keep up in ratings and competitiveness. Smaller companies that lack the financial resources to achieve high ESG ratings may instead want to focus on transparency and targeted sustainability efforts to attract investors focused on genuine sustainability commitments, such as local sourcing and partnerships or employee well-being and fair wages. Policymakers and stakeholders should account for company size, regional context, and operations when standardising ESG ratings, as higher scores may reflect financial capacity rather than a true commitment to sustainability.

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CREATING A SUPPORTIVE BUSINESS ENVIRONMENT FOR INNOVATIVE PHARMACEUTICAL SUBSIDIARIES IN SLOVENIA

1 Introduction

Rapid technological development, increasing life expectancy, and personalised healthcare are reshaping the global healthcare landscape (IESE, 2024). Patient-centred healthcare systems with all involved stakeholders are under increasing pressure to continuously improve patient care and mitigate the growing economic burden of diseases. The latter encompasses direct, indirect and intangible costs from a societal perspective, i.e., costs incurred by all relevant stakeholders, including patients, their family members, the healthcare system, employers, and so on (Jo, 2014).

This chapter examines how innovative pharmaceutical companies operating in Slovenia through subsidiaries can contribute to this goal. The chapter will explore their contribution to the country's ecosystem, which is linked to transparent and effective collaboration with all other relevant stakeholders, the potential to establish a regional pharmaceutical hub, and risks associated with their relocation to other countries or reduced involvement, potentially affecting accessibility to innovative medicines. The focus will be on researching the perceptions of interviewees from innovative pharmaceutical companies and other relevant stakeholders such as regulatory bodies and public agencies. Only interviewees from innovative pharmaceutical companies operating in Slovenia through their subsidiaries with activities that go beyond market sales were included in this research.

Such innovative pharmaceutical companies have the capacity to contribute to assuring financial sustainability in healthcare. This task is among the most significant challenges for all stakeholders in healthcare systems, given that approximately 30 percent of the burden of diseases is preventable – some by preventive measures, some by early intervention, and the **bigger responsibility** of patients, highlighting the need for prioritising prevention and early treatment to improve outcomes and reduce costs (McKinsey & Company, 2020). OECD data similarly show that up to 20 percent of healthcare expenditures can be considered waste due to late diagnosis, overtreatment, organisational issues, etc.

The chapter includes a short outline of the research area, the research questions, and the adopted methodology. Then, it presents and discusses the multi-stakeholder perceptions about the added value innovative pharmaceutical subsidiaries bring to healthcare and the economy, the strengths and challenges of Slovenia's business environment, the importance of collaboration among different stakeholders, and the challenges this entails. It also addresses the country's potential to support regional pharmaceutical hubs. The chapter ends with a summary of the findings and their implications.

2 Exploring the business environment of innovative pharmaceutical companies

2.1 Research area

Innovative pharmaceutical companies need a supportive long-term business environment to innovate and spread new innovative products. This environment includes suitable and effective regulation, market access, and incentives for investment (Jeck et al., 2021). Such a supportive environment for pharmaceutical innovation and accessibility to innovative products requires several elements. First, a favourable regulatory framework at the EU level can accelerate drug approval and protect intellectual property (IP), thus encouraging research and development (R&D) investment (European Federation of Pharmaceutical Industries and Associations, 2022). Ensuring fair competition and addressing profit shifting among multinationals also help maintain a balanced market (Garcia-Bernardo & Janský, 2024).

Secondly, adequate funding is essential. Investments in European biopharmaceutical research and development from both public and private sources are needed for a robust R&D ecosystem (Fowler et al., 2024). Building an innovation hub, enhancing capabilities, and investing in science, technology, engineering and mathematics education to develop a skilled workforce is also crucial (European Commission, 2023). Collaboration between academia, industry, and research institutions is critical in transforming discoveries into marketable therapies, particularly in emerging fields such as gene and cell therapy, and, ultimately, their distribution to patients (Olk & West, 2019).

Finally, national culture and governance influence innovation and its dissemination. A culture of openness and strong governance encourages diverse perspectives and aligns policies with broader goals (Attah-Boakye et al., 2020). For EU countries, this entails clear national health policies, strategies and plans, transparent legislation of healthcare systems, and effective EU general pharmaceutical regulation assuring patient safety and efficacy and regulation on health technology assessment (European Commission, 2023 & 2024).

Four key research questions were outlined to achieve the purpose of this chapter:

- What is the added value of innovative pharmaceutical companies operating in Slovenia?
- What is the current business environment in Slovenia?
- What is collaboration among stakeholders like?
- Could Slovenia become a regional hub for innovative pharmaceutical companies?

2.2 Methodology

The role of specific industries can be analysed using either quantitative (e.g., by analysing data on GDP and employment contribution and investments) or qualitative approaches. In this chapter, qualitative methods were employed by conducting semi-structured in-depth interviews, enabling us to investigate the perceptions of multiple stakeholders about the posed research questions. Interviewees were representatives of pharmaceutical companies, all in leadership positions at various levels, and leaders and professionals from other relevant stakeholder groups, including regulators, payers, agencies, and associations.

The goal was to obtain diverse perspectives on the business environment and potential improvements that could foster innovation and improve multi-stakeholder collaboration to advance healthcare in Slovenia. This combination of industry and public sector perspectives provided valuable insights into factors influencing the innovative pharmaceutical sector to establish and maintain their subsidiaries and activities beyond just sales in Slovenia.

In total, 18 semi-structured in-depth interviews were conducted (see Table 1). This interview style was chosen because it allowed focusing on understanding the interviewees' perspectives rather than attempting to generalise their experiences. These interviews, ranging from 40 to 75 minutes, were conducted between August 28 and September 10, 2024, either in person or online.

Table 1. Interviewees from innovative pharmaceutical subsidiaries and other stakeholder organisations

Company	Type of organisation	Size*	Gender	Code
Company 1	MNE** subsidiary	Medium	Female	InnoPharma1-1
			Male	InnoPharma1-2
Company 2	MNE subsidiary	Small	Male	InnoPharma2
Company 3	MNE subsidiary	Medium	Female	InnoPharma3
Company 4	MNE subsidiary	Small	Female	InnoPharma4
Company 5	MNE subsidiary	Large	Female	InnoPharma5-1
			Female	InnoPharma5-2
Company 6	MNE subsidiary	Small	Female	InnoPharma6
Company 7	MNE subsidiary	Medium	Female	InnoPharma7
Company 8	MNE subsidiary	Medium	Female	InnoPharma8
Company 9	MNE subsidiary	Small	Male	InnoPharma9
Stakeholder 1	Nonprofit	Small	Female	SH1
Stakeholder 2	Government	Large	Male	SH2
Stakeholder 3	Nonprofit	Medium	Female	SH3
Stakeholder 4	Public	Large	Male	SH4
Stakeholder 5	Government	Medium	Female	SH5
Stakeholder 6	Public	Medium	Male	SH6
Stakeholder 7	Public	Medium	Male	SH7

Note: *Small: less than 50 employees in Slovenia, Medium: less than 250 employees in Slovenia, Large: more than 250 employees in Slovenia.

** MNE: Multinational enterprise.

Source: Own Work (2024).

3 Analysis of multi-stakeholder perceptions about the business environment of innovative pharmaceutical companies in Slovenia

3.1 Results

3.1.1 Perceptions about the value added of the presence of innovative pharmaceutical companies in Slovenia

According to some interviewees, the presence of innovative pharmaceutical subsidiaries in Slovenia significantly contributes to the development of healthcare and the improvement of patients' quality of life by making medicines more accessible and providing innovative therapies for diseases that previously had no effective treatments, as stated *"Medicines arrive sooner than if they were from, for example, Vienna, because pharma companies have greater human resource power through their employees to prepare everything necessary for the medicine to enter our market and quickly go through the process"* (SH1). Interviewees from pharma companies emphasised that the industry creates job opportunities, offers good and rewarding financial and working environments for highly educated professionals and provides opportunities for further education and development. *"We can help develop skill sets in society"* (InnoPharma1-1). Some also highlighted that they contribute to the internationalisation and success of Slovenia by bringing in foreign experts, as expressed with *"We bring new talent from other countries to help fill the Slovenian gap"* (InnoPharma1-1).

Moreover, interviewees emphasised that the pharmaceutical industry provides a variety of career prospects, including international experiences and flexible work arrangements such as remote work. One respondent pointed out that employees in these companies have a high multiplier effect: *"According to our calculations, each job creates five new jobs in Slovenia every year"* (InnoPharma1-2). Interviewees from pharma companies addressed the provision of continuous training of employees, including virtual and digital learning formats, which enables ongoing personal and professional growth and low employee turnover rates. *"We believe that if you train people well, they will stay"* (InnoPharma1-1).

The interviews with respondents from innovative pharma companies revealed their strong belief that their activities contribute to the development and enhancement of general knowledge in the country by collaborating with universities and contributing to the education of healthcare professionals, which improves healthcare practices nationwide. One company representative, for example, emphasised, "*Two-thirds of the funds for the continuous education of doctors and healthcare staff come from pharmaceutical companies, with the remaining third provided by the state"* (InnoPharma2). Another also highlighted that the industry regularly invests in the continuous education of doctors, provides donations to hospitals, and organises awareness campaigns, stating *"pharma companies spent €11 million on education for general practitioners and other healthcare personnel in Slovenia last year"* (InnoPharma9). One interviewee highlighted, *"We focus on building digital infrastructure to support future digitalisation"* (InnoPharma1-1), indicating they are also investing in building digital and artificial intelligence capabilities and competencies of healthcare workers to support the future of the data-driven healthcare system.

Some interviewees emphasised that a strong healthcare system that provides access to the latest medicines prevents the brain drain of experts and contributes to the stability of the economy by stating *"If companies leave Slovenia, it is a big loss for the country. It should be a strategic political decision of the state to prioritise healthcare and fully support it"* (InnoPharma7), and *"If a patient is diagnosed earlier, they remain active longer, so we contribute to reducing sick leave periods"* (InnoPharma3).

Interviewees from pharma companies believe that they significantly impact the healthcare system in Slovenia by continuously introducing new technologies and treatments, which contribute to better health and a higher quality of life, particularly among the older population, as stated by an interviewee, *"With new, innovative medicines, we save lives faster"* (InnoPharma5-1), and *"If there are no innovative medicines, we will be treating everything with aspirin and so on"* (InnoPharma5-2). Access to healthcare services is perceived as high, including the early introduction of new medicines and a focus on prevention., as illustrated by the statement that *"Slovenia is currently among the top ten European countries in early access to medicines"* (InnoPharma1-1). It is important to note that, according to the 2023 European Federation of Pharmaceutical Industries and Associations (EFPIA) Patients W.A.I.T. Indicator Survey (published in June 2024), the average time for a new medicine to become available in the European market is 531 days (based on data for 167 innovative medicines with central marketing authorisation between 2019 and 2022). In Slovenia, the average time from central approval to availability was 563 days, placing us slightly below the European average but still within a competitive range. However, it is crucial to remember that the W.A.I.T. index varies among individual medicines and companies. Delays in the availability of new medicines or any other novel healthcare technology can be linked to an accuracy-timeliness trade-off in decision-making that has to weigh the expenditures against the added benefit. One interviewee from a stakeholder organisation highlighted the work of Brinkhuis and others (2024), indicating that most oncology drugs, particularly those with conditional marketing authorisations, recover R&D costs within a few years despite providing little added benefit.

The need for better evidence is highlighted also by interviewees from other stakeholder organizations. This is shown, for example, by SH6 noting, *"We would like better drug data (to drive real innovation on the basis of data) and clearer criteria on, for example, what constitutes an unmet medical need. (...) I would also like to establish a link between price, clinical performance and sold volumes."* Achieving a good balance between R&D costs and patent protection that incentivises innovations, on the one hand, and increasing pressure to slow down medical inflation and the growth of healthcare expenditures is not a simple task. SH4 notes, *"Having a patent law is very harmful to Slovenian healthcare."* This statement indicates the need to protect the financial sustainability of healthcare systems.

Most interviewees from other stakeholder organisations thus acknowledge the pharmaceutical industry's role in medical advancement and disease treatment. Still, they put more emphasis on expenditures, budgetary constraints and the value for money. Some believe that the overall contribution of innovative pharmaceutical subsidiaries to Slovenia's economy and healthcare system is limited. For example, some argue that *"the majority of big innovative companies spend on sales and marketing costs around 20 percent of their total revenue. The rest is transferred out of Slovenia through transfer prices"* (SH6), and that *"their presence provides little beyond a few well-paid jobs"* (SH4). There is scepticism regarding the claim that having local branches speeds up access to medicines, with one stating, *"It is not necessarily true that medicines arrive sooner because companies have branches here"* (SH4). They emphasised that *"what matters is timely access to new medicines at reasonable prices"* (SH4) rather than the physical presence of multinational companies.

However, interviewees from other stakeholders also acknowledged certain benefits, such as the potential for *"new collaborations with domestic institutions"* (SH2) and *"improved communication between the parent company and the Slovenian market"* (SH7). The presence of these companies is seen as a *"guarantee that manufacturers recognise Slovenia as a market"* (SH3). However, it is important to note that *"11 markets comprise half of the global pharmaceutical market"* (SH6), which implies that small countries such as Slovenia face more challenges in providing timely access to novel therapies. Some interviews from stakeholder organisations also noted that innovative pharmaceutical companies are *"key for treating rare and genetic diseases where no generics are available"* (SH5). Overall, most interviewees from other stakeholder organisations advised a more balanced approach, with one cautioning that *"it would be a mistake to rely solely on corporate pharmaceutical companies for innovation"* (SH2).

3.1.2 Current business environment and operations

Interviewees from innovative pharmaceutical companies noted that their headquarters have decided to establish their branches in Slovenia due to its strategic location, access to local talent, and a relatively stable healthcare system. One, for example, noted, "*Slovenia is a mirror of what will happen in the future"* (InnoPharma9), which indicates the belief that Slovenia offers a promising environment for the development of new pharmaceutical approaches. The interviews also revealed the aim to assure access to innovative therapies. It was, for example, stressed that *"the environment is encouraging enough that accessibility for patients will be better if the branch is here"* (InnoPharma6). It was also noted that *"Slovenia has talent, highly skilled workers in healthcare (e.g., doctors), proximity to Switzerland, good gross domestic product spent per capita, and is well located geographically"* (InnoPharma1-1), all of which represent strong reasons for the presence of pharmaceutical companies in Slovenia. Companies in Slovenia carry out a varying scope of their entire set of functions, with four out of ten companies implementing a full outsourcing strategy, mostly at the regional level. However, some interviewees from the innovative pharmaceutical industry believed that *"the business environment does not seem to be the most encouraging to us; there is potential for improvement"* (InnoPharma1-2).

Regarding employment, some interviewees from pharma companies noted that they face challenges such as long recruitment processes and a shortage of doctors. This is indicated by statements such as *"There is a limited pool of people, and it takes us about six months to find a person"* (InnoPharma1-1). Interviewees from stakeholder organisations also recognise this and SH2, for example, agrees by stating, *"Today, there is a battle for talent"*, which causes pharmaceutical companies to face lengthy processes in finding suitable candidates.

According to the interviewees, the Slovenian regulatory framework for the pharmaceutical industry involves multiple decision-makers. While some pharma interviewees rated the work of the Agency for Medicinal Products and Medical Devices of the Republic of Slovenia (JAZMP) and Slovenian regulations as good, four interviewees from the pharma industry criticised rigid procedures and excessively long waiting times for drug approvals and reimbursement supported by the statement, *"The drug approval processes are longer than we would like them to be. The industry average is 500 days. We want 180 days"* (InnoPharma1-1). It is, however, also important to note that *"procedures are laid down in the EU legislation and by the national Medicinal Products Act"* (SH6), implying that the timeliness of drug approvals and reimbursement are conditional on both EU and national regulation. The European Medicines Agency (EMA) runs the approval process for most innovative medicines through a centralised procedure, in which companies take time for clock stops to respond to questions posed in the assessment. According to a recent EMA report (2024), the average duration of clock stops for initial marketing authorisation applications in 2023 (198 days) was comparable to the average time of assessment (204 days). After EMA's approval of national rules on setting prices (Official Gazette No. 32/15, 15/16, 19/18, 11/19, 26/20, 51/21 and 52/21) and making reimbursement decisions (Official Gazette No. 110/10 in 35/13) that are harmonised with the EU legislation indeed set a 180-day time window for actual availability to patients that is exceeded according to the previously mentioned W.A.I.T. index. This indicates a need for improved processes of decision-makers as well as companies given that SH4 highlights *"hierarchical decision-making processes in pharmaceutical companies and (...) response times of weeks."*

Interviewees noted that complications extend to clinical trials, which face significant administrative and legislative hurdles at the EU level. *"We have aspirations to conduct them, but we lack dedicated people who are educated and motivated for this, and there is also a lack of good documentation"* (SH7). As many as eight out of ten participants from the pharma industry reported complicated administrative procedures for clinical trials. Four stated that the legislation is complex; it is *"difficult to get them, and we are trying to get them (clinical trials), but in the end, due to some completely logistical reasons, it does not go through"* (InnoPharma5-2). One interviewee from other stakeholder organisations pointed out other reasons that hinder progress, such as *"insufficient clinical research staff and competencies, lack of incentives for healthcare staff to undertake clinical research from their employers, lack of research nurses and issues with conflict of interest"* (SH6). A pharma interviewee noted, *"We have lost clinical trials because of administrative burden in Slovenia"* (InnoPharma1-2), which represents a serious obstacle to the development of new therapies. Pharma interviewees also highlighted, *"The situation has worsened significantly in the last 15 years"* (InnoPharma7).

More than half of the interviewees from the innovative pharmaceutical industry expressed concern about high payroll taxes, with one of them noting, *"Because of high taxes on salaries, they are also relocating our centres elsewhere"* (InnoPharma2). The interviewees believe that high payroll taxes burden companies and hinder competitiveness in the global market. If the situation does not improve, they fear innovative pharmaceutical companies will withdraw from Slovenia and switch to operating only through distributors.

Interviewees from pharma in Slovenia emphasised the need to optimise administrative procedures and create a more agile regulatory environment. They noted that *"The system and bureaucracy for importing labour need to be improved"* (InnoPharma1-1). In addition, some miss the state's active measurement of the added value of medicines. As they emphasised, *"It should be that the clinical value is being assessed separately from the economic value, the overall impact of the drug on the healthcare system is being considered too little, it is being viewed too narrowly"* (InnoPharma3), indicating that the contribution of medicines to treatment is clear. Still, they miss specific data on the savings and broader socio-economic value that medicines bring to the healthcare system and society. The medicines reduce further medical complications and the number of days of hospitalisation as well as productivity losses due to sick leave, early retirement, premature mortality, work inactivity of patients and the burden on informal caregivers.

Interviewees from pharma expressed concern about the state of the Slovenian healthcare system, which they view as deteriorating, as stated *"A historically well-designed and functioning healthcare system is now losing its aura"* (SH1). They emphasised that *"a reorganisation of hospitals and the establishment of a network with transparent leadership, with serious managerial staff in hospitals, with management expertise is necessary"* (InnoPharma7). *"We have more money than in previous years, but spending is not well organised. We should have better IT systems for cost accounting and financial controlling. Although Slovenia is small, we are not harmonised"* (SH6), pointing out a major financial inefficiency in the Slovenian healthcare system.

Furthermore, the need for better management and accessibility of data in healthcare has been stressed. One stated that although *"Everything is digi-*

talised, but is not organised in a way that is usable, we need a high-quality data structure in a standardised format that would enable good analysis for informed decisions" (InnoPharma1-1). Interviewees from the pharma industry also advocate for the digitalisation of registries and the establishment of clinical registries for each disease, which would provide *"a better overview [that] would show which drugs and therapies are truly important, what brings added value to the patient"* (InnoPharma7). It was pointed out, *"We collect a lot of data, but we do not know what to do with it – this seems to be a big problem, not only in Slovenia but also in the European Union"* (SH5). Although the country has digital systems like zVem (Healthcare Information Portal), *"the data is not connected"* (SH5). Another interviewee from stakeholder organisations similarly noted, *"Many times when we are looking for data in the registers, we get them in an outdated form"* (SH7) and added, *"Data is like a knife. You can spread jam with it, but you can also stab someone"* (SH7), showcasing the importance of handling data with caution. Additionally, structural issues were pointed out, such as *"Structured data exist but in limited numbers. [...] As many IT systems are developed within hospitals and locally, big potential is lost. The easiest part to digitalise is medicines for which most structured data exist. The central medicines database should be upgraded"* (SH6).

Stakeholders have varying perceptions of the pharmaceutical industry's added value and, consequently, different views on the risks of the industry exiting the Slovenian market. *"If innovative companies left, we would likely lose access to some innovative drugs"* (SH3). *"The majority of companies are relocating their commercial operations to other countries and establishing CEE clusters"* (SH6). The cost of maintaining general directors in Slovenia was highlighted as another issue. *"Each general director costs half a million euros, plus the living space and benefits"* (SH6), suggesting that these costs are too high for companies to justify their presence. *"If they left, it would be a great loss due to the loss of highly educated personnel, and the brain drain would only worsen. Their presence not only brings scientific advancement but also introduces new perspectives to the Slovenian system"* (SH5). *"We want their presence and would help them with everything we legally can, such as good treatment and open and fair communication"* (SH2).

3.1.3 Stakeholder relationships and collaboration

Most interviewees agreed that among the most significant stakeholders of the Slovenian healthcare system in the field of medicines that need to work together for the benefit of patients are the Ministry of Health, JAZMP, which regulates medicines, the Institute for Health Insurance (HIIS), which ensures patient access to medications and influences pricing and suppliers of medicines. The role of the National Institute of Public Health (NIPH) was also noted as vital for public health. Moreover, the Ministry responsible for Economy, Tourism and Sport is also important as its role is to foster economic growth and innovation.

A vast majority of interviewees also believed that healthcare professionals, including doctors, other medical staff, and healthcare organisations that employ them, are essential in implementing new therapies and bringing innovative solutions to patients. Although patients are not active stakeholders due to legal restrictions, they are considered central as the ultimate beneficiaries of these innovations.

Pharma interviewees expressed dissatisfaction with their level of involvement in decision-making, stating that *"Trust between the public and private sectors should be strengthened, and more efficient systems should be established"* (InnoPharma3), and that *"Cooperation with public institutions could be smoother"* (InnoPharma4). They emphasised the need for more dialogue and participation in policy-making, *"in which we would like to be involved from the early stages of preparing new policies"* (SH1). They advocated for being *"seated at the same table in certain panels or working groups so that we can have our say on how to solve certain issues"* (InnoPharma5-2). As noted by SH6, *"pharmaceutical companies can provide suggestions on proposed legislation during calls for public debate, thereby avoiding lobbyist contacts."*

Several interviewees from innovative pharma companies reported difficulties in communication and collaboration with key public institutions. Most company representatives assess that JAZMP is too slow and rigid, as stated *"There is room for improvement. The procedures could be faster"* (InnoPharma8), and *"They are really strict; they do not see the problem but just follow protocol, nobody sees the total picture, and unfortunately, the protocol is outdated (written 15 to 20 years ago)"* (InnoPharma9). It is, however, important to stress that *"JAZMP is one of the smallest agencies in Europe with limited human resources for more competencies than the majority of comparable agencies"* (SH6). While most respondents from pharma appreciate the *"very wisely defined basket of our medicines in Slovenia"* (InnoPharma6) and note that *"they cooperate very well during emergencies"* (InnoPharma2), they desire faster drug reimbursement processes. A third of the pharmaceutical interviewees expressed a need for more up-to-date drug consumption data. According to SH4, *"HIIS regularly releases its report on drug expenditure and consumption by April and its business operations report by June for the previous year."*

Pharma interviewees are generally dissatisfied with the Ministry of Health due to a lack of dialogue and direct communication, as they *"have the least dialogue"* (InnoPharma4, InnoPharma5-1) with this ministry. They described the Ministry of Health as *"an umbrella body that adopts legislation, but there is no direct communication with them because they are too closed for cooperation, even for a conversation"* (InnoPharma7), making *"a formal visit to the Ministry of Health almost impossible"* (InnoPharma5-2). As a result, the ministry is not perceived as an important stakeholder because *"practically everything is done by others."* (InnoPharma2).

There are also challenges related to obtaining data from NIPH, with several interviewees from pharma companies reporting a lack of cooperation with NIPH. For instance, *"NIPH does not want to have meetings; they are inaccessible, and they would need to be an active participant among other stakeholders in healthcare system optimisation"* (InnoPharma7). *"We tried to get data regarding the therapeutic area, but we gave up because we did not see interest from NIPH. Our cooperation with them is weak"* (InnoPharma2).

On the business front, some interviewees from pharma companies are concerned about Slovenia's long-term viability, with the most common reasons being the lack of communication, bureaucratic obstacles, excessively long hiring processes, high taxes, and a shortage of doctors. One interviewee, for example, noted, *"Slovenia is no longer profitable in the long run (after three years)"* (InnoPharma9). While interviewees confirmed that pharmaceutical companies are not yet considering leaving Slovenia, they expressed a willingness to expand their presence under more favourable business conditions. This is illustrated by statements such as *"We have been present for several years and intend to stay, but we do not find the business environment very encouraging; there is potential for improvement"* (InnoPharma1-2).

Interviewed pharma respondents were unanimous in their call for systematic cooperation among all stakeholders in Slovenia to improve the development and implementation of projects. They emphasised the need for greater transparency and a more defined collaboration framework and noted, *"We wish to foster collaboration of private and public partnerships. I believe we need more good examples so that it becomes a norm"* (InnoPharma1-1). As highlighted by WHO (2023), this solution is not always straightforward and careful consideration must be given to implementing such partnerships, considering if they are the most cost-effective solution. Interviewed pharma respondents called for *"a formal way of cooperation on projects, where we are prepared to be open to sugges-*

tions and joint projects" (InnoPharma1-2). Overall, all companies agree that transparent cooperation is the most important aspect of improving stakeholder relationships in Slovenia.

Interviewees from other stakeholder organisations in Slovenia have varied perspectives on collaborating with innovative pharmaceutical companies. Some expressed concern that the companies influence decision-makers by providing non-public information, sometimes pushing the boundaries of acceptable practices, with one noting that *"it becomes marketing at times"* (SH3). While recognising the necessity of communication, others stressed the importance of maintaining integrity, with frustrations over the Ministry of Health's inaccessibility. *"Communication is necessary because we work in the same field, but we must be careful about integrity"* (SH3). There were concerns that the industry often focused too much on profit rather than addressing societal needs. *"The industry complains too much. It should meet the needs of society, not just chase profit"* (SH4). Some interviewed stakeholders appreciated that pharmaceutical companies do not have unfettered access to the Ministry of Health, feeling it is better that way. *"I am glad they do not have access to the Ministry [of Health]"* (SH4).

Some interviewed stakeholders highlighted the need for better dialogue and collaboration, stating that their *"doors are always open"* for engagement with the industry (SH2). Others also recognised that *"stakeholder engagement and dialogue are crucial"* (SH5). There was also a shared desire to foster greater cooperation among different stakeholders to ensure the development of better working conditions and improved outcomes for the healthcare system. Despite some concerns, there was optimism that more transparent and structured collaboration could lead to mutually beneficial results for Slovenia's healthcare and economic landscape.

3.1.4 Slovenia's path to a regional pharmaceutical hub

According to some of the interviewees, Slovenia faces several challenges that hinder the attraction of larger investments. They noted that the lack of modern infrastructure, particularly poor transport connections, and an unstable economic environment deter potential investors. One said, "*To attract more investment, it is essential to improve the tax situation and create a stable business environment; we can start by listening to each other"* (InnoPharma2). Less than half of the interviewees from the pharma companies believed that Slovenia could become extremely attractive as a centre of operations if it offered even better conditions for companies. One interviewee pointed out, *"As a small market, we are ideal for pilot projects and introducing innovations, but we would need better conditions to become truly competitive, e.g., lower taxes and simpler employment of foreigners would be a big step in the right direction"* (InnoPharma6). However, some respondents employed in the pharma sector believed that Slovenia has all the potential to become a centre of operations. One noted, "*We would need to establish long-term strategic goals for the country, what the main pillars are, which key stakeholders to include, and then this would happen regardless of who is in charge of the country"* (InnoPharma8). Additionally, some highlighted that Slovenia needs *"favourable business legislation (we can look at Switzerland and Singapore, for example), reasonable taxes, favourable talent exchange laws and incentives for talent to come to the country"* (InnoPharma1-1). Others also emphasised: *"The data exists! Let's establish a system for advanced data use. With this, I believe Slovenia can become a hub"* (InnoPharma1-2), and added, *"We want to be a centre! Cooperation, partnership, and a long-term vision are the foundations of our endeavour. By removing bureaucratic obstacles, promoting clinical research, and establishing a long-term awareness program that we are all responsible for moving Slovenia forward in a better direction, the standard of living will also increase"* (InnoPharma1-2).

Some interviewees from pharma companies believed that we are not moving in a direction where Slovenia could become a centre of operations for innovative pharmaceutical companies, stating for example that *"There is no chance (Ireland and the Netherlands, for example, are very strong), even Croatia is overtaking us due to the attractiveness of its tax policy and employment costs"* (InnoPharma5-2), and adding that *"We do not have a competitive workforce to become a centre, as there is too little of it and it is too expensive"* (InnoPharma5-2). One interviewee noted, *"The Serbian government is actively courting pharmaceutical companies to establish centres of excellence in Belgrade, offering a range of incentives. Slovenia, despite its proximity, is not even being considered as an alternative due to its significantly higher operating costs"* (InnoPharma9). Another one pointed out that *"Due to missed opportunities and insufficient state support in building a suitable business environment, we have failed to realise our vision of becoming a leading regional centre. With appropriate measures and the promotion of good practices, we could significantly improve the situation"* (SH1).

The interviewees from stakeholder organisations were slightly more optimistic and believed that Slovenia has the potential to become a regional hub for innovative pharmaceutical companies. One for example stated that *"The state is an* *extremely important factor in innovating new technologies, and it is important to set some goals (mission-driven strategies)"* (SH2) and noted, *"If you can make it here, you can make it anywhere"* (SH2) – suggesting that Slovenia can become a global player in this field. However, to realise this potential, a stable business environment must be created, as emphasised, *"Companies want a predictable environment, and they come to places where the system is stable"* (SH7).

To make Slovenia an attractive destination for pharmaceutical and healthcare innovations, it is also crucial to have adaptable regulations, with one interviewee stating that *"If they [innovative pharmaceutical companies] approach us with an idea, especially if it concerns the entire ecosystem, we can temporarily freeze a rule if something needs to be tested"* (SH2). This indicates a belief that culture of experimentation and flexibility should be introduced into the regulatory environment. *"We should introduce a culture of a testing environment (e.g., a sandbox) for technological and regulatory matters"* (SH2).

3.2 Discussion

The in-depth interviews and their analysis provided insights into Slovenia's pharmaceutical industry's environment, highlighting the key factors that foster innovation. One of the central findings is the vital role that innovative pharmaceutical companies perceive they play in contributing to healthcare quality and economic development. Interviewees from pharma companies emphasise their positive impact, from early access to new medicines to job creation and international collaboration. However, some interviewees from other stakeholder organisations expressed concerns about their long-term economic contributions, raising questions about the extent of their value and highlighting the need for clear evidence on added benefits to justify the increasing burden on financially constrained healthcare systems. They also raised the issue of profit shifting abroad and limited local investment.

Regarding the business environment, the research identified Slovenia's strategic location, the need for continued improvements and accessibility of the healthcare system, and local talent as key motivators for multinational pharmaceutical companies to establish subsidiaries in the country. However, challenges such as high payroll taxes, complex administrative procedures, lengthy drug reimbursement processes, and a shortage of skilled personnel have been identified as significant barriers to industry growth. Furthermore, the regulatory environment and lack of efficient data management also deter the development of a more robust pharmaceutical ecosystem. Other stakeholders, on the other hand, also stress their challenges, which are external, i.e., EU general pharmaceutical regulation, joint EU HTA regulation and data privacy rules, and internal, i.e., primarily limited resources coupled with increasing demands.

Collaboration among stakeholders was also recognised as a crucial yet contentious point. Interviewees from pharmaceutical companies advocate for greater involvement in decision-making and policy development. They note difficulties in establishing productive communication with public institutions, especially with the Ministry of Health. Despite these challenges, there was a consensus on the need for increased transparency, structured frameworks, and formalised cooperation to implement cost-effective solutions to benefit the country's healthcare and the overall economy.

The research revealed varying opinions of interviewed stakeholders about the potential for Slovenia to become a regional hub for pharmaceutical innovation. While some expressed optimism about Slovenia's potential due to its small market size, strategic location, and opportunities for pilot projects, others pointed out obstacles such as inadequate infrastructure, unsatisfactory communication, high operating costs, and competition from other countries with more favourable tax policies. Key findings from the interviews are summarised in Table 2.

Table 2. Summary of key findings

Perceptions about:	Key findings
Value added of the presence of innovative pharmaceutical companies in Slovenia	• Enhanced availability of medicines and therapies in Slovenia (varied opinions). • High-paying jobs for highly educated people (all agreed). • The multiplier effect effect on employment (some pointed out). • Collaboration with educational and healthcare institutions (most do). • Funding continuous education for healthcare professionals (most agreed). • Catalysts for healthcare innovations (some pointed out). • An understanding of value from a wider societal perspective (some pointed out).
Current business environment and operations	• Strategic importance of Slovenia for pharma companies (most agreed). • Rigid regulatory framework at EU and national levels (most agreed). • Long processes in public institutions (varied opinions). • Lack of clinical trials (most agreed). • High payroll taxes (most agreed). • Weak healthcare system management (some pointed out). • Need for improved data management and digitalisation (varied opinions). • Need for improved evidence-informed decision-making. • Threat of exit of some pharma companies (some fear).
Stakeholder relationships and collaboration	• Key stakeholders – JAZMP, HIIS, NIPH, Ministry of Health, Ministry of Economy, Tourism and Sport, healthcare professionals, healthcare organisations, patients (most agreed). • Limited collaboration and communication (most agreed). • Low involvement in decision-making processes (most agreed). • Inaccessible Ministry of Health (most agreed). • NIPH is uncooperative (InnoPharma2, InnoPharma7). • Concerns about Slovenia's long-term viability due to bureaucratic obstacles (some pointed out). • Shortage of healthcare professionals (most agreed). • Call for a more systematic, transparent and formal cooperation between public and private sectors focused on cost-effective solutions (most agreed). • The need to strengthen the resources and capacities of national regulatory bodies and agencies with a clear division of responsibilities (most agreed).
Slovenia's path to a regional pharmaceutical hub	• Lack of digital infrastructure (varied opinions). • Unstable economic environment (some pointed out). • High payroll taxes and complex employment processes for foreign workers (some pointed out). • Need for strategic long-term goals in Slovenia (most agreed). • Potential pilot project country (some pointed out). • Scepticism about Slovenia as a regional hub (most agreed). • Need for strong state support (varied opinions). • Potential "sandbox" environment (some pointed out).

Source: Own Work (2024).

4 Conclusion

The interviews with high-ranking decision-makers from various stakeholder organisations identified several key areas crucial for maximising the benefits of innovative pharmaceutical companies in Slovenia's healthcare ecosystem.

These include fostering stronger and transparent collaboration and open dialogue between public and private sectors, strengthening the healthcare system, improving access to medicines, and creating a regulatory environment that encourages innovation and enables evidence-informed resource allocation decisions in severely strained healthcare budgets. Effective management, developing a national consensus on long-term strategic goals for the public sector, and establishing favourable business legislation and regulations are essential. Promoting clinical trials is vital for driving innovation and advancing healthcare in the country. Lastly, favourable taxation policies, a stable business environment, and appropriate labour market regulations are crucial factors that could contribute to Slovenia's potential as a regional pharmaceutical hub.

In our opinion, all stakeholders fundamentally desire a unified national healthcare strategy for Slovenia that remains consistent regardless of political leadership. This approach is essential for ensuring that Slovenia's healthcare system remains resilient and effective in the long term. It requires ongoing collaboration and open, transparent communication among all parties to foster mutual trust. While each stakeholder may have its own specific agenda, maintaining an open dialogue and adhering to ethical principles is crucial. By prioritising societal well-being and continuously striving for improvement and innovation, Slovenia has a promising future in healthcare, characterised by a supportive business environment where all stakeholders collaborate to shape an even more efficient and effective healthcare system.

The research provided valuable insights by interviewing high-level pharmaceutical executives, providing an industry perspective on the business environment and future strategic planning. Interviews with relevant stakeholders from public institutions provided insights into challenges faced by public healthcare systems that struggle to meet the increasing healthcare demands and are under pressure to ensure transparent use of public funds for diverse healthcare technologies and to avoid expenditures that do not improve health outcomes. However, the research had limitations due to the higher number of company interviewees compared to the interviewees from the public sector and the small sample size. To address these limitations, future research could employ a survey-based approach (quantitative research) to include a broader range of stakeholders, such as patients and the general public, providing a more comprehensive understanding of healthcare in Slovenia.

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SHIFTING GEARS: SLOVENIA'S AUTOMOTIVE INDUSTRY IN A COMPETITIVE GLOBAL MARKET

1 Introduction

Globally speaking, the automotive industry is currently going through significant changes, including the transition from internal combustion engines (ICE) to electric powertrains and software-driven differentiation (Cornet et al., 2023). Additionally, Chinese automakers have started undercutting European rivals. With strong export momentum, sales growth in China is predicted to reach two to four percent in 2024. Due to high expenses and geopolitical uncertainties, European sales are expected to decline. In contrast, USA growth will improve somewhat but still be below pre-pandemic levels. By 2030, it is predicted that both Tesla and Chinese original equipment manufacturers (OEMs) will have 7 percent of the European market share (Ferraris et al., 2024). The overall share of Chinese car brands in Europe is estimated at 2.35 percent in 2024 (Mobility Portal, 2024). As these global shifts accelerate, it becomes increasingly important for Slovenia to assess its position and competitiveness to stay relevant, given its strong integration into the European automotive industry.

This chapter aims to assess the potential for Slovenia's automotive industry, both within the EU and in comparison to global competitors. The chapter first analyses the current global landscape of the automotive industry. The second objective focuses on assessing the current state of Slovenia's automotive industry and its competitiveness. Following this, the focus is on exploring Slovenia's views on sustainability trends and the transition to e-mobility. Lastly, the chapter studies the role of regulatory frameworks in promoting advancements within the automotive sector. By addressing these issues, the findings can help guide the industry in a more competitive and sustainable direction.

The chapter is structured as follows: first, an overview of the global automotive industry is provided, followed by an overview of the Slovenian automotive industry. Next, a literature review offers deeper insights into key challenges and trends. Finally, an empirical analysis based on interviews with Slovenian automotive and mobility companies provides insights into the industry's current situation and future prospects.

2 Overview of the industry

2.1 Global automotive industry

The global automotive industry is undergoing a significant structural transformation (European Commission, 2024a). It struggled in 2020 and 2021 due to the pandemic and a slowing economy. The war in Ukraine worsened supply chain issues and caused a semiconductor shortage, affecting production also in 2022 (Carlier, 2024a). As economies reopened, car demand decreased by only 1.4 percent from 2021 to 2022. However, supply bottlenecks continued, and rising inflation, along with higher raw material costs, further impacted profits in both 2022 and 2023 (Carlier, 2024a).

In 2023, global car sales rose to 75.3 million, up from 67.3 million in 2022 (Carlier, 2024b). However, Chinese passenger vehicle sales in 2022 were already 9.9 percent higher than pre-pandemic levels, even as global sales slowed (Carlier, 2024c). Since 2017, China has led global passenger vehicle production, contributing nearly 30 percent of total output, driven by rapid economic growth and expanding middle class. It sold 26.9 million vehicles in 2022, outpacing the USA by 11 million units (Zhang, 2024).

While China's output has rapidly increased, vehicle production in the EU has been steadily declining over the past two decades. EU automotive production at constant prices has not yet fully reached pre-pandemic levels. Additionally, EU vehicle exports dropped from 7.45 million units in 2017 to 6.26 million in 2022, reflecting a 16 percent decline. On the other hand, imports of vehicles from China to the EU have surged significantly, with the number of vehicles increasing fivefold from 114,000 in 2017 to 561,000 in 2022. By 2022, China supplied 14 percent of the EU's vehicle imports, making it the largest non-European supplier (European Commission, 2024a).

In response to global emissions regulations, automakers are shifting toward electric mobility. The EU is falling behind in the rapidly growing 'New Energy

Vehicle' segment (battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)) (European Commission, 2024a). In contrast, China and the USA lead the electric vehicle (EV) sector, with China's EV registrations growing by 82 percent in 2022 (Carlier, 2024b). The surge in Chinese EV sales can also be attributed to substantial subsidies from the Chinese government. From 2009 to 2023, it allocated \$230.9 billion to support new-energy vehicles (NEVs), with initial annual funding of around \$6.74 billion (2009–2017), which tripled from 2018 to 2020. This support covered rebates, sales tax exemptions, infrastructure funding, R&D, and government procurement. While rebates and tax exemptions were the main sources of support, the government reduced and then eliminated the rebates in 2022 and 2023 to cut costs and streamline the industry (Kennedy, 2024). Chinese brands made significant inroads in the EU market, representing nearly 4 percent of BEV sales in 2022, up from 0.4 percent three years earlier. Chinese carmakers' market share for EVs (BEVs and PHEVs) in Europe has increased from 5 percent in 2015 to nearly 15 percent in 2023, while European carmakers' share of the European EV market has dropped from 80 percent to 60 percent over the same period (European Commission, 2024a). As a consequence, Europe started imposing tariffs on Chinese EVs. In 2024, it imposed additional tariffs from 17.4 percent to 37.6 percent, aiming to curb the influx of cheap, state-subsidised vehicles that threaten European carmakers (European Commission, 2024b). In comparison, the United States has imposed a 100 percent tariff on Chinese EVs, significantly higher than Europe's rates. Additionally, the USA has applied tariffs to various other products, from raw materials to finished goods (Ghiretti, 2024).

2.2 Slovenian automotive industry

The Slovenian automotive sector (C29 - Manufacture of motor vehicles, trailers and semi-trailers and C30 - Manufacture of other transport equipment) plays an important role in European vehicle production since it supplies essential parts and systems to major automakers and exports to over 120 countries (SPIRIT Slovenia Business Development Agency, 2023). Slovenia is a global leader in high-end titanium exhaust systems for motorcycles, diesel cold-start systems, and gas springs (SPIRIT Slovenia Business Development Agency, 2023). Despite having only one OEM, the industry includes over 100 suppliers and 600 sub-suppliers, contributing around 10 percent of GDP (Tomažin, 2023) and employing approximately 17,000 people in 2023 (SPIRIT Slovenia Business Development Agency, 2023). The automotive sector accounts for 7 percent of the country's manufacturing value-added, which is only 1 percent below the EU average (European Commission, 2024a). Key export markets in 2023 include

Germany (33 percent), France (13 percent), and Croatia (9 percent). The main export goods are motor vehicles (65 percent) and parts and accessories (27 percent) (SPIRIT Slovenia Business Development Agency, 2023).

Like the European industry, the Slovenian automotive sector has also experienced significant fluctuations in recent years. Table 1 presents the financial performance of the Slovenian automotive sector from 2020 to 2023. In 2022, many financial ratios declined, with a particularly notable drop in ROE for other transport equipment. This decline was driven by significant losses during the year, which outweighed the reduction in capital. However, the industry experienced some improvements in 2023.

Table 1. Financial ratios of the Slovenian automotive sector, 2020–2023

	Motor vehicles, trailers and semi-trailers				Other transport equipment			
Financial indicator	**2020**	**2021**	**2022**	**2023**	**2020**	**2021**	**2022**	**2023**
Net revenue (in mio €)	3,298.671	3,470.830	3,413.792	3,520.909	140.841	180.577	194.163	234.285
EBITDA margin (in percent)	7.4	9.0	8.0	8.7	12.5	12.0	7.6	5.8
Net profit margin (in percent)	1.7	3.5	2.8	3.4	5.7	5.8	-6.7	0.2
ROA (in percent)	2.6	5.4	4.1	4.8	5.1	6.0	-6.6	0.3
ROE (in percent)	6.6	13.1	10.3	11.0	13.1	14.6	-22.8	1.1
No. of employees	14,149	14,330	13,611	13,993	879	909	1,018	1,196
Value added per employee (in €)	46,223	52,132	53,631	57,914	50,307	55,340	48,123	49,806

Source: Own work, based on Dun & Bradstreet (2024).

For motor vehicles, trailers and semi-trailers net revenues increased and reached €3.5 billion in 2023. EBITDA and net profit margin fluctuated over the years and peaked in 2021 (Dun & Bradstreet, 2024). The primary productivity measure, value added per employee, was the only statistic that showed improvement throughout all four years (Dun & Bradstreet, 2024). This finding indicates that companies have become more efficient and productive.

3 Automotive industry: The literature review

3.1 Sustainability trends and e-mobility

The transition towards e-mobility is driven by multiple sustainability trends across regions, with the EU and USA focusing on reducing emissions and promoting alternative technologies. At the same time, China emphasises economic growth and technological leadership. The EU prioritises BEVs through stringent emissions standards and the European Green Deal (Pichler et al., 2021) while also supporting hydrogen as an alternative fuel source via the European Hydrogen Strategy (Olabi et al., 2021). China leads in battery production and is rapidly expanding its fuel cell vehicle (FCEV) infrastructure, aiming for self-sufficiency in critical materials (Richert & Dudek, 2023). Through the Inflation Reduction Act, the USA incentivises domestic EV production and is also investing in hydrogen mobility, particularly for heavy-duty transport (Ordóñez, 2024). Across all regions, a key challenge remains the environmental impact of battery production and disposal, as well as scaling up green hydrogen production to ensure sustainability in the long term (Richert & Dudek, 2023).

3.1.1 European Union's regulatory framework

In the EU, the shift towards sustainable mobility is primarily driven by regulatory frameworks aimed at reducing greenhouse gas emissions and encouraging the adoption of EVs. The European Green Deal outlines a long-term goal of reaching zero net emissions by 2050, consistent with the Paris Agreement's 1.5°C target (Pichler et al., 2021). As the automotive sector contributes 27 percent of the EU's CO_2 emissions, it is a key focus of these efforts (Pichler et al., 2021). The Vehicle Fleet Emission Standards are central to this strategy, mandating that manufacturers progressively lower the average CO_2 emissions of new cars. However, German OEMs were late in embracing electrification due to their specialisation in ICE technologies (Krzywdzinski et al., 2023). The 2015 Dieselgate scandal, however, led to a significant shift towards electromobility (Krzywdzinski et al., 2023). The European Battery Alliance and the Important Projects of Common European Interest (IPCEI) framework aim to build a sustainable, domestic supply chain for battery production, reducing reliance on foreign suppliers (Pichler et al., 2021). One major player in this was Northvolt, once seen as Europe's answer to Asian battery dominance, but is now facing setbacks, including production delays and cancelled contracts (Ronan, 2024). Despite public investments and demand from OEMs like BMW and Volkswagen, these issues slow down Europe's ability to build a domestic battery supply chain and meet its green energy goals. In addition to BEVs, the EU is actively promoting FCEVs as part of its broader mobility strategy. Fuel cells, which use hydrogen as fuel, offer a cleaner alternative for long-distance travel and heavy-duty vehicles, where batteries may be less effective. The EU has also supported research and infrastructure development for hydrogen refuelling stations (Olabi et al., 2021).

3.1.2 China's regulatory framework

China is considered the benchmark for BEVs and the production of their components, especially batteries. Historically, it never had a strong global presence with its OEMs, which allowed for rapid conversions in technology and productivity (Ordóñez, 2024). This shift, combined with a lack of competition and large money injection through subsidies, allowed China to reposition itself as one of the global leaders in the electrification megatrend, especially considering that most battery production and the processing of required materials, like graphite and lithium, take place there (Richert & Dudek, 2023). China's regulatory approach focuses on maintaining its position as a global leader in BEVs and producing critical materials. China dominates the global supply chain for batteries, producing around 65 percent of the world's battery cells and processing nearly 100 percent of the graphite used in lithium-ion batteries (Richert & Dudek, 2023). This control over critical raw materials allows China to set global pricing and secure its dominance in the electrification of the automotive industry (Richert & Dudek, 2023). China is also making progress in the development of FCEVs. Government policies have supported hydrogen fuel cell technology, especially for commercial and heavy-duty vehicles (Olabi et al., 2021). China's control over the global supply chain of critical materials, along with its growing investments in both battery and hydrogen technologies, reinforces its leadership position in the transition towards sustainable mobility (Richert & Dudek, 2023).

3.1.3 United States' regulatory framework

The USA regulatory framework towards e-mobility is driven by the Inflation Reduction Act (IRA), which was passed to accelerate the country's transition to sustainable technologies, particularly EVs. This legislation provides tax credits and incentives for EVs, specifically those that source critical materials from within the United States or from countries in the USA-Mexico-Canada Agreement region (Ordóñez, 2024). This legislative framework aims to strengthen domestic production capabilities and reduce reliance on imports, particularly from China, which dominates the global supply chain for materials like graphite and lithium (Ordóñez, 2024; Richert & Dudek, 2023). Like the EU and China, the US is also heavily investing in fuel cell technology as part of its broader e-mobility strategy. States like California are leading efforts to develop hydrogen refuelling infrastructure, supporting the growth of FCEVs (Olabi et al., 2021).

4 Empirical analysis

4.1 Research methodology

The primary focus of the interviews was to examine four key areas: the competitiveness of the Slovenian automotive sector, perceptions of sustainability and the transition to e-mobility, the impact of regulation and policy, and the resilience of the supply chain. An empirical analysis included nine in-depth interviews with Slovenian automakers between August 26 and September 6, 2024.

Table 2. List of interviewed companies

Company	Position in the value chain	Size	Interviewees	Code
Company 1	Tier 1	Medium	CTO	AUT01
Company 2	Tier 2	Large	CEO	AUT02-1
			Sales	AUT02-2
Company 3	Supportive services	Large	Head of e-infrastructure and charging service for EVs	AUT03-1
			Product manager	AUT03-2
Company 4	OEM	Large	Member of the management board	AUT04-1
			Supply chain and purchasing officer	AUT04-2
Company 5	Tier 2	Large	CEO	AUT05
Company 6	Tier 2	Large	CEO	AUT06
Company 7	Tier 3	Small	CEO	AUT07
Company 8	Tier 3	Small	CEO	AUT08
Company 9	Tier 1	Large	Vice president of mechatronics	AUT09

Source: Own work (2024).

Companies were selected deliberately to include a diverse group of businesses representing various stages of the supply chain, including OEMs, Tier 1, Tier 2 and Tier 3 suppliers, to gain an understanding of the whole automotive value chain (Table 2). It is also important to note that all businesses produce products that are compatible with EVs. Additionally, the scope was extended by considering companies more broadly involved in the automotive industry. The semi-structured interviews allowed us to tailor questions according to each company's expertise and position within the value chain.

4.2 Results

4.2.1 Competitiveness of Slovenian and European automotive industry

The majority of interviewed companies acknowledge the competitiveness of the automotive sector within the Slovenian economy. Slovenia's competitive advantage includes know-how and geographical positioning. *"We are faster, cheaper and put more effort in"* (AUTO8). *The quality of the products remains a strong selling point. "Quality is absolutely something we excel in"* (AUTO5). However, higher corporation taxes, a lack of cohesive governmental support and less governmental assistance are some of the problems Slovenia is facing. *"We have the know-how and the geographical advantage, but we have limited state aid, and we also pay higher taxes on profits. There is no comprehensive policy; everyone has to figure it out for themselves, the state does nothing to help you (unlike in other countries)"* (AUTO7). Slovenian companies are also relatively small, which presents challenges in production capacity. Companies often cannot produce large quantities. Therefore, it is harder to compete with larger players, and they must find a broader customer base to supply smaller batches of products rather than relying on a few large clients. *"The supplier has to be ready to develop a lot of different products, which Slovenian suppliers cannot do. They make excellent products but do not have the capacity. That is where Germans are better"* (AUTO4-2). There is also intense competition within a limited market, forcing Slovenian companies to rely heavily on exports. *"In Slovenia, the car industry is quite strong, but the market is small, competition is very fierce and practically everything is exported"* (AUTO4-2). Slovenia has similar infrastructure and economic conditions to large European players, such as Germany and their producers, yet it still faces a high level of dependency on larger economies. *"We are pretty similar to Germany and Austria in terms of infrastructure and problems, but we are highly dependent on them"* (AUTO2-1).

Since the automotive industry in Europe is facing significant challenges, the Slovenian automotive sector is no exception. *"We are heavily dependent on other countries and, at the moment, everyone is suffering. Labour shortages,* *competition from the East, interest rates, everything is grinding to a halt. As a result, there are fewer orders, and in the car industry, the sales of components declined by up to 50 percent"* (AUTO7). Additionally, Slovenian producers are increasingly challenged by the growing competitiveness of suppliers from Eastern countries. *"Suppliers from the Far East are more responsive and generally have lower prices"* (AUTO4-1). Given the current situation, some companies are considering strategic shifts to stay competitive. *"We need to diversify (who we supply to, decide to compete with China or enter American or West EU markets) and also go more upstream"* (AUTO1).

4.2.2 E-mobility as a future trend

Sustainable mobility development is Europe's highest interest at the moment, and a lot is being done in this regard. The development dictates the trends in the automotive industry. Electrification is currently promoted as a solution for a greener future, though it is not always the most sustainable option. The industry respondents largely agree that electric vehicles present significant challenges overall. *"Electrification may be an ideal story in principle, but there are still several problems. One of them is raw materials and the primacy of the countries from which we buy them. There is also the problem of recycling batteries and their impact on the environment"* (AUTO5).

It is not yet clear what electrification will bring, and it certainly is not the solution for everyone. Some experts are also more critical about this topic and note that EVs are not the future. *"Electric cars have no future because it is illogical and unreasonable to invest so much in infrastructure for too little benefit. Electric cars are only good for big cities. For now, there is no better choice than ICE"* (AUTO7). The coexistence of multiple propellant technologies is the realistic, feasible future the industry is moving towards. EVs will represent a part of that; however, it seems there are no prospects of replacing the existing technologies completely.

From a purely financial standpoint, EVs are also more expensive to produce and have lower margins for producers. *"We are a bit disillusioned. EVs cannot really be mass adopted since costs are very high, OEMs are losing money on them. Products are also not yet good enough"* (AUTO1). The remark stands out, especially when compared to the competitive products aggressively entering the European market from the Far East. Currently, EVs are catching on to the population; however, the *"key deciding factor for mass adoption is the price of cars (EVs are much more expensive)"* (AUTO3-2).

Digging deeper into electric car purchases, experts highlighted that whole electrification is run by subsidies and tax exemptions. *"Companies buy EVs only because of subsidies, tax exemptions, and other benefits"* (AUTO7). Other than that, there are no big benefits for the consumer in Slovenia's local market, and other European markets are not far from this pragmatism either. Many are concerned with the range of EVs, charging times, and the general convenience of a car, but the main concern remains the price. *"E-vehicles for the EU market are not made for the consumer, but they are made to satisfy regulation. They are products designed for the upper class. The Chinese, on the contrary, have products for 90 percent of the people"* (AUTO6). *"If it is not convenient, people will not make a switch"* (AUTO2-1).

An alternative propellant recently gaining in popularity in the consumer markets is hydrogen. The benefit of the propellant is that it can be used in both ICEs as an alternative to fossil fuels and EV applications with the use of fuel cells. The technology seems promising; however, concerns have been posed from multiple perspectives, questioning its feasibility in general. At the moment, extracting hydrogen is an overly energy-intensive process for which the propellant gets many critics. *"There is no greener way than hydrogen, but if it takes so much energy to enable it, it is not green anymore. Most hydrogen is brown, so it is not green. It is even more absurd than the battery"* (AUTO2-1).

Conversely, some express a more favourable outlook on hydrogen, particularly for heavy-duty traffic. *"Hydrogen is a better alternative to electricity. Especially for city buses, trains and ferries, hydrogen is an absolute winner because there is no time problem (charging) and no emissions. The infrastructure would, of course, have to be properly sorted out. The problem is, therefore, safe infrastructure and hydrogen storage"* (AUTO5). It is worth noting that the current infrastructure is considerably better suited for hydrogen adoption than it is for the adoption of an electric charging infrastructure. *"The EU does not have materials for batteries, so in this regard, we are moving closer to hydrogen. It is the most natural evolution for us; there are a lot of similarities between fossil fuel and hydrogen fuel pumps"* (AUTO3-1).

The ultimate solution to increasing sustainability is not electrification, after all. The current trends are pushing towards higher consumerism of EVs, while the average number of occupants per passenger car is 1.3 (SURS, 2021). As stated by one of the interviewees, *"Reducing ICE would be the responsible thing to do. But it would be even more responsible to reduce mobility. We can only change the way we drive. An electric car weighs more, so it will also use* *more energy. Physics cannot be cheated"* (AUTO6). Such actions would not be financially lucrative for either the European industry or the local Slovenian industry. Potentially accepting such abrupt changes would bring many businesses within the sector to an end, which is not in the public interest either.

4.2.3 EU regulation and policy

European regulation and policy play a crucial role in shaping the future of the automotive industry and determining its direction. There is consensus that the overarching goals of European regulations are well-intended. However, many experts express significant criticism toward the current regulatory approach and state that implementation and communication of these guidelines should be improved. *"The guidelines are correct, but I do not know if they are properly expressed and enacted. We should not set guidelines that are too strict"* (AUTO4-2). *"We no longer have our own aluminium, and therefore we need to import it, which has a much bigger carbon footprint, but if you ask the regulators, we are greener"* (AUTO6). One interviewee stated, *"I think we have gone too far into coercion. We should have given more incentives (instead of penalties), and we would have had the same effect. Penalties usually end badly, and all the indications are that this one will, too. People need to accept this as evolution and not as a dictate"* (AUTO4-2).

Respondents also mentioned increasing concerns over Europe's diminishing competitiveness in the global automotive market. Compared to other major players, the EU's stricter policies and regulations are seen as barriers that impede innovation and growth within the industry. *"The EU is systematically and rigorously tightening its regulations. China, for example, has no such regulations; they use non-recycled materials, which are easier to work with. Our competitiveness is therefore declining"* (AUTO5). *"The important difference between China and Europe is regulation. Strict policies are probably suffocating us. Chinese EV vehicles are on a par with European ones, except they are cheaper"* (AUTO4-1). The EU's leadership in environmental regulation brings challenges. The connection between politics and industry must be strengthened to foster a more innovation-friendly environment. *"There is too little connection to the economy and industries. Because of regulation, we (Europe) are losing competitiveness"* (AUTO8). As noted, *"EU is the bleeding edge of environmental regulation"* (AUTO1). While markets generally regulate themselves through profit-driven incentives, regulation remains the only lever to steer industries in the desired direction. By introducing both incentives to encourage the production of environmentally friendly products and penalties for non-compliance, governments are influencing market behaviour. *"Market, in general, develops itself; profit always determines it, and it starts to change only with incentives and penalties"* (AUTO3-1).

Some experts are even more critical of the current regulatory trajectory, expressing concerns that the policies, while aligned with governmental goals, may not serve the best interests of the people or the industry. One interviewee expressed frustration with the regulatory environment, stating, *"In my view, we are going in the wrong direction. It is the direction for the country, but not for the people"* (AUTO7). Moreover, the pressure to meet regulatory requirements forces producers to focus on compliance rather than innovation or customer satisfaction. This circumstance creates a situation where the focus shifts from creating superior products to simply meeting regulatory standards, which may not always align with producing better vehicles for consumers. One interviewee explained, *"We only carry out cars that comply with regulation. If we pull off from some goals, there will be problems"* (AUTO1).

4.2.4 Supply chain resilience and disruption

Supply chain resilience has become one of the larger concerns of the automotive industry amid the COVID-19 pandemic. Considering that vehicle production requires the largest number of parts and, thus, has the highest logistics complexity, the negative effect on the industry was immense. The shift towards electrification has led to an increased demand for raw materials, which are essential not only for batteries but also for other vehicle components. Europe's domestic production is limited, as mines in places like Germany have been closing due to environmental concerns, leaving the region heavily dependent on imports, primarily from China. *"It is impossible by 2030 to fill the need for EVs. We are dependent on receiving products from elsewhere"* (AUTO2-1). The EU's reliance on external suppliers is a growing concern not only due to dependency concerns but primarily due to economic feasibility.

Industry respondents argue that increasing self-reliance is crucial for long-term stability. *"Mining would have a big impact on us, but we should still be more independent"* (AUTO4-2). The need to balance environmental sustainability with economic and strategic interests is a major point of contention. Without boosting local sourcing, the EU risks exposing the majority of the automotive industry to extinction in the long run. The competitors from the Far East are shown to be ahead not only in productivity but also in technology and pricing.

“If the EU does not start mining, others will. It would be better to focus on hydrogen anyway. Even if one fraction of the effort were to translate into that, we would be much better off” (AUTO5). Hydrogen, while still in its early stages, presents a potential that could reduce the reliance on critical raw materials that Europe currently imports. Considering the presence of all technologies, the debate is favouring BEVs despite the potential upsides of alternatives. However, any changes in the EU directives would bear considerable negative financial consequences for the industry due to new-born R&D costs.

Table 3. A summary of key empirical findings

Aspect	Findings
Competitiveness of the Slovenian automotive industry	• Know-how and location as advantages. • High taxes, limited government support. • Small company size limits production. • Reliance on exports and larger economies.
E-mobility as a future trend	• EV challenges: raw materials, recycling, costs. • High production costs hinder adoption. • Hydrogen potential for heavy-duty vehicles. • EV sales are driven by subsidies.
EU regulation and policy	• Strict regulations stifle innovation. • Europe is losing competitiveness to China. • Focus on compliance, not innovation or consumers.
Supply chain resilience and disruption	• Increased dependence on imports, especially from China. • Limited EU production threatens stability. • Mining, hydrogen crucial for self-reliance. • Concerns over meeting 2030 EV demand.

Source: Own work (2024).

5 Conclusion

The Slovenian automotive industry stands at a crossroads with its European counterparts, facing both opportunities and challenges as it seeks to maintain its competitiveness in the global markets. With a strong foundation in high-quality production and a well-established network of suppliers, Slovenia is well-positioned to continue being a renowned contributor to the automotive sector. However, the industry’s dependence on external resources, particularly China’s, underscores the importance of localising supply sources by exploring local alternatives, including initiatives such as reopening mines within Europe. These efforts are crucial to reducing vulnerability and mitigating reliance on foreign suppliers, ensuring a more stable and resilient future for the industry.

At the same time, the shift towards electrification, while critical for achieving sustainability goals, presents its own set of challenges. The high production costs of EVs, combined with the complexities of the electric infrastructure, raw material sourcing, and recycling processes, indicate that electrification alone may not be the universal solution. A more diversified approach to mobility, including the development of hydrogen as an alternative propellant, could offer greater flexibility and sustainability for the industry in the long term.

In addition to these supply and technological challenges, regulatory pressure from the EU is pushing the industry to adapt quickly. While the overarching goals of sustainability are necessary, there is a growing concern that the stringent policies may be halting competitiveness, particularly when compared to less regulated markets in other regions. Striking a balance between regulatory compliance, innovation, and competitiveness will be critical for Slovenia and the EU in the near future.

Slovenia's role within the sector remains strongly dependent on larger European players and is likely to remain so in the future. Enhancing agility in Slovenian local suppliers and integrating local industry products and services into the supply chains of Chinese manufacturers entering Europe could be one of the first steps toward a successful industry transformation.

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THE STATE'S ROLE IN COMMERCIALISING NEW TECHNOLOGIES

1 Introduction

Innovation drives progress across industries, but to unlock its full potential, sectors require tailored policies that address their unique challenges and opportunities (Gibson, 1999). This chapter examines five pillars of innovation: intellectual property rights, research and development (R&D) subsidies, research universities, tax policy, and institutional quality. Intellectual property rights incentivise innovation by ensuring financial returns (Arrow, 1962). R&D subsidies support high-risk projects that may not attract private investment. Research universities foster innovation through knowledge creation and industry collaboration (Kovač, 2024). Tax policies, like R&D credits, lessen financial burdens and stimulate investment (Akcigit et al., 2016). High institutional quality, including strong governance and transparent legal systems, promotes a favourable innovation environment (North & Weingast, 1989). While public education, trade policy, and socio-economic conditions are also relevant, they are not the focus of this chapter. In Slovenia, despite robust research institutions, commercialisation is impeded by the "Valley of Death" (VoD) – the gap between research and market readiness (Gbadegeshin et al., 2022). VoD challenges include limited collaboration between research institutions and the private sector, bureaucratic inefficiencies, and inadequate support for young entrepreneurs (Hansen & George, 2015).

This chapter focuses on two main objectives. The first objective is to identify the government policies required to bridge the gap between research and commercialisation to ensure its successful commercialisation with maximum economic and societal impact. In addition, the second objective is to determine how an institutional framework, along with supportive government policies, can foster a dynamic innovation ecosystem that promotes commercialisation while empowering the young to achieve start-up growth and "unicorn" status.

This chapter begins by examining the stages of innovation, followed by a literature review of challenges, including the importance of intellectual property (IP) protection, financial challenges, tax policy, and administrative delays. It then presents solutions to address these issues. The chapter also discusses the development of Research Networks and the National Innovation Portal (InnoNet) as initiatives to strengthen Slovenia's innovation ecosystem. Finally, the chapter concludes by suggesting government actions.

2 Bridging the innovation chasm: From research to market

The journey from initial research to market, often referred to as the "lab-to-market" pathway, involves several stages – initial research, proof of concept, prototyping, and market entry. Each stage has its unique challenges. One of the most critical phases is the "Valley of Death," where many innovations falter due to a lack of funding and operational hurdles (Branscomb & Auerswald, 2003). Start-ups and small to medium enterprises (SMEs) often struggle to secure capital during this phase, as investors are hesitant to finance high-risk projects without proven markets (Sussan & Acs, 2021), hindering the transition from research to commercialisation (Markman et al., 2021). To address these challenges, strategic government interventions, such as targeted subsidies, grants, and the establishment of innovation ecosystems, are essential to facilitate access to venture capital and provide vital resources for start-ups (OECD, 2021a).

An approach combining a literature review with semi-structured in-depth interviews with stakeholders from various sectors was employed to examine the topic. From 27 August to 3 September, a researcher from the Jožef Stefan Institute (SCIENCE1), a scientist at the National Institute of Chemistry (SCIENCE2), and the CEO of a private sector company (SCIENCE3) were interviewed to share their insights.

2.1 Stages of innovation

The commercialisation process begins with initial research and the development of a proof of concept, primarily driven by universities and research institutions with public funding. While early research generally secures academic support, the proof-of-concept stage faces greater challenges due to scarce and risky funding sources (Branscomb & Auerswald, 2003). This challenge is evident in Slovenia, where public R&D expenditures are lower than the EU average, and risk capital is limited (European Commission, 2023). Once a proof of concept is validated, innovations move into the prototyping and development phase, introducing challenges such as scalability, manufacturing, and market-fit assessments. At this stage, the need for specialised skills and technical expertise grows, and companies must secure additional funding from investors or public subsidies to cover high development costs (OECD, 2020a). In Slovenia, this funding is often difficult to obtain due to limited venture capital and insufficient government support mechanisms (OECD, 2023b). Successfully crossing the "Valley of Death" requires sufficient resources to move to commercialisation, which involves navigating market demand, regulatory challenges, and competition. Government policies, including tax incentives, IP protection, and R&D subsidies, are critical at this stage (Yue et al., 2022; Mramor et al., 2020). However, in Slovenia, despite policy improvements, firms continue to face inadequate tax incentives and complex regulatory environments that hinder scaling (OECD, 2020a).

2.2 Intellectual property: A strategic tool for innovation

Intellectual property protection is vital throughout the commercialisation process, serving as a tool for securing investments, establishing market dominance, and incentivising further innovation. Companies should establish an IP strategy early, integrating it into their overall business plans to protect innovations and enhance their commercial potential (Singh, 2021). For start-ups and SMEs, patents and trademarks are particularly important. Studies indicate that SMEs with registered IP rights are more likely to experience high growth; for example, those with European patents are 34 percent more likely to succeed in sectors like pharmaceuticals and electronics (EUIPO, 2015). However, in Slovenia, many SMEs are unaware of these benefits and lack the resources for effective IP management, which limits their growth potential (Mramor et al., 2020). Despite these advantages, only 10 percent of European SMEs hold registered IP rights. Those that do generate 68 percent higher revenue per employee, highlighting the economic benefits of effective IP management (EUIPO, 2022). Simplifying the IP registration process and educating companies on IP management are essential to fostering innovation (OECD, 2020b).

2.3 Financial challenges: The "Valley of Death"

The "Valley of Death" occurs because investors are reluctant to invest in projects that are still perceived as high-risk (Branscomb & Auerswald, 2003). The lack of early-stage funding leads many promising innovations to be abandoned, as confirmed by studies showing a high attrition rate of start-ups at this critical juncture (Yue et al., 2022). Government interventions such as R&D subsidies and public-private partnerships can help mitigate these risks. For example, the UK's Enterprise Investment Scheme (Yilong & Yinghua, 2021) and Slovenia's evolving innovation policies (Mramor et al., 2020) aim to provide tax relief and financial incentives for SMEs. However, restrictive banking policies, limited venture capital, and insufficient mentorship continue to hinder commercialisation efforts in Slovenia (Mramor et al., 2020).

2.4 Other challenges: Taxes and administrative burdens

2.4.1 Tax policy

High taxes can limit R&D investment, hindering growth and competitiveness (OECD, 2021b). Lowering taxes, as seen in Ireland and Singapore, can boost innovation by freeing up capital for R&D and attracting foreign investment (Singapore Economic Development Board, 2023). Slovenia's 23.6 percent tax rate hampers innovation. Reducing it to 12 to 15 percent could enhance competitiveness (OECD, 2023a). High social security contributions also limit high-tech hiring. Reducing these rates, especially for start-ups, by 50 percent in the first five years would alleviate financial pressure (OECD, 2021a). Moreover, the 25 percent capital gains tax deters long-term investments. Adopting accelerated depreciation policies, like in the USA, could spur technological investment (Internal Revenue Services, 2023). However, tax incentives alone are insufficient; access to private capital and risk-tolerant investors is crucial to help start-ups overcome the "Valley of Death" (Gbadegeshin et al., 2022).

2.4.2 Administrative delays

One of the interviewees, who has experience with patenting processes in Slovenia, stated: *"In Slovenia, patent approval often takes two to three years due to the complexity of applications and the backlog at the Slovenian Intellectual Property Office"* (SCIENCE2). This delay is particularly challenging for fast-paced sectors like technology, where slow patent processing can lead to missed market opportunities (OECD, 2023b). To address these issues, Slovenia could benefit from adopting reforms similar to the US "Track One" program, which offers expedited patent examinations within 12 months (Track One Data | Patents Dashboard | USPTO, n.d.). Proposed reforms include simplifying and digitising the application process to reduce delays, implementing prioritised examinations to shorten approval times, and providing special conditions for start-ups, such as reduced fees and simplified procedures to facilitate faster commercialisation. The Action Plan for Higher Productivity Growth in Slovenia also supports reducing administrative barriers and suggests establishing research-innovation hubs to improve collaboration between universities and the private sector (Mramor et al., 2020). By implementing these reforms, Slovenia can enhance the efficiency of its patent system and support the timely commercialisation of new technologies.

3 Solutions for bridging innovation challenges

To effectively bridge the innovation chasm, a comprehensive strategy is required to address the challenges at each stage of the commercialisation process. The following solutions are proposed:

- **R&D subsidies and public-private partnerships:** Providing robust financial support for high-risk projects, particularly in sectors like pharmaceuticals and advanced manufacturing, is essential. This support could be achieved through enhanced public-private partnerships and increased R&D subsidies, reducing the risks associated with early-stage investments (OECD, 2020b; Mramor et al., 2020).
- **Tax policy reforms:** Lowering corporate taxes and capital gains taxes can attract investment and reduce operational burdens for SMEs and start-ups. A more competitive tax regime could make Slovenia more attractive for innovation-driven investments (Deloitte, 2023). Reducing social security contributions, especially for new businesses, can support high-tech hiring and innovation (OECD, 2023c). The interviewee from the private sector expressed the same view, stating: *"Reducing social security contributions would discourage companies from finding alternative ways to hire people just to keep costs down. It would make it easier for start-ups to hire top talent permanently and focus on growing the business without cutting corners"* (SCIENCE3).
- **IP education and simplified registration:** Educating firms about the importance of IP and streamlining the registration process is crucial for enhancing innovation capacity. Initiatives could include developing IP awareness programs and simplifying application procedures to make IP protection more accessible, especially for SMEs (EUIPO, 2015; Mramor et al., 2020).

- **Accelerated depreciation and patent boxes:** Encouraging investment in new technologies through policies like accelerated depreciation and patent box regimes can offer significant tax benefits on IP-derived income. For example, adopting an approach similar to the USA or Belgium could lower effective tax rates on IP income, stimulating innovation and technological advancement (Ford, Koutsky, & Spiwak, 2007).

4 Strengthening Slovenia's innovation ecosystem: Research networks and a national innovation portal, InnoNet

4. 1 Key stakeholders in the innovation ecosystem

Innovation ecosystems are complex networks comprising six key stakeholders: entrepreneurs (start-ups, manufacturing firms, small businesses), government entities (at local and national levels), corporations (act as major employers, investors, research sponsors, providers of equipment), human relation development programs (build a skilled and competent employee base), capital providers (venture capitalists, banks, private investors), and research institutions (universities, research institutes, national laboratories). They create a dynamic ecosystem that aligns resources, promotes collaboration, and accelerates innovation (Budden & Murray, 2019). The UK government report (2013) identifies four key resources in the innovation system: knowledge, finance, services, and people. It highlights the importance of collaboration between universities and industry, recommending initiatives like innovation vouchers and catapult centres to foster partnerships (UK Parliament, 2013).

4.2 Balancing physical and soft infrastructure in innovation

Commercialisation of innovations requires both **physical** and **'soft' infrastructure**, each playing a distinct role. 'Soft' infrastructure refers to the networks and services that support collaboration and knowledge sharing, which includes networking, fostering partnerships, and providing mentorship or guidance to innovators. In contrast, physical infrastructure focuses on tangible, resource-intensive facilities such as laboratories, specialised equipment, R&D centres and other institutions (Jibril et al., 2023). In Slovenia, the physical infrastructure is well-developed, with 19 public research institutes (Urad RS za mladino, 2024), but there is a notable gap in 'soft' infrastructure. Although entities like the Slovenian Innovation Hub and the Slovenian Research and Innovation Agency (ARIS) exist, there is **a lack of network and connection within the industry**, as emphasised by the interviewees: *"What I miss more than the participation of the government is the participation of the private sector and connections with industry"* (SCIENCE2).

4.3 Strategic initiatives and investments

Leading innovators in the EU invest more than three times more per capita in R&D than Slovenia. Over the past decade, Slovenia's R&D investment has consistently fallen below the EU average. For instance, in 2021, Slovenia's R&D intensity (total of public and private R&D expenditure as a percentage of GDP) was 2.11 percent, compared to the EU average of 2.27 percent (Eurostat, 2023). The Resolution on the Scientific Research and Innovation Strategy of Slovenia 2030, adopted in 2021, aims to increase public investment in scientific research and innovation to 1.25 percent of GDP by 2030 and total investment in scientific research, development and innovation to 3.5 percent of GDP by 2030. This strategy emphasises sustainable development and aims to strengthen collaboration between science and business, focusing on knowledge transfer and innovation (Ministry of Higher Education, Science and Innovation, 2022). By emulating successful models such as Germany's mission-oriented investment bank (Mazzucato & Penna, 2015), Slovenia could better direct public investments towards high-potential sectors such as biotechnology and green energy to boost commercialisation.

4.4 The role of industrial clustering

Geographic proximity, often referred to as industrial clustering, fosters collaboration among universities, corporations, start-ups, and government facilities, driving technology-based economic growth (Abramovsky & Simpson, 2011). The clustering can occur naturally or through the development of research parks, such as the NASA Research Park (Chapman & Wu, 2023). In Slovenia, the upcoming relocation of the Faculty of Mechanical Engineering and the Faculty of Pharmacy to Campus Brdo, alongside other natural sciences faculties and Technological Park Brdo, highlights the potential of such clustering to enhance collaboration within academia and with the industry (Univerza v Ljubljani, 2024).

4.5 Research and innovation networks: A path forward

The concept of **research and innovation networks** is a strategic approach to concentrate expertise, resources, and infrastructure in specific areas to drive innovation and commercialisation. Effective networking and collaboration are crucial for success. Educating entrepreneurs and researchers on building IP portfolios is also important for protecting innovations, securing investment, and gaining market advantages (Hsu & Ziedonis, 2013). One example is the **European model of competence centres** (European Commission, 2024), a project called Procure2Innovate, where they offer institutional support for innovation procurement in key sectors, including information and communication technologies. They function by improving collaboration between public and private entities, offering expertise, and helping reduce barriers to innovation (Procure-2Innovate, 2024). Expanding these centres into new countries has also been a focus of European initiatives to enhance innovation ecosystems (Procure2Innovate, 2024). The US experience shows that sustained education and mentorship improve commercialisation outcomes (Barr et al., 2009). For Slovenia, adopting a similar model could effectively overcome the innovation "Valley of Death" by providing a network for knowledge transfer, public procurement support, and incentives for commercialisation. These networks create an ecosystem where businesses and researchers can work together with governmental support to turn research into market-ready innovations.

Currently, the Slovenian National Competence Centre operates within the Slovenian National Supercomputer Network – SLING, with its primary task being to enhance user knowledge and raise general awareness of the benefits of using high-performance computers (EuroCC, 2024). However, Slovenia needs a new competence centre or network that facilitates collaboration among public institutions, private companies, and researchers. Such a centre would drive innovation, foster partnerships, and reduce risks for investors and innovators. As one of the interviewees said: *"With all physical products, there is a crazy lack of understanding of the business perspective; how you have to prepare for success"* (SCIENCE3). This stance underscores the **need for centres that provide technical expertise and support the business skills** necessary for successful innovation and commercialisation. Another notable example is the Interuniversity Microelectronics Centers (IMEC) in Belgium, a leader in nanoelectronics and digital technologies. It focuses on research, development, and scaling of advanced semiconductor technologies. It serves as a platform for collaboration among academia, industry, and government. IMEC is built on three key pillars: a unique infrastructure, more than 5,500 expert scientists, and a network of more than 600 leading industry partners and global academics (Imec, 2024).

Innovation in SMEs is often hindered by a lack of market knowledge and collaboration networks (Meijer et al., 2019). Slovenia would benefit from establishing **research and innovation networks**, which would function as associations that bring together researchers, scientists, and industry stakeholders. These networks facilitate collaboration by promoting the exchange of knowledge and expertise while also supporting joint efforts to drive innovation. By connecting various actors across sectors, they help align research activities with industry needs, fostering more effective innovation outcomes. Biotech Hills, a biotechnology business accelerator, is an example of such an initiative (Vlada RS, 2024). While Biotech Hills excels in biotechnology, the Center for Development, Demonstration, and Training for Carbon-Free Technologies (Center DUBT) focuses on green technologies. Center DUBT, with its advanced facilities, will bridge the gap between research and industry, advancing technologies to higher levels of readiness (TRL 5-6) and fostering collaboration between different stakeholders, including large companies and start-ups (Pravični prehod Zasavja, 2024). This €30 million initiative, led by the Chemical Institute and co-financed by the Ministry of Higher Education, aims to drive product development, create jobs, and support Slovenia's emissions reduction goal of 40 percent by 2030 while also enhancing research and providing essential training. Center DUBT will enhance research capabilities, provide essential training for students and young researchers, and help overcome commercialisation challenges (Kemijski Inštitut, 2024).

4.6 Global innovation portals: Learning from successful examples

A key feature across successful portals is their focus on simplifying access to funding and fostering collaboration between businesses and academia. Portals streamline the process for businesses, particularly SMEs, to apply for funding through sector-specific competitions and innovation loans (Dirken, 2024). Companies can post specific challenges or technical problems, inviting researchers and innovators to submit solutions. This approach reduces research and development costs for businesses and offers academic institutions opportunities to commercialise their research, creating a mutually beneficial ecosystem (Dirken, 2024). Studies have shown the potential for significant economic returns of these portals, generating £7 in benefit for every £1 of investment in innovation initiatives (Source Advisors, 2024).

Another feature is the facilitation of IP protection and commercialisation. Several portals offer fully digital experiences for registering patents, trademarks, and designs, significantly reducing the time and cost for companies. These systems also provide marketplaces where businesses can access legal and economic services related to IP strategy and commercialisation to protect and monetise their creations (IPOS, 2024).

In addition to funding and IP management, some portals specialise in identifying and promoting high-potential innovations, connecting them with businesses and investors to accelerate commercialisation. These portals categorise innovations based on their market maturity, potential impact, and alignment with Sustainable Development Goals to align investments with global priorities (European Commission, n.d.).

4.7 InnoNet Slovenia: A one-stop hub for innovation

Existing portals are fragmented, focusing on one aspect of commercialisation – funding, IP registration, or networking. They lack an integrated solution that supports every stage of commercialisation. Therefore, a fully integrated portal, **InnoNet Slovenia**, should be established, which would be **government-backed** and managed under the Ministry of Digital Transformation. This approach would ensure a well-supported system, with the government being able to monitor progress toward the Research and Innovation Strategy of Slovenia 2030. The portal could also play a role in shaping new national policies by providing valuable data.

InnoNet Slovenia would offer features, including an innovation matchmaking system, an integrated funding database, an innovation showcase, a business development support office, training and skill-building, a centralised IP registration hub, and an innovation forum.

The core feature of InnoNet would be its **innovation matchmaking system**, which connects researchers, businesses, investors, and public institutions. It would allow businesses to post specific challenges they are facing while researchers and innovators could offer their expertise and solutions. Each user could create a detailed profile, enabling personalised connections between stakeholders. The matchmaking feature could be enhanced by suggestions of relevant connections based on interests, making the process more efficient. This functionality would ensure that businesses find solutions quickly while researchers and start-ups gain exposure to potential partners and investors.

In addition to the matchmaking system, InnoNet would include an **integrated funding database**. This tool could consolidate all available funding opportunities from Slovenian, EU, or international sources into a single platform. Users could filter funding options based on their specific needs, e.g., by sector or stage of commercialisation. Automated notifications would keep users aware of new opportunities, and the portal would even provide guidance on how to apply for funding, making the process smoother and more accessible, which could be especially valuable for start-ups and SMEs.

Another key element would be the **innovation showcase**, which would give researchers and innovators the chance to present their technologies to a wider audience. Each project page could offer a detailed description of the innovation, accompanied by technical specifications and multimedia elements like videos of working prototypes. InnoNet could also host **virtual demo days**, where start-ups could pitch their ideas directly to potential investors, further increasing visibility.

To further support commercialisation efforts, the portal could house a **business development support office**, which would provide essential resources such as legal assistance for intellectual property (IP) management, including patent applications and licensing agreements, as well as templates for business plans and financial planning services. InnoNet could also connect innovators with **mentors** from various industries, offering advice on business development and scaling technologies, helping to mitigate common risks in the commercialisation process.

InnoNet would also feature a **training and skill-building section**, offering e-learning courses on innovation management, entrepreneurship, and IP protection. These courses could be supplemented by recordings from live workshops held at various research and innovation networks so users can access the educational content.

Additionally, the portal could offer a **centralised IP registration hub**, which would provide links to the portals and step-by-step guides for patent, trademark, and copyright applications, making the IP protection process more user-friendly.

Finally, InnoNet would foster collaboration through an **innovation forum** where users could post questions, share knowledge, and seek advice on interdisciplinary challenges. This feature would cultivate a collaborative culture in Slovenia's innovation ecosystem, allowing stakeholders to engage more openly. The government could also use the portal to promote national innovation programs to better align research efforts with national priorities.

The research and innovation networks and InnoNet would create a more dynamic and collaborative environment, allowing Slovenian innovators to move seamlessly from research and development to market-ready products.

4.8 Government actions to enhance commercialisation success

Based on insights from the reviewed literature and interview findings, a set of targeted actions should be carried out to strengthen Slovenia's innovation environment (Table 1).

5 Conclusion

To overcome the "Valley of Death" and foster technology commercialisation, Slovenia must implement key fiscal policies, including tax incentives such as patent boxes, reduced tax rates, and accelerated depreciation for high-tech investments. These measures would alleviate financial burdens and incentivise greater private investment in innovation. Simplifying the intellectual property registration process and offering expedited patent approvals would further support start-ups in protecting and commercialising their inventions.

Additionally, creating robust institutional frameworks through research and innovation networks is vital. These networks would promote collaboration between academia, industry, and government, facilitating knowledge exchange and providing mentorship to innovators. By fostering such connections, Slovenia can drive commercialisation in emerging sectors like biotechnology, green technologies, and pharmaceuticals. In this effort, InnoNet Slovenia would also play a pivotal role, connecting different stakeholders and offering business development support, funding databases, and a centralised IP registration hub. All mentioned novelties, as well as the mentioned policies that lower social security contributions for start-ups and provide R&D tax credits, are crucial for nurturing the next generation of innovators.

By implementing these recommendations, Slovenia can overcome its innovation bottlenecks. The strategic combination of fiscal policy reforms, enhanced institutional support, and the establishment of research and innovations networks and InnoNet will strengthen commercialisation, attract investments, and foster sustainable economic growth.

Table 1. Proposed government actions

Pillar	Name and type of action	Responsibility	Activity	Deadline	Performance indicators
Tax policy	• Comprehensive tax incentives for R&D and innovation.	Ministry of Finance	• Patent boxes. • Reduce corporate income tax. • Social security relief for R&D-intensive companies. • Reduce capital gains tax on long-term innovation investments. • Enable accelerated depreciation for R&D equipment and technology.	2027	• R&D investment activity. • Number of companies benefiting from tax incentives. • Number of start-ups receiving investments. • Number of high-tech firms investing.
R&D subsidies	• Increased R&D subsidies for start-ups and SMEs.	Ministry of Finance	• Provide additional government subsidies for high-risk R&D projects (sectors like green tech and biotechnology).	2026	• Number of riskier R&D project.
Research universities	• University-industry collaboration grants.	Ministry of Education, Science and Sport	• Provide grants to commercialise research projects.	2027	• Number of university-industry partnerships. • Number of collaborative research publications.
Institutional quality	• Administrative streamlining.	Ministry of Public Administration	• Enhance administrative efficiency by reducing time for business registration, work permits, construction permits, and intellectual property filings.	2026	• Average processing time for permits and administrative services. • Number of processed applications.
Institutional quality	• Research and innovation networks.	Ministry of Higher Education, Science and Innovation	• Establish research and innovation networks.	2027	• Number of networks. • Number of pieces of educational content. • Number of collaborative projects.
Institutional quality	• InnoNet Slovenia.	Slovenian Research and Innovation Agency (ARIS), in collaboration with the Ministry of Higher Education, Science and Innovation	• Develop a digital platform (with innovation matchmaking, business development support, legal assistance, financial guidance, and training programs).	2027	• Launch of the platform. • Number of active users. • Number of successful matches.
Intellectual property rights	• Expedited patent approval process.	Slovenian Intellectual Property Office (SIPO)	• Streamline and digitise the patent approval process. • Offering expedited options for start-ups and SMEs.	2025	• Reduction in patent approval times. • Number of start-ups utilising the expedited process.

Source: Own work (2024).

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MACHINE MANUFACTURING FOR A GREEN AND SUSTAINABLE FUTURE

1 Introduction

The global industrial landscape is experiencing an unprecedented transformation driven by technological advancements and the growing imperative for sustainability. The machine manufacturing sector, valued at $2.55 trillion in 2023 and projected to grow at a 5.2 percent compound annual growth rate (CAGR) through 2028, stands at the forefront of this transformation (Statista, 2023). It plays a critical role in supporting the shift towards greener economies by providing the essential tools and innovations needed across various industries (Ramdoo, 2019). As nations strive to achieve net-zero emissions and adhere to stricter environmental policies, the machinery sector must not only innovate for its customers but also undergo significant internal transformations to align with global sustainability goals (Bastas, 2021).

Globalisation, digitalisation, the push for sustainability, and shifting geopolitical dynamics have reshaped the manufacturing landscape. Manufacturers are increasingly adopting green technologies and advanced digital tools like artificial intelligence (AI) and automation to enhance efficiency and reduce environmental impact (Peetz, 2019). In response, industrial leaders such as the United States, the EU, and China are adapting policies to stay competitive and addressing challenges posed by global trade disruptions and evolving geopolitical tensions (Manning, 2020).

This chapter explores how the machinery manufacturing sector is positioned to drive sustainability while navigating the technological, economic, and geopolitical challenges shaping the future. The chapter is organised into four sections, starting with an industry overview, followed by global trends and green manufacturing practices. It continues with an empirical analysis based on interviews with industry leaders, providing insights into current practices and challenges, and concludes with a discussion of future prospects for the engineering sector.

2 Industry overview

The machinery and equipment manufacturing industry, classified under NACE codes C27 and C28, contributes 2 percent to the output of the world economy (Statista, 2023). This industry covers the manufacture of a wide range of machinery and electrical equipment used in a variety of sectors, including pharmaceuticals, biotechnology, agriculture, renewable energy, medicine, logistics, construction, defence, manufacturing, and other industrial applications, making it a backbone of industrial production (Zhang et al., 2021).

In recent years, the industry, like many others, has faced transformational changes, largely driven by digitalisation, an ageing population and the green transition (Broccardo et al., 2023). The industry's dual contribution to green initiatives is a crucial element of this transformation. From one perspective, the industry plays a key role in the green transition by providing essential products for energy production and renewable technologies. On the other hand, the industry must adapt by becoming more energy efficient and environmentally responsible, aligning its operations with the broader sustainability goals it helps to support (Jibhakate et al., 2021). At the same time, rapid advances in digital technologies have revolutionised processes, enabling greater efficiency, automation, and data-driven decision-making (Broccardo et al., 2023).

In the global context, the machine manufacturing industry is centred in three major regions (EU, USA, and China), each distinguished by specific factors such as precision engineering and sustainability, cost-effective labour and large-scale production, and innovation driven by advanced technology and level of automation. The key regions of the global machinery industry each have distinct advantages and challenges. In Europe, strengths include precision engineering and leadership in sustainable practices, but high labour costs and strict regulations are drawbacks, with ongoing developments focused on green technologies and automation. China, for now, still benefits from low-cost labour and large-scale production, but its progress in digitalisation and automation has been comparatively slower. Additionally, Western companies are hesitant to work with Chinese companies due to security concerns related to data privacy and potential government interference. North America excels in innovation and advanced technology, particularly in AI and automation, but faces challenges from rising operating costs and skill shortages, with developments focused on reshoring and infrastructure modernisation (Zhang et al., 2021).

Table 1. Indicators for the manufacture of machinery and equipment industry in 2023

Indicator*	Slovenia	Germany	EU	USA	China
Mean value added per employee (in €)	52,802	86,667	83,065	175,049	27,540
Share of value added in manufacturing total (in percent)	8.12	16.50	11.26	9.31	10.60
Share of employment in manufacturing total (in percent)	7.57	15.67	10.06	9.89	6.67
Number of companies	740	17,570	76,450	21,000	43,030
Mean value-added margin*** (in percent)	34	39	36	49	35
Value-added growth potential** (2024–2029, in percent)	1.39	0.69	0.82	1.47	0.58
Market growth potential** (2024–2029, in percent)	1.23	0.58	0.79	1.06	0.40

Notes: * Mean value if not indicated differently; ** CAGR: Compound Annual Growth; *** Value-added margin: the share of value added in total revenues.

Source: Own calculation, based on Statista (2024).

The USA has by far the highest value added per employee in the machine manufacturing sector, with fewer companies, but each company tends to be larger, more specialised and focused on high-value production (Table 1). An important factor is that many multinational companies are headquartered in the USA, allowing them to concentrate revenues at the parent company by using subsidiaries abroad to produce goods at lower transfer prices. This practice increases the value added per employee. Although lagging behind the USA, Europe shows promising potential for value-added growth, driven by significant investment in automation and green technologies. It also has a more fragmented industry with many smaller companies. In contrast, China has the lowest value added per employee in the machine manufacturing sector, reflecting a larger number of smaller, less specialised companies focused on high-volume, lower-cost production.

Recent geopolitical crises and supply chain disruptions have shifted the global focus from cost alone to resilience and national security, with reshoring and reindustrialisation efforts in the USA and Europe further driving growth in this industry (Gur & Dilek, 2023). Those shifts are particularly challenging for smaller countries, which may struggle to navigate these evolving dynamics as global trade patterns change. Additionally, a critical factor in manufacturing, especially for machinery and electrical equipment, is access to raw materials. Having strategically secured and produced many scarce resources, China controls much of the value chain. In contrast, despite its expertise, the EU faces increasing challenges due to its reliance on external raw materials, which could hinder its competitiveness and resilience in the future, especially as global demand grows and supply chains remain vulnerable (Noyan, 2023).

Slovenia's mechanical and electrical machinery industry, with a strong tradition in precision engineering, now focuses on improving value-added, fully automated production lines tailored to industries that require customised, advanced solutions. As an important contributor to Slovenia's value added in manufacturing, the sector provides state-of-the-art machinery for many high-growth niche industries, such as renewable energy, biopharmaceuticals, and mobility. Regarding value added per employee, Slovenia is still well below the EU and German averages but much cheaper in terms of labour costs (Table 1). The industry's focus on innovation and automation is helping it bridge this gap, positioning Slovenia as a key player in global markets in supplying high-tech equipment to specialised sectors while maintaining a competitive edge through cost efficiency and technological advancement. Despite their smaller size, Slovenian companies remain competitive by offering specialised, tailor-made solutions. Their agility allows them to adapt quickly and focus on niche markets, offering a level of customisation and flexibility that larger competitors often struggle to match.

3 Machine manufacturing in the context of the net-zero transition

3.1 Sustainable practices and technological integration in machine manufacturing

Transitioning to net-zero emissions has become a pivotal focus in the global industrial landscape, particularly in machine manufacturing. This transition is not merely a response to regulatory pressures but also a strategic shift towards sustainable development that can offer long-term economic and environmental benefits. The move towards net zero involves adopting various innovative practices and technologies to reduce carbon emissions, optimise resource use, and minimise waste throughout the manufacturing process (Bastas, 2021).

One of the primary strategies for achieving net zero in machine manufacturing is adopting green manufacturing practices, which is particularly important due to the energy and resource-intensive nature of the sector. Green manufacturing involves redesigning production processes to minimise environmental impact, primarily through waste reduction, energy efficiency, and renewable resources (McKinsey, 2023). For example, in the metalworking and machining industry, energy-intensive processes such as casting, forging, and milling are being redesigned to minimise their environmental impact. Some manufacturers have introduced advanced machinery that captures and reuses energy during production, significantly reducing overall energy consumption in processes like metal cutting and shaping (Haleem et al., 2023). Additionally, the machine industry highlights the importance of circularity in industrial design by primarily using highly reusable raw materials, such as steel. This approach brings them a double benefit: cost efficiency as they require less new material, and enhanced sustainability. Moreover, integrating renewable energy sources, such as solar and wind power, into the manufacturing process further reduces dependency on fossil fuels and contributes to lower carbon emissions (Yoon et al., 2016).

Machine manufacturers are also adopting specialised approaches to the net-zero transition. Using energy-efficient CNC (Computer Numerical Control) machines and electrifying machine fleets, such as electric forklifts, specifically address emissions from energy-heavy processes and internal logistics (Deloitte, 2023). The adoption of ISO 14001 environmental management standards in manufacturing plants is becoming increasingly common. These standards help companies systematically reduce their environmental impact, ensuring compliance with international regulations and enhancing their competitive advantage in global markets. The push towards obtaining such certifications and obligations to sustainability reporting underscores the growing importance of sustainability in the manufacturing sector (Steinhöfel, 2019).

Machine manufacturing, traditionally a significant contributor to global carbon emissions, faces challenges and opportunities in the net-zero transition. On one hand, the transition demands substantial investments in new technologies, restructuring supply chains, and adopting sustainable materials. Retrofitting existing plants can be costly, and there is a growing need for skilled labour capable of managing advanced manufacturing technologies, which highlights a critical skills gap. On the other hand, these challenges create opportunities for companies to gain a competitive edge through cost reductions, innovation, and meeting the rising consumer demand for eco-friendly products. The global shift toward sustainability drives technological advancements and process innovations that further reduce environmental impact, positioning sustainable manufacturers to lead the future market (Ramdoo, 2019).

3.2 Role of machine manufacturing in different industries

Machine manufacturing is crucial for the green transition of traditional industries and the development of emerging sectors such as biotechnology, pharmaceuticals, and laboratory-grown meat production. These industries rely on precision manufacturing processes that benefit significantly from advanced sustainable practices and technologies (Lomonossoff, 2023).

For instance, in the biotechnology and pharmaceutical industries, machine manufacturing plays a key role in producing high-precision equipment such as bioreactors, which are essential for drug production and biotechnology research. Cleanroom technologies and automation are critical to ensuring product purity and operational efficiency, reducing resource consumption and environmental impact (Sarkar et al., 2024).

As the biotechnology and pharmaceutical industries continue to innovate, the market is set for significant expansion. Emerging technologies and increasing demand for high-precision manufacturing are driving this growth. The biotechnology market is expected to grow at a CAGR of 13.96 percent from 2023 to 2030 (Grand View Research, 2023). As the industry expands, machine manufacturing will be essential in meeting the rising demand for high-precision equipment and sustainable production processes, further enabling technological advancements and scalability (Madzík et al., 2024).

In the emerging sector of laboratory-grown meat, machine manufacturing is crucial for scaling up production to meet market demands while minimising environmental impacts. Bioreactors, a key technology in this industry, require precise control over conditions to grow cultured meat cells, and advancements in automation and sensor technologies have made these systems more energy-efficient and sustainable (Madzík et al., 2024).

As consumer interest and investment in sustainable food alternatives increase, the laboratory-grown meat industry is experiencing rapid advancements. The cultured meat market is projected to grow by 51.6 percent until 2030 (Grand View Research, 2022). This rapid growth creates substantial opportunities for machine manufacturing, particularly in scaling bioreactor systems and enhancing automation to support industry expansion.

Beyond these sectors, machine manufacturing plays a key role in rapidly growing industries, including electric vehicles (EVs), renewable energy, and agricultural technology. In the EV sector, advanced manufacturing techniques are vital for producing components like batteries, electric motors, and lightweight materials, driving market growth projected to grow by 33.6 percent until 2030 (Grand View Research, 2023). Similarly, precision manufacturing is key to scaling up renewable energy production, with investments in clean energy technologies expected to reach $1.5 trillion by 2030 (IEA, 2023). In the agricultural technology sector, innovations like autonomous tractors and drones benefit from precision manufacturing, enhancing resource efficiency and reducing environmental impacts (IEA, 2023).

As these industries grow, machine manufacturing is vital in providing the infrastructure needed for sustainable development. By integrating smart technologies, automation, and energy-efficient systems, machine manufacturing supports green transition and innovation in these emerging fields (Sarkar et al., 2024).

4 Empirical analysis

4.1 Research methodology

This analysis aims to provide insights into how machinery manufacturing companies in Slovenia generate added value, focusing on assisting policymakers in creating conditions that foster industry growth, environmental sustainability, and long-term competitiveness. The empirical analysis is based on 11 in-depth interviews conducted between 26 August and 11 September 2024 with 17 selected executives of companies located in Slovenia. A group of top-performing machine manufacturing companies was selected, focusing primarily on original equipment manufacturers (OEMs) and Tier 1 suppliers, all classified under NACE codes C27 (Manufacture of electrical equipment) and C28 (Manufacture of machinery and equipment). Table 2 provides the main characteristics of these companies and the interviewees.

Table 2. Key sample characteristics

Company	Value chain position	NACE code	Size*	Interviewee's position(s)	Gender	Code
Company 1	OEM	C28	Medium	Sales Regional Manager	Male	MACHINE 1-1
				Chief Financial Officer	Female	MACHINE 1-2
Company 2	OEM	C28	Small	Chief Executive Officer	Male	MACHINE 2-1
				Project Manager	Male	MACHINE 2-2
Company 3	OEM	C28	Large	Brand and HR Manager	Female	MACHINE 3-1
				Purchasing Manager	Male	MACHINE 3-2
				Production Manager	Female	MACHINE 3-3
Company 4	OEM	C28	Large	Chief Executive Officer	Male	MACHINE 4
Company 5	OEM/Tier 1	C28	Large	Production Manager	Male	MACHINE 5-1
				Head of Finance	Male	MACHINE 5-2
Company 6	OEM	C28	Large	Chief Executive Officer	Male	MACHINE 6
Company 7	OEM	C28	Medium	Deputy Managing Director	Male	MACHINE 7
Company 8	OEM	C28	Large	Chief Executive Officer	Male	MACHINE 8
Company 9	OEM/Tier 1	C27	Medium	Chief Executive Officer	Male	MACHINE 9-1
				Marketing Manager	Female	MACHINE 9-2
Company 10	OEM	C27	Large	Chief Executive Officer	Male	MACHINE 10-1
				Sales Manager	Female	MACHINE 10-2
Company 11	Tier 1	C28	Large	Chief Executive Officer	Male	MACHINE 11

Notes: OEM - Original Equipment Manufacturers; *Small company: 10–49 employees, Medium company: 50–249 employees, Large company: 250+ employees

Source: Own work (2024).

4.2 Results

4.2.1 Competitive advantages and reasons for high added value

In a small country like Slovenia, machine manufacturers face challenges in competing with global players on a scale alone. Instead, they focus on creating high value through a customer-centric approach, tailoring their products and services to meet specific industry needs. *"Our main competitive advantage is our customer-focused approach. We develop machines that closely follow customer requirements. The knowledge, flexibility, and commitment to customer satisfaction that we offer are key competitive advantages"* (MACHINE 2-1). Various sub-sectors within the machine manufacturing industry were analysed, including compressed air and gas systems, electronic components, agricultural and woodworking machinery, hydraulics and lifting equipment, stainless steel solutions for the pharmaceutical industry and biotechnology, renewable energy systems, and forestry machinery. Across all these sub-sectors, companies differentiate themselves by offering flexibility, innovation, and personalised solutions. *"The flexibility and adaptability of the company, especially in terms of production adjustments, is considered a significant competitive advantage. The ability to quickly ramp up or slow down production in response to market demands is highlighted as a key strength"* (MACHINE 3-2).

Several companies prioritise maintaining independence by controlling the entire production process, from raw materials to finished products. *"We are one of the companies that take raw material, such as sheet metal, and go from start to finish. We have cutting, welding, blasting, painting, and assembly, along with our own mechanical processing"* (MACHINE 3-2). This independence ensures they maintain control over quality and production timelines, which is crucial for reliability, especially during supply chain disruptions. Providing a full range of services, from product development to after-sales support, enables companies to meet all customer needs under one roof. *"We offer a complete service package, ensuring our clients receive end-to-end support"* (MACHINE 6). It shows how companies shift their focus from simply selling products to offering tailored solutions. *"Our approach to sales is centred around offering expertise rather than just products. We deliver value, not everyday commodities, but the value that comes from specialised knowledge and solutions"* (MACHINE 9-1). This solution-orientated approach helps companies stand out and build lasting customer relationships.

In the global context, Slovenia has relatively small and highly specialised companies operating in niche segments of the machine manufacturing sector. Yet, they can offer a comprehensive range of services to their partners. *"We produce some parts for our customers, and they take the whole package from us because we offer the complete service, including product development, manufacturing, and installation"* (MACHINE 1-1). Many of these companies generate the majority of their revenue from international markets, reflecting their strong global orientation. This global reach diversified their revenue streams and enhanced their competitiveness.

4.2.2 Value chain ecosystem

The machine manufacturing sector in Slovenia is strong and diverse, supporting multiple industries through a range of specialised equipment and technologies. *"Our machinery industry supports everything from automotive to* *green energy, showing how adaptable and important it is across industries"* (MACHINE 11). Companies within the sector play key roles in traditional industries like automotive and construction, as well as emerging fields such as biotechnology, pharmaceuticals, and green energy. This diversity reflects the sector's capacity to serve different value chains, from high-tech manufacturing to sustainable energy, making it an essential part of established and innovative industries. This extensive ecosystem supports innovation and efficient production processes, allowing companies to maintain high standards and adapt swiftly to industry demands. *"We have knowledge here. There is a lot of know-how in the area, which helps maintain a strong production base"* (MACHINE 5-1). OEMs occupy critical positions within the value chain, often achieving higher value added, especially when supplying directly to major industries such as automotive, biotechnology, and pharmaceuticals as Tier 1 suppliers.

Most of the interviewed companies prioritise R&D as a key driver of innovation and competitiveness. *"We have around 15 employees directly involved in the development, and approximately 20 percent of the company is engaged in R&D, with other departments contributing in various stages of the process"* (MACHINE 7). Interviewed companies allocate between 5 to 10 percent of their revenues to R&D activities, recognising its importance in staying competitive, fostering innovation, and creating new products that align with market needs. *"Everything we sell is the result of our own development, including the 35 patents we hold and the 17 protected trademarks we own"* (MACHINE 10-2). Companies also stress the importance of quality and reliability in their supplier networks, often choosing suppliers based on proximity to enhance efficiency and responsiveness. *"Most of our components come from European suppliers, ensuring reliability in the supply chain. The proximity helps to mitigate disruptions, and we saw how fragile global supply chains could be during the Suez Canal crisis and other interruptions"* (MACHINE 7).

Vertical integration is a common strategy among these companies, allowing them to manage large projects more efficiently and achieve critical mass in infrastructure. This approach ensures consistency in quality and operational optimisation. *"We are vertically integrated, meaning that from the design point and engineering point of view, we do everything on our own. We just buy raw materials and components and then manufacture everything in-house, test everything in-house, and install everything on our own again"* (MACHINE 6).

4.2.3 Export and geopolitical implications

All the machine and electrical equipment manufacturing companies in the analysis are export-driven, with the majority maintaining partnerships worldwide. *"We are present on all continents. In Germany, we have direct sales because we bought the dealer, but in other markets like Spain and Austria, we use local dealers"* (MACHINE 5-1). They are highly specialised and operate in specific niche segments, such as manufacturing advanced woodworking machinery and production lines, where they are leaders and presented worldwide. *"We started working all over the world. That means from Japan to Northern America. Also, in the southern hemisphere, we work in South Africa, South America, Australia, and New Zealand. Our equipment is on every continent all over the world"* (MACHINE 4). Consequently, their business is significantly influenced by international markets and geopolitical events, which present numerous opportunities but also considerable risks. Recent geopolitical developments have impacted these companies in various ways, particularly those with suppliers and customers in the affected regions. Despite these challenges, companies consistently stress that the ability to respond swiftly during crises is vital, recognising that future crises are inevitable. *"We try to have redundancy by having two options where you can buy things to mitigate supply chain risks"* (MACHINE 2-1). Dual sourcing is becoming a trend in supplier selection, combining the reliability of domestic suppliers with the cost-effectiveness of suppliers from developing countries. This approach is particularly important for companies using semi-products such as steel plates, pipes, and electronic components.

A recent trend has emerged where Western companies increasingly avoid using Chinese components in their products. This shift is part of a broader geopolitical landscape where the influence of Eastern countries is growing. As a result, the United States and the European Union are imposing more obstacles, such as tariffs and regulations, to limit their reliance on Chinese companies. While the United States continues to hold a dominant position, this is largely due to its control over financial infrastructure. *"We have observed that the USA exerts significant control over global systems, particularly through the flow of money. The SWIFT system, which manages international transactions for all banks, including Chinese banks, is largely under American control"* (MACHINE 2-1). All of this is driving a trend of deglobalisation, with companies increasingly relocating or establishing new manufacturing facilities in Europe. This trend is particularly evident among the partners of Slovenian companies. However, some Slovenian companies in the machine manufacturing sector have, according to Company 4 and Company 5, traditionally kept their manufacturing and R&D facilities within Slovenia, with only sales offices and showrooms abroad, making them less affected by these changes.

4.2.4 Digitalisation and green transition

Companies in the machinery and electrical equipment sector are essential in driving digitalisation and the green transition in other industries. Their research and development activities are key to enabling the innovations needed for a sustainable transformation. All the companies included in the analysis are actively implementing digitalisation and green transition strategies, not only in their production processes but also within the products they manufacture, as part of their broader efforts to align with global sustainability goals. *"Digitalisation is not just a part of our production but also embedded in the products we manufacture, ensuring that they are ready for the future demands of the market"* (MACHINE 4). On the one hand, this poses certain barriers to cost reduction, such as the high level of investment required, but on the other hand, it opens up new markets and increases demand for certain products. The green transition is opening up new markets for engineering companies, particularly in sectors focused on renewable energy and sustainable technologies. As global demand for green products and services grows, these companies increasingly find opportunities in emerging markets, such as hydrogen production and carbon capture. *"We are seeing significant expansion into new markets driven by the green transition, creating unprecedented opportunities for growth and innovation"* (MACHINE 1-1). Overall, companies that have successfully embraced the green transition by actively offering relevant products and services are seeing their financial performance improve, with a growing proportion of their revenues coming from these areas. Their success in renewable energy also makes it easier for them to implement their own green initiatives and investments in digitalisation, ultimately boosting their growth and long-term value.

4.2.5 Human resources

The machine manufacturing industry is experiencing a significant challenge in maintaining a skilled workforce. The demand for qualified engineers is rising rapidly, largely driven by the increasing complexity of new technologies and machinery that require a higher level of technical expertise. As companies invest in advanced machinery and digital systems, there is a growing need for engineers with specialised skills, particularly in electrical engineering and software development. *"It is difficult to get new employees. For example,* *around four years ago, we got around 60 to 70 applications for the position. Now, you get around ten, and most of them are not relevant. Especially if we are talking about electrical engineers, it is impossible to get them nowadays"* (MACHINE 1-1).

Furthermore, despite a solid educational system that produces highly competent engineers, the industry faces challenges in retaining talent due to the absence of a social security cap, which limits the ability to offer competitively high salaries and aligns poorly with changing workforce priorities. *"The average salary in Slovenia is increasing, and Slovenia has become very expensive"* (MACHINE 6). This situation is compounded by changing generational attitudes toward work, where work-life balance is becoming increasingly important, making it harder to attract and retain skilled professionals. *"It is not so much about the skills. It may be this cultural thing that has also changed society in the last couple of years. Work-life balance right now is maybe more important than it was ten years ago"* (MACHINE 6). However, Slovenia is already facing a significant challenge with its declining birth rate, leading to a workforce shortage that government policies alone may struggle to address. *"Slovenia's biggest economic challenge cannot be solved by government measures — it is the declining birth rate, which will lead to a significant shortage of labour in the future, which we will not be able to fully compensate for by importing foreign labour in the long term"* (MACHINE 11).

Despite these challenges, companies are committed to building strong engineering teams, which can take up to 15 years. However, continuous investment in training programs is essential, as new engineers require extensive training to meet the industry's evolving demands. *"New engineers require extensive training, and the demand for software engineers has increased, particularly for those with experience in electronic software"* (MACHINE 2-2). This finding highlights the complexity of maintaining a skilled workforce in the machine manufacturing industry, where education, training, and shifts in societal values – such as the growing preference for work-life balance and job flexibility – play critical roles.

4.2.6 Government support and regulatory obstacles

Companies operate in an environment where the influence of the state is unavoidable. While often intended to solve problems, government intervention can sometimes create more issues than it resolves, particularly for medium-sized and larger companies. "*Sometimes it is better for the government to do* *nothing. Maybe the best solution is for them to just leave us alone"* (MACHINE 4). Companies need to have a stable and predictable environment in terms of legislation and taxation, as any change requires a lot of effort and time to adapt properly and can cause problems in planning. In today's global business, companies will always be exposed to the market and competition. *"Projects must be financially viable on their own, without relying on government support. While such support can boost a project's viability, we never base investments entirely on it. The core investment must stand independently"* (MACHINE 8). In the long term, support must be focused on helping prosperous companies accelerate their growth and development rather than just using it to keep struggling companies alive.

Compared to companies in developing markets, there is an opinion that Slovenian and EU companies receive less support. "*Turkish and Chinese companies benefit from significantly more government support, particularly for international activities"* (MACHINE 1-1). The challenges also include high taxes on highly qualified employees, who are the primary contributors to high value-added output, and lengthy waiting times for permits for foreign workers. *"The biggest issues are high taxes on companies with well-paid engineers and the difficulty in obtaining permits for foreign employees"* (MACHINE 4). In conclusion, while the state strongly supports the R&D activities, there is still considerable room for improvement in other areas.

4.2.7 Future prospects

The prospects for the machine manufacturing industry are closely tied to the ongoing green transition, with significant investments being made in sustainable energy projects across the European Union. Companies within the industry are increasingly focusing on green projects, seeing them as key areas for growth. *"Our company is highly optimistic about the future, particularly in the fields of hydrogen and CO_2 capture technologies. We see these areas as key growth opportunities as global demand for sustainable energy solutions continues to rise. We are already involved in significant projects in these domains and expect them to become major parts of our business moving forward"* (MACHINE 1-1).

In addition to green energy, there is a strong emphasis on investing in new facilities and enhancing the work environment. This approach is not merely about expansion but about improving the conditions for employees, which in turn supports long-term growth. *"We are building new facilities. We are also building quite a lot of new offices for our people. It is not mainly for growing*

10 percent per year or 20 percent; it is because we want to give our people a better working environment" (MACHINE 4). Such investments are critical for maintaining flexibility and staying competitive in a rapidly changing market.

However, the path forward is not without challenges. Rising costs and increased competition are expected to exert pressure on both the workforce and the customer side. *"I think we will have quite the pressure in the next 2 to 3 years in terms of costs from both sides — the workforce, which will probably demand higher wages, and we will have pressure from the customer side to lower the cost because the competition will increase"* (MACHINE 5-1). That is why companies must have owners who understand the business and have long-term interests. It is also important to understand that it is not just about companies; the environment in which they operate also plays an important role. *"We struggle with slow bureaucracy and high taxation, especially when trying to offer competitive wages compared to neighbouring countries like Austria"* (MACHINE 4).

Despite these challenges, the industry remains cautiously optimistic about the future, with many seeing the potential for growth if they can continue to adapt and innovate. *"Given the challenges we face, I believe the future holds potential for growth but requires cautious optimism. We must navigate economic uncertainties, particularly in terms of rising costs and geopolitical impacts. However, by focusing on adaptability, investing in technology, and maintaining strong relationships with suppliers, we can continue to thrive"* (MACHINE 3-1).

The optimism around future growth is shared by many industry leaders, particularly in the electrical sector, which is set to benefit from global trends such as electrification and renewable energy adoption. *"I believe that the electrical industry will have a very bright future due to global trends such as electrification and renewable energy sources"* (MACHINE 10-1). This optimism reflects the broader potential of Slovenia's machine and electrical equipment manufacturing sector, which is rapidly adapting to global shifts towards green technologies. Moreover, the ability of Slovenian companies to manage their production processes independently allows for quick adjustments to market changes, ensuring resilience in a volatile global environment. *"When purchasing new machines, we always prioritise those that are technologically advanced and sustainable"* (MACHINE 7). By integrating advanced technologies and predictive maintenance, manufacturers can optimise the use of resources, improve product quality, and free up human capital for more value-added tasks. *"It is crucial to ensure people are used effectively, not for pointless manual* *tasks, but with measured efficiency, monitoring, and automation or integration wherever possible"* (MACHINE 11).

Overall, the future looks promising, particularly for companies that can stay ahead of technological trends and expand into new markets. *"I am confident that by staying ahead of technological trends and expanding into new markets such as green energy and bioplastics, we can double our revenue in the next 5 to 10 years"* (MACHINE 2-1). The combination of deep technical knowledge, strong customer relationships, and strategic investments positions the industry well for future growth despite the challenges that lie ahead.

Table 3. Key findings

Topics	Key findings
Value added and competitive advantage	• Fast adaptation to market demands. • Flexibility, customer focus, vertical integration in niche markets. • Agility due to independence from suppliers.
Value chain ecosystem	• Diverse industries supported (pharma, biotech, agriculture, etc.). • Focus on R&D (5 to 10 percent of turnover), patents, local suppliers.
Export and global competitiveness	• Export-driven but faces raw material dependencies, geopolitical challenges, and the need for technological upgrades.
Digitalisation and green transition	• Key role in driving digitalisation and green transition in other industries. • New opportunities in renewable energy and sustainability.
Workforce and human resources	• Skilled workforce but issues with attracting and retaining talent due to high wages, declining birth rates, and foreign worker regulations.
Government support and regulatory obstacles	• Beneficial support but hindered by high taxes, slow permits, and excessive regulation. • Competitors with stronger government backing hold an edge.
Future prospects	• Growth in renewable energy and biotechnology. • Continued investment in innovation and workforce skills is key to future success.

Source: Own work (2024).

5 Conclusion

Slovenia's machine manufacturing industry is well-positioned to succeed in the global marketplace due to its flexibility, customer-focused approach, and vertical integration, which allows companies to respond quickly to market demands. Despite their relatively small size, these companies are important players in their niche markets. By embracing sustainable practices and digitalisation, companies are maintaining their competitive edge and expanding into new sectors like biotechnology, pharmaceuticals, and renewable energy. To increase value added in Slovenia's machinery manufacturing industry, companies should focus on increasing automation and digitalisation, which can streamline processes, reduce energy consumption, and increase productivity. Slovenia has hard-working, knowledgeable people, and with a better organisation in the future, their skills should be used much more effectively. In addition, offering the best products means pricing accordingly, which directly increases added value. Besides that, the ownership structure is also important. When profits are transferred out of the country through mechanisms like transfer pricing between subsidiaries and parent companies, the value added remains limited, regardless of the knowledge and technology used. Therefore, the key to stimulating the sector will be to create a more favourable business environment by providing preferential access to land, reducing red tape, facilitating the recruitment of foreign talent and improving access to capital.

In general, Slovenia should foster an entrepreneurial mindset similar to the spirit it has in sports, where successful entrepreneurs are respected like athletes and not seen as outliers. Slovenia must aim for higher ambitions and goals and be ready to take that extra step toward progress and innovation. The machinery and electrical equipment manufacturing sector exemplifies this potential, and it will play a critical role in shaping a better future for Slovenia, driving innovation, sustainability, and economic growth in the years to come.

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TRANSFORMING THE FUTURE: THE CASE OF KOLEKTOR ETRA

1 Introduction

The European Union is currently undergoing two major transitions: the digital transition and the green transition, collectively known as the 'twin transitions'. These transitions are critical to the EU's strategy to recover from the socio-economic impacts of the COVID-19 pandemic and to address the challenges posed by climate change (Diodato et al., 2023). Central to the green transition is the transformation of the EU's energy system to achieve climate neutrality by 2050 as part of the European Green Deal. As the energy sector is the largest source of greenhouse gas emissions in the EU, this transition focuses on shifting from fossil fuels to renewable and low-carbon energy sources, improving energy efficiency, and adopting clean technologies (Widuto, 2023).

Kolektor Etra (KE) is recognised as an important player in the European transformer market, with 548 employees and €228 million in revenues in 2023 (Ajpes, 2024). As a transformer manufacturer, KE is at the forefront of the green transition, contributing to the modernisation of power grids and the integration of renewable energy sources. The company's strategic focus on innovation, sustainability, and expansion has positioned it in the wider ecosystem driving this change. This chapter examines KE in the context of the energy transition, focusing on how the company's strategies and operations align with the broader goals of the twin transitions. Energy transition involves many different players, including suppliers, technology developers, regulators, and consumers, working together as the energy ecosystem (Energy Council, 2024).

The chapter begins by establishing the theoretical framework, outlining the European Union's industrial strategy, the twin transition, and the significance of ecosystem building within the energy sector. The first section addresses green transformation, focusing on the role of transformers. Next, the case study of KE is presented, examining the company's history, operations, and strategic direction. The chapter concludes with an analysis of the impact of KE's contributions to the energy transition and a review of the broader implications for the industry.

2 New industrial strategy, ecosystem building, twin transition, green transformation, and the role of transformers in the energy sector

The new industrial strategy lays the foundation for an industrial policy that will support the twin transitions, make the EU industry more competitive globally, and enhance Europe's strategic autonomy. Europe's industry is undergoing a major transformation, faced with twin challenges of climate neutrality and digital transformation (European Commission, 2020). The twin transitions have their foundation in the European Commission's Next Generation EU (NGEU) plan (European Commission, 2022). With an allocated budget of €800 billion, the initiative is designed to advance a future characterised by environmental sustainability, digital transformation, and resilience (Celeste & Dominioni, 2023). Digital technologies drive the green transition by improving resource management and reducing carbon footprints, with AI and big data optimising energy use and digital platforms supporting renewable energy adoption.

2.1 Ecosystem building

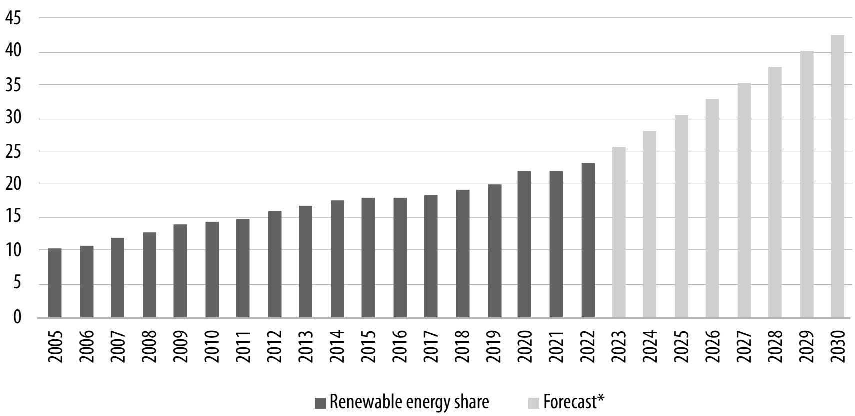
The energy industry is now rapidly transforming into a complex, decentralised ecosystem driven by technological advances, regulatory changes, and evolving consumer behaviours. In this dynamic environment, the success of the energy sector depends on the ability of its diverse ecosystem comprising suppliers, buyers, technology developers, and regulators to forge strategic alliances, engage in joint research and development (R&D), and harness technological advancements for sustainable growth. Consumers are increasingly active in the energy market, generating their own energy and feeding excess back into the grid (Energy Council, 2024).

As the transformer market evolves, companies are strengthening their positions through a comprehensive value chain strategy that covers all stages of production and service. This process begins with sourcing raw materials like silicon steel sheets, copper wires, insulating materials, and transformer oil and continues by manufacturing key components. Essential internal activities include transformer design, technology development, parts processing, and component assembly. Downstream activities, such as product distribution, marketing, after-sales services, and customer feedback management, further enhance product value and support sustained growth (Liang et al., 2018).

2.2 Green transformation and the role of transformers in the energy sector

The energy sector plays a crucial role in the green transformation by increasing the use of renewable sources such as wind, solar, and thermal energy while reducing reliance on non-renewable resources (Kozar & Sulich, 2023). According to Eurostat, the share of renewable energy in the EU increased to 26 percent in 2023, as shown in Figure 1, with the highest growth in the power sector, where 41.2 percent of all electricity was generated from renewable sources. The rapid growth of clean energy and renewable sources is mainly attributed to the growing usage of electric vehicles and initiatives to reduce CO_2 levels and climate change (Harris Williams LLC, 2023).

Figure 1. Share of energy consumption from renewable sources in Europe from 2005 to 2030 (in percent)

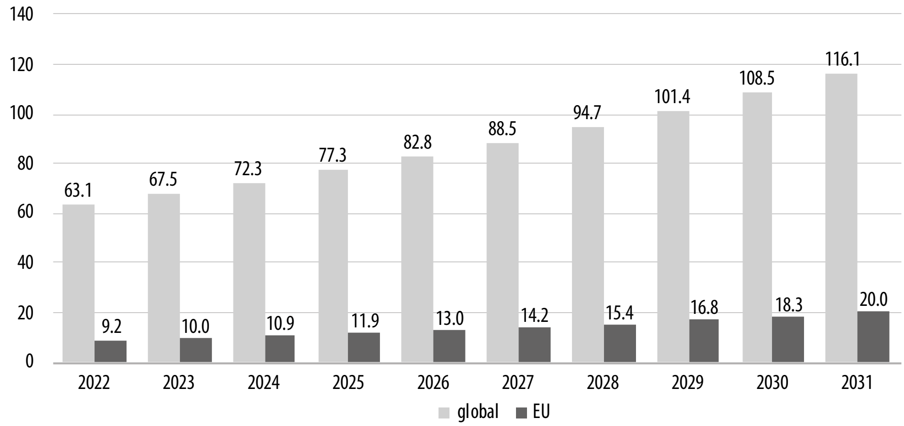


Note: * based on a linear prediction.

Source: Share of Energy Consumption from Renewable Sources in Europe (2024).

These plans necessitate targeted investments in grid infrastructure, particularly to support the integration of renewable energy sources. Transformers ensure efficient voltage regulation and stability throughout the grid, from generation at power plants to distribution across transmission lines and delivery at end-user locations with minimal losses. The transformer market is segmented into two major categories: power transformers and distribution transformers. The power transformer market remains highly competitive globally, whereas the distribution market relies on local, high-quality producers. Distribution transformers are used for distribution and industry applications with stepping-down voltage up to 69kV. In contrast, power transformers serve transmission, generation, and industry applications, helping transmit voltage exceeding 69kV throughout the grid (Harris Williams LLC, 2023).

Figure 2. EU and global transformer market value from 2022 to 2031 (in $ billion)



Source: Research (2024); Europe Distribution Transformer Market Size & Analysis 2031 (2024).

The global transformer market was valued at $63.13 billion (Figure 2) and is expected to grow at a compound annual growth rate (CAGR) of over 7 percent through 2032 (Research, 2024). Future Market Insights (FMI) states that ABB (now part of Hitachi Energy), General Electric, Siemens AG, Toshiba Corporation, and Schneider Electric are the top five market players operating in the power transformer market. They collectively accounted for more than 35 percent of the global market share in 2023. At the regional level, Europe has achieved near self-sufficiency in meeting its annual market demand through local production capacity. The European transformer market was valued at $9.2 billion in 2022 and is projected to grow at a CAGR of 9 percent from 2024 to 2031. Germany is the fastest-growing market, reaching a value of $2.3 billion by 2031. Other key manufacturing hubs in the region include Ireland, France, and Turkey, with key market players comprising Siemens AG, Hitachi Energy, General Electric Company, Schneider Electric, and Emerson Electric Co. (Europe Distribution Transformer Market Size & Analysis 2031, 2024). Increasingly strong competitors in the power transformer market are also emerging from the Asian market, such as TBEA Group from China and HD Hyundai Electric and Hyosung from South Korea.

Increasing electricity demand with rising investment in infrastructure is expected to be the key driving force for the European market's growth. The EU plans to unlock €584 billion in grid investments by 2030 to increase grid capacity (Fayyaz & Ikhlaq, 2024). Transformers are non-reusable, meaning each new power plant must have a new transformer. Additionally, ageing infrastructure is anticipated to receive meaningful equipment upgrades while undergoing significant revitalisation and modernisation to minimise outages and prevent high-cost grid failures, creating profitable growth potential for players in the power transformer industry (Grand View Research, 2023). Because of the sudden growth, demand and supply imbalances have emerged and will intensify as energy-intensive sectors, such as data centres, electric vehicles, and renewable energy, place further demand on increased infrastructure capability (Harris Williams LLC, 2023).

Over the last several years, supply chain disruptions negatively affected transformer manufacturers. Due to ongoing raw material shortages, transit times, and intensive manufacturing processes, power and distribution transformers have average lead times of 12 to 38 months, which have nearly doubled since the onset of the pandemic. A lack of skilled labour has also contributed to declining capacity (Harris Williams LLC, 2023).

With the growing integration of smart transformers into power grids, the technology continues to advance through digitalisation, which allows for real-time monitoring of power transformers and digital twins, which can present transformers' physical counterparts in a virtual environment (Picher & MacArthur, 2023). An example of current trend makers is Hitachi Energy, which enabled TXpert transformer digitalisation solutions with AI in 2023 (Harris Williams LLC, 2023).

2.3 Sustainability in transformer manufacturing

When it comes to transformers' carbon footprint, the focus has been on CO_2 emissions linked to transformers' efficiency, as transformer losses represent around 2.5 percent of EU energy consumption. In 2015, an ECODESIGN directive was implemented, defining specific rules and minimum efficiency requirements for the design of distribution and power transformers. Now, Tier-3 of the ECODESIGN directive is under discussion, which strengthens previous Minimum Energy Performance Standards (MEPS) and proposes that almost all new transformers would be required to be manufactured using new materials to make transformer cores more efficient (Fayyaz & Ikhlaq, 2024). At the EU scale, introducing Tier-3 MEPS for distribution transformers would lead to 1.8 TWh per year of electricity savings, equal to half of Denmark's total annual electricity consumption. These energy savings represent a reduction of 3.7 Mt of CO_2 emissions per year. The net material savings per MWh of electricity saved per year would range between 400 and 900 kg[2], which is, in total, 0.8 to 1.6 million tons of materials. This amount translates into a 4 percent to 8 percent material use reduction when introducing Tier-3 compared with a continuation of Tier-2. ECODESIGN also introduced Design-for-Recycling requirements to ensure the reutilisation of raw materials with minimum downcycling, using a design and materials that aim at easy dismantling and recycling (European Copper Institute, 2023).

The goal is to decrease CO_2 emissions and improve the environmental footprint by using biodegradable materials for the insulation fluid of transformers. Ester diluted fluids are a viable natural alternative to traditional mineral oils, providing environmental, fire, performance, and life extension benefits. In the case of spillage, ester fluids are not as dangerous and do not cause such an environmental hazard as mineral oils. The EU is actively deploying ester-filled transformers as pilot projects, with expectations of broader adoption in the future. This shift will likely reduce the market share of dry-type transformers in the coming years. In Europe, the ester-filled transformer market capacity accounts for about 1.29 percent of the total installed base, with the UK, Netherlands, and Spain being the top countries adopting ester fluid (Fayyaz & Ikhlaq, 2024).

3 The case of Kolektor Etra

3.1 A description of the company

Kolektor Etra (KE) is part of the Kolektor Group and has been a leading transformer manufacturer for over 90 years, specialising in the production of various types of transformers. The company is present in more than 40 countries around the world, has 548 employees, and generates more than €228 million annually. Their most important products are power transformers with capacities up to 500 MVA and voltage ratings up to 420 kV. They also produce special transformers and distribution transformers (Kolektor Etra, 2023).

KE's modern manufacturing facilities and highly skilled workforce ensure the production of high-quality transformers. Its employees are experienced and professionally trained to perform all necessary routine, type, and special tests following international standards. Their focus areas include electromagnetics, structural mechanics, thermodynamics, acoustics, and corrosion protection (Kolektor Etra, 2023).

Sustainability plays a significant role in its business strategy. The company's view on sustainable development is not just managing risk associated with climate change but also an opportunity for business development. To reduce the environmental impact of the technological process, KE can make strategic decisions during the design of transformers to minimise their environmental footprint. This approach includes optimising materials and energy utilisation, investing in green technologies, and implementing control measures over suppliers to ensure compliance with sustainable practices (Kolektor Etra, 2023).

The company has grown significantly in recent years, driven by the global transition towards a more environmentally conscious approach. The company's principal markets are traditionally located in Europe, with a strong presence in Scandinavia, Germany, the United Kingdom, and Central Europe. KE has also strengthened its position in the offshore transformer market, delivering more than 60 high-power transformers for installations in the North, Baltic, Irish, and China Sea (Kolektor Etra, 2023).

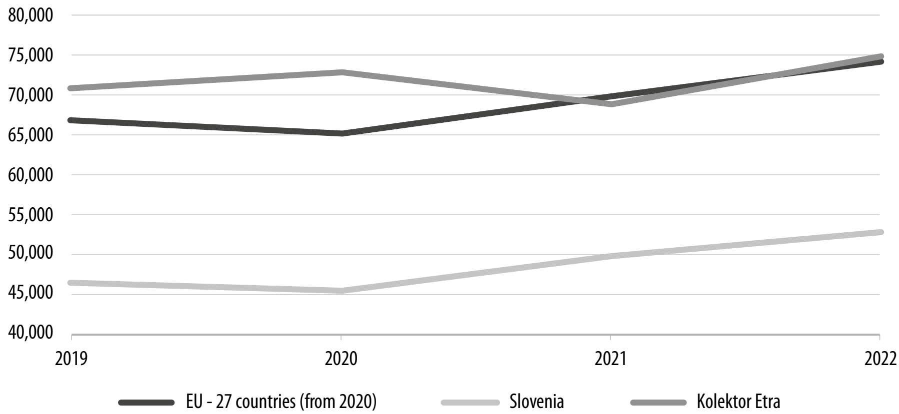
Table 1. Financial and operational performance of Kolektor Etra from 2019 to 2023

	2019	2020	2021	2022	2023
EBITDA (in thousand €)	12,298	14,670	13,837	15,513	38,785
Average number of employees	409	464	496	525	548
Value added per employee (in €)	71,000	73,000	69,000	75,000	124,000

Source: Ajpes (2024).

Table 1 shows the financial and operational performance of the company from 2019 to 2023. EBITDA increased steadily, reaching a peak of €38.8 million in 2023. The average number of employees also grew from approximately 409 in 2019 to 548 in 2023, indicating company expansion. Value added decreased during the COVID-19 crisis, following a sharp increase to €124,000 per employee in 2023. The results for 2023 are better due to favourable market conditions and improved efficiencies from economies of scale (Kolektor Etra, 2023).

Figure 3. Nominal labour productivity per person from 2019 to 2022 in EU-27, Slovenia and Kolektor Etra (in €)



Note: the value added for Slovenia and EU is based on the national account methodology, while the company value added is calculated according to AJPES methodology. Therefore, directly only the trends are comparable.

Source: Eurostat (2024); AJPES (2024).

Figure 3 shows the nominal labour productivity per person at current prices for the EU-27 countries, Slovenia, and Kolektor Etra from 2019 to 2022. Throughout this period, Slovenia's nominal labour productivity per person has consistently remained below the EU-27 average. When KE is compared to Slovenian and EU-27 averages, KE, with €124,000 value added per employee in 2023, as seen in Table 1, is performing significantly above the Slovenian average and currently higher than the EU-27 average.

3.2 Qualitative analysis

The empirical analysis is based on three in-depth interviews conducted from 29 August 2024 to 9 September. Employees from Kolektor Etra with top managerial positions from different departments, such as general manager (ETRA1), sales (ETRA2) and R&D (ETRA3), were interviewed. The intention was to explore the company's strategic focus and market dynamics, particularly in the context of the green energy transition. The goal was to gain insights into the company's positioning within the transformer ecosystem, the impacts of European green initiatives, and the future outlook for the company. For each field, several of the most relevant topics were explored. At the managerial level, the chapter primarily focuses on strategy development, market dynamics, and the ecosystem. In sales, the analysis focused on key markets, market expansion, customer relationships, and suppliers. Lastly, research in the R&D department emphasised learning about innovation, the importance of skilled workers, and sustainability in manufacturing and design.

3.2.1 Market dynamics and strategic positioning

Kolektor Etra has become an important part of the energy ecosystem, driven by the increasing focus on the green transition and rising demand for renewable energy sources. This transition is creating new demands for transformers that are compatible with renewable energy technologies, such as those used in offshore and onshore wind farms, as well as solar power plants. *"We operate in the energy sector, which has experienced significant growth over the last few years. One of the main factors is the so-called green transition, which is widely discussed and is happening in Europe and other countries"* (ETRA1). This transition, particularly strong in European markets like Germany, Scandinavia, and increasingly France, has influenced KE's strategy and expansion efforts. *"In Germany, the phasing out of nuclear power plants under Chancellor Merkel has created a need for alternative energy sources, leading to a surge in the development of wind farms"* (ETRA1). The industry is regionally oriented within Europe since there are different standards throughout the regions[1], and logistics are a major challenge due to high transport costs. Despite the mentioned challenges, they accomplished a big offshore wind farm project in Taiwan, strengthening their global presence. The transportation of transformers, which can weigh several hundred tons, requires planning, using specialised equipment and compliance with regulations. Transport from the company premises can be done by train or on road, using specially designed vehicles. Afterwards, the transformers can also be moved by boat on rivers or sea. It is essential to plan each step, including obtaining permits, checking transport routes, and considering factors such as weather. All this leads to very high transportation costs.

KE's strategy has been focusing on targeting established markets as they can meet their requirements. Their vision is to become the most respected transformer manufacturer globally. Flexibility and product quality differentiate them

1 IEC-Europe, GOST-Russia, IEE-USA

from larger, not as adaptable competitors. While larger companies like Siemens and Hitachi offer standardised solutions, KE specialises in creating tailored transformers. *"We are willing to make something unique, like a pink car, while others offer standard colours"* (ETRA1). Their flexibility is also seen in their approach to entering new markets. Unlike competitors, KE adapts to the local language and market preferences. *"Our German counterpart, SGB, tried selling in France using English or German but did not adapt to the market, so the French did not buy from them. We, on the other hand, adapt to our clients in every way"* (ETRA1). KE's commitment to flexibility and customer-centricity sets it apart in a competitive European market of around 50 transformer manufacturers, where it consistently competes with approximately ten key rivals.

3.2.2 Development and the role of the ecosystem

KE's development has been influenced by expansions, strategic partnerships, internal knowledge, and an ecosystem of regulations, customers, and suppliers. *"We have a regulatory framework that is already known, and we must produce our transformers in line with those regulations"* (ETRA2). The company is also influenced by regulations of its customers, led by the shift towards renewable energy. *"Years ago, there were no wind farms or solar parks. Now, we are heavily involved in these offshore platforms"* (ETRA2). Customers now expect transformers that minimise their environmental impact, focusing on energy loss levels and noise reduction.

Suppliers are another crucial part of KE's ecosystem. *"We buy many components, mostly from Europe, but also from Japan, particularly high-quality steel that is better than European steel, even though it is more expensive"* (ETRA2). Reflecting on concerns about raw material shortages in the supply chain, KE noted: *"They always said that there is only a limited amount of copper in the world and that the growth would stop when we ran out. But that has been said for 30 years, and I have never encountered a situation where we could not get copper"* (ETRA2). However, challenges with raw material availability can still occur due to external factors. *"Sometimes, the Chinese are blocked; other times, there are issues with Brazilian or Argentine copper mines. For instance, large strikes at these mines can result in a temporary shortage of copper, but it is not because there is a fundamental lack of the material. It is more about labour disputes and negotiations"* (ETRA2).

In recent years, rising taxes in Slovenia have made neighbouring Serbia an increasingly attractive location for business expansion. *"In Slovenia, taxes have* *been rising significantly, making Serbia more competitive, with a corporate tax rate that is half of ours and much lower labour costs"* (ETRA1). In 2018, KE bought a factory in Belgrade, which will double the company's capacity by the end of 2025. Similarly, in Poland, the company acquired a factory producing transformer tanks, enabling control of the production process and reducing dependency on external suppliers. Besides daughter companies, collaboration with strategic partners, such as the Danish engineering firm Semco Maritime, offers them expansion and global exposure. *"We have worked with Semco Maritime for many years and have completed several successful projects together. They trusted us to partner with them as they expanded into Asia"* (ETRA1).

3.2.3 The impact of the Green Deal and sustainability initiatives

KE has experienced steady growth, doubling its turnover every four to five years. To maintain quality, their expansion is limited since their work is mostly manual. *"Growth cannot be too fast because the quality would suffer"* (ETRA1). Since the Green Deal, the most significant change has been that they are now sold out two years in advance with nearly $800 million in orders, compared to the previous six months to one year.

The company is trying to address environmental concerns related to transformer components, which include copper, iron, sheet metal, and oils. *"Some time ago, we started replacing the oil with esters, which are less harmful to the environment. If a transformer leaks oil, it can cause significant environmental damage"* (ETRA2). Additionally, to reduce waste, they are also exploring the option of purifying old oils to be reused in new transformers. *"KE is also doing a lot of work in making transformers more efficient by reducing energy losses and noise levels due to customer demand, initiated by the ECODESIGN directive"* (ETRA3).

The company is also undergoing a digital transformation, focusing on optimising the use of existing technology. *"We began implementing these changes a decade ago, entering all transformer designs and parameters into a database"* (ETRA3). With the help of artificial intelligence, individual designs can be compared to one another, allowing for the comparison of expected results at a later stage. The challenge in digital transformation is the integration of internally developed applications with external digital solutions that enable the company's digital transformation to be seamless but require significant investment to adapt to the specific needs of the business.

Regarding the impact of EU subsidies on the green transition, KE only experiences an indirect effect. *"We are experiencing increased demand due to the development of electric vehicle charging stations and photovoltaic power plants, which has consequently boosted the demand for transformers"* (ETRA1). In line with sustainable development guidelines, KE has implemented several measures. The most important measures are installing a photovoltaic plant on their factory roof, introducing paperless operations with screens displaying video instructions, and continuously improving production processes. *"The whole industry is moving towards sustainability and lower losses"* (ETRA1). Consequently, even without big changes, KE has kept up with industry trends by using better materials and collaborating with suppliers from Germany, Japan, and other countries.

3.2.4 The future of Kolektor Etra

For KE, sales growth is essential for progress. The company's strategic focus is expanding into new markets and continually upgrading its knowledge of market-specific needs. *"If you stop growing, you start to decline. However, growth alone is not enough; it must be accompanied by results"* (ETRA1). The future of KE lies in its ability to develop a skilled workforce. *"As the company expands, it is essential to recognise that capacity expansions are currently underway, but we must also have the appropriate personnel available"* (ETRA3). The main challenge will be ensuring that employees are properly educated and equipped for their roles, as this is a long-term process and will be shown after ten years. They also believe that in the coming decade, the value of technical personnel will rise significantly, and companies that fail to recognise this will struggle to survive in the market. Another challenge also represents the global supply of copper. *"The global supply of copper is limited, and some studies suggest that by 2045, copper will be practically depleted or very difficult to obtain"* (ETRA3). Therefore, they believe there will be a shift towards using alternative conductors, such as aluminium or recycled copper.

As KE looks to the future, its focus on sustainability and innovation will continue to play a big role. *"All trends indicate that electricity will become even more important than it is today, which is excellent for us. We are clearly in the right industry"* (ETRA1). The company's strategy will remain to adapt to emerging technologies and market demands while leveraging its growth potential to drive long-term success. With its constant growth, the company's capacities are becoming limited. It is addressing the issue by investing in building a new factory in Črnuče and planning on doubling its capacity.

Table 2. Key findings of the KE case study

Topic	Key findings
Increased demand and limited capacity	• Rising electricity demand and grid investments. • Transformer demand outpacing supply (Green Deal). • KE investing in automation and workforce expansion. • KE expansion by building a factory in Črnuče. • Offshore wind farms in Taiwan.
Positioning and market expansion of KE	• Flexibility and customisation.. • Strong market presence in Germany and Scandinavia. • Strategic expansion to Poland and Serbia.
Sustainability in transformer manufacturing	• New efficiency standards reducing carbon footprint. • Biodegradable ester fluids. • ECODESIGN and Design-for-Recycling. • Sustainable manufacturing practices. • Reducing noise and energy losses. • Digital transformation.
Technological advancements in transformers	• Smart transformers for real-time monitoring. • Digital twins for performance prediction and maintenance optimisation. • AI and machine learning.

Source: Own work (2024).

4 Conclusion

KE plays an important role in the rapidly evolving energy ecosystem, especially as the world moves towards greener and more sustainable energy solutions. With over 90 years of expertise, KE's role is to provide power grid infrastructure and support the integration of renewable sources. The company's strategic focus on innovation, flexibility, and sustainability has allowed them to navigate the competitive environment effectively. Positioned within the European market, KE differentiates itself from larger global players by offering tailored, high-quality transformers that meet specific client needs. By excelling in developing custom transformers for demanding sectors like offshore wind farms, KE has secured a strong market position and successfully expanded into global markets, including significant offshore projects in Asia.

The green transition has been a major driving force behind KE's growth, particularly as the demand for transformers compatible with renewable energy sources continues to rise. With the European Union's Green Deal and other sustainability initiatives pushing for a reduction in carbon emissions, transformers play a vital role in ensuring the efficient operation of energy grids that increasingly rely on renewable sources. The company's sustainable practices, which include using ester-based transformer oils and minimizing energy losses, have also resonated with environmentally conscious customers, further fueling demand.

In conclusion, KE's future growth depends on its strategic focus on market expansion and the continuous improvement of its understanding of market needs. The company's success will depend on developing a skilled workforce, adapting to emerging technologies, and navigating challenges like raw material scarcity. Recent financial performance is promising, with turnover and profit expected to exceed projections, bolstered by favourable economic conditions, economies of scale, and digitalisation. Investing in new capacity will address current limitations, and KE's commitment to sustainability and innovation positions them well for long-term success in the evolving energy sector.

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SHAPING THE WOOD ECOSYSTEM FOR HIGHER VALUE ADDED

1 Introduction

The wood industry[1] is a vital driver of sustainable development and economic progress, particularly in regions with extensive forestry resources like Slovenia (Lesni Forum, 2023). Globally, the demand for renewable materials has surged, positioning wood as a key player in eco-friendly industries such as construction and manufacturing (World Economic Forum, 2024). In Slovenia, where over half the land is forested (European Environmental Agency, 2015), the wood industry contributes significantly to the economy, especially in rural areas, and aligns with national sustainability goals (European Environmental Agency, 2015). The country's strong tradition of forest management ensures the preservation of this resource, supporting both environmental objectives and economic growth (Lesni Forum, 2023).

However, the industry faces considerable challenges, including technological shortcomings, fluctuating markets, and a shortage of skilled labour, which hinder competitiveness, particularly compared to neighbouring markets like Austria and Germany. The industry is modernising production processes and embracing digitalisation to improve competitiveness and add value to Slovenia's wood products in global markets (Slovenia Times, 2023).

This chapter examines the Slovenian wood industry's status, analysing its strengths, challenges, and strategies for improvement. Drawing on secondary data and interviews with stakeholders, it explores how companies are addressing

1 The wood industry, includes activities defined under NACE codes A02 (Forestry and Logging), C16 (Manufacture of Wood and of Products of Wood and Cork, except Furniture; Manufacture of Articles of Straw and Plaiting Materials), and C31 (Manufacture of Furniture). This definition covers the entire value chain, from the cultivation and harvesting of raw wood materials to the manufacturing of wood products and furniture.

market demands, sustainability challenges, and technological advancements. The analysis concludes with policy recommendations and future research directions to ensure the wood industry remains central to Slovenia's economic and environmental progress.

2 Overview of the wood industry

Forests cover 58 percent of Slovenian land (Eurostat, 2021), with a growing stock of 386.1 million cubic metres (Slovenian Forest Service, 2023). In 2022, roundwood production was 4.156 million m^3, while roundwood exports and imports were 1.414 and 0.801 million m^3, respectively. Therefore, the share of roundwood exports was 34 percent, while the coverage of roundwood imports with exports was 0.56. Exports primarily go to Austria and Italy (Ministry of Agriculture, Forestry, and Food, 2021). In contrast, in both Austria and Germany, the share of roundwood exports is substantially smaller. On the other hand, the coverage of roundwood imports with exports in Germany is similar to that in Slovenia, while Austria imports substantially more roundwood than it exports (Table 1).

Table 1. Forest resources and wood harvesting in 2022

	Slovenia	Austria	Germany
Forest area (in percent of land)	58	48	32
Growing stock (in million m^3)	386.1	1,216	3,700
Roundwood production (in million m^3)	4.156	19.357	78.872
Roundwood export (in million m^3)	1.414	1.319	10.096
Roundwood import (in million m^3)	0.801	8.701	5.860
Share of roundwood export (in percent)	34.02	6.81	12.80
Coverage of roundwood imports with exports	0.56	6.59	0.58

Source: Forest Stewardship Council (2023); Slovenian Forest Service (2023); Austrian Forest Report (2023); Association of the Austrian Wood Industries (2023); German Federal Statistical Office (2023); Food and Agriculture Organization of the United Nations (2024).

Globally, the wood industry, which includes the manufacture of wood and wood products and furniture manufacturing, employs around 13 million people, with significant investments in advanced machinery and sustainable practices driving modernisation (European Timber Federation, 2022). Globally, these sectors contribute about 1 percent to the GDP, with the global furniture market alone valued at $500 billion in 2021 and expected to reach $650 billion by 2027 (European Timber Federation, 2022). Wood is becoming an increasingly important material in sustainable construction, particularly in Europe, where it is considered an eco-friendly alternative to traditional materials like concrete and steel (EESC, 2021).

The wood industry contributes approximately 1.5 percent to the GDP in Slovenia and employs around 8,500 people (Statistical Office of the Republic of Slovenia, 2022). Despite abundant forest resources, the value added per employee in Slovenia's wood sector was €39,000 in 2023, which still lags behind more developed countries like Austria (€63,000) and Germany (€70,000) (Table 2). This gap demonstrates Slovenia's potential to modernise and increase value added through innovation and advanced technologies.

Table 2. Financial metrics comparison in 2023

Metric	Slovenia	Austria	Germany
Value added per employee (in €)	39,000	63,000	70,000
Return on assets (ROA) (in percent)	5.4	6.7	6.1
Return on equity (ROE) (in percent)	9.6	14	12.5
Gross profit margin (GPM) (in percent)	22–26	27–33	24–30
Operating profit margin (OPM) (in percent)	7–9	12	10

Note: All the stated numbers in the table are means.

Source: Eurostat (2023); NetSuite (2023); FinModelsLab (2023).

In 2023, the wood industry in Slovenia invested approximately €95 million in fixed capital, focusing on modernising production processes and implementing sustainable practices. Research and development (R&D) spending in the sector remains relatively low, accounting for 1.5 to 2 percent of revenues, compared to 2.5 to 3 percent in Austria and Germany (Lesni Forum, 2023; GOV.SI, 2023). This disparity underscores the need for Slovenia to increase R&D investment to drive innovation, especially in areas such as circular economy models and bioenergy production.

Circular economy models in the wood industry involve reusing and recycling materials to minimise waste, reduce environmental impact, and enhance resource efficiency, supporting Slovenia's shift toward sustainable and bio-based production (Wood Industry Directorate, 2024). The global wood industry is expected to grow at an annual rate of 4 to 5 percent over the next decade, with sustainable construction and bio-based products driving this expansion (Timber Market Review, 2023). European countries such as Finland, Sweden, and Germany are projected to experience growth rates of 2.5 to 3 percent, driven by innovation (European Timber Trade Federation, 2021). Slovenia is expected to follow this trend with an estimated annual growth rate of 2.5 percent (GOV.SI, 2023).

3 Enhancing value and sustainability in the wood industry

The global wood industry supports sustainable development through carbon sequestration, reducing reliance on non-renewable materials like concrete and steel (EESC, 2021). Countries like Finland and Sweden have successfully integrated wood into their bioeconomy strategies, promoting its use in bio-based products and energy production (Ministry of Agriculture, Forestry and Food, 2021).

Slovenia's vast forest resources position the country to contribute significantly to sustainability goals. However, the high export of raw wood underscores the potential to develop more domestic processing and value-added production. Investments in modern technologies, particularly in circular economy practices, could boost Slovenia's role in sustainable development and reduce greenhouse gas emissions (Lesni Forum, 2023).

Finland and Austria provide models for maximising value added in the wood industry. Finland's Bioeconomy Strategy aims to generate €100 billion annually by 2030 through the use of wood in chemical production and energy generation (Ministry of Agriculture and Forestry of Finland, 2022). Austria has focused on engineered wood products, such as cross-laminated timber (CLT), which is gaining popularity in sustainable construction for its low carbon footprint and superior strength (Austrian Wood Industries Association, 2021).

Slovenia has adopted similar strategies, with the Slovenian Industrial Strategy 2021–2030 focusing on green technologies and value-added products like designer furniture (GOV.SI, 2022). However, further investment in branding and internationalisation is required for Slovenia to compete with leaders like Finland and Austria (Lesni Forum, 2023).

To enhance the added value in Slovenia's wood industry, it is essential to explore strategies that can stimulate domestic demand for wood products despite the challenge of higher production costs resulting from the absence of economies of scale. This approach requires an understanding of potential consumer incentives, market development, and policies that can foster increased usage of locally produced wood. Additionally, identifying the key barriers to modernisation, such as outdated infrastructure, limited R&D investment, or regulatory constraints, is crucial. By examining how investments in advanced technologies, automation, and digitalisation can boost productivity and profitability, Slovenia can improve its competitive edge. Furthermore, exploring the significant growth opportunities available to Slovenia's wood industry, particularly in sustainable construction, bio-based products, and renewable energy, is vital, aligning with global trends and the growing demand for eco-friendly and circular economy solutions in international markets.

4 Research methodology

The primary research goals are to explore the current state of Slovenia's wood industry with a focus on its challenges and opportunities and to assess how technological advancements, sustainable practices, and regulatory frameworks influence its development. The research also aims to identify strategies for enhancing value-added production and assess the industry's growth potential in domestic and international markets.

Table 3. Sample characteristics

Company	Company's position in the chain	Interviewee's position	Size	Code
Company 1	Modular home construction	Managing Director	Small	WOOD1
Company 2	Window and door manufacturing	Managing Director	Small	WOOD2
Company 3	Sawmill	Managing Director	Medium	WOOD3
Company 4	Forestry management	Representative of the Ministry	Small	WOOD4
Company 5	Modular home construction	Managing Director	Small	WOOD5
Company 6	Forestry association	President of Association	Small	WOOD6
Company 7	High-end wood product manufacturing	Managing Director	Small	WOOD7
Company 8	Door manufacturing	Managing Director	Small	WOOD8
Company 9	Timber and modular home construction	Managing Director	Small	WOOD9
Company 10	Furniture manufacturing	Managing Director	Small	WOOD10
Company 11	Custom yacht interiors	Managing Director	Medium	WOOD11
Company 12	Window and door manufacturing	Managing Director	Medium	WOOD12
Company 13	Wood and furniture industry association	Managing Director	Small	WOOD13
Company 14	Modular home construction	Managing Director	Large	WOOD14
Company 15	Engineering and interior design	Managing Director	Medium	WOOD15
Company 16	Wood construction consulting	Managing Director	Medium	WOOD16

Source: Own work (2024).

Sixteen semi-structured, in-depth interviews were conducted with directors and representatives of key companies involved in various stages of wood processing. Sample characteristics are presented in Table 3. These interviews were held between August 23 and September 6, 2024, primarily at company headquarters across Slovenia. Three interviews were conducted via video call. Open-ended questions were used to capture a range of perspectives on the challenges and opportunities within the wood processing sector, with interviews recorded for transcription purposes.

5 Insights from the interviews

The Slovenian wood industry, deeply connected to the nation's economic and environmental structure, faces significant challenges. Involving a range of stakeholders, from forest owners to high-tech producers, the sector relies heavily on Slovenia's vast forest resources, which cover 58 percent of the country, making it one of Europe's most forest-rich nations. *"Slovenian forests are a national treasure, providing both economic and environmental benefits that are essential for sustainable growth"* (WOOD6). The industry faces several structural issues, the most pressing of which is fragmented forest ownership, complicating effective management and strategic planning. *"The fragmentation of forest ownership creates major challenges in ensuring effective management and achieving sustainability goals"* (WOOD6). This fragmentation hinders the sector's ability to fully utilise its resources and plan for long-term sustainability. *"Our forests are divided into many small plots, making it difficult to implement coordinated management strategies that would benefit both the environment and the economy"* (WOOD1). Difficult effective management and strategic planning in Slovenia in comparison to Austria and Germany is the consequence of three factors: *"First, Slovenia has strong business intermediaries on the market between weak economically unrelated owners and the timber industry (e.g., SiDG, GG Bled, Petrol, trade and transport companies), while Austria and Germany are betting on strong associations of forest owners as business entities on the market. Second, Slovenia has the majority of expert foresters employed in a public institution, where they lead administrative procedures and do not provide economic advice to owners, while in Austria and Germany, forestry experts manage forestry operations, advise owners and are largely employed in the private sector and finally, unlike Austrian and German legislation, Slovenian legislation enables completely relaxed nomadic entry into forests and free picking"* (WOOD6).

In addition to ownership issues, outdated technologies remain a major obstacle. Many companies still operate with machinery that is well past its prime, slowing down production and making it difficult to keep pace with international competitors. *"We are operating with machines that are over 30 years old, and this seriously hampers our ability to scale production efficiently"* (WOOD5). Countries like Austria and Germany, with more modern and automated facilities, have set a higher standard, which Slovenia struggles to match. *"Slovenian managers know they need to invest heavily in technological equipment"* (WOOD13). *"Without investment in new technologies, we are falling behind our international counterparts, which puts us at a significant disadvantage in terms of production efficiency"* (WOOD7). However, *"they do not have enough capital available for this purpose, as they spend as much as 70 percent of the added value to cover labour costs. Therefore, to increase competitiveness, a radical reduction in labour taxation is necessary"* (WOOD13). The evolving global market places additional pressure on the industry to adapt. Consumer demand is shifting toward sustainable and eco-friendly products, requiring companies to rethink their strategies. *"The market is moving towards sustainable products, and if we do not adapt, we will be left behind"* (WOOD11).

5.1 Technological challenges and workforce development

The growth of Slovenia's wood industry is hindered by technological gaps and a lack of workforce skills, particularly in digital literacy. Many companies continue to operate with outdated machinery that limits their productivity and international competitiveness. *"Many companies still operate with technology that is significantly behind the times, which limits their ability to compete in the global market"* (WOOD3). The reliance on older equipment puts these businesses at a disadvantage compared to technologically advanced competitors in countries like Austria and Germany, where investment in state-of-the-art equipment has become the norm.

High initial costs and a lack of expertise have slowed the adoption of automation and digitalisation. *"Automation and digitalisation are not only costly but require a significant shift in how we operate, and many companies simply do not have the resources or knowledge to make this leap"* (WOOD8). Without substantial investment in modern technologies, companies struggle to keep pace with international standards and lose ground in global markets. This challenge is particularly pronounced in sectors such as wooden house construction, where transport costs and sustainability concerns limit market reach. *"For wooden* *houses, we can realistically compete only within a 1000-kilometre radius due to high transport costs and the need for sustainable practices"* (WOOD9). The focus on sustainability is becoming increasingly important, especially for modular house companies, which greatly emphasise environmentally friendly practices. *"Sustainability is not just a trend, but a necessity for the future of our industry, especially when it comes to transportation and reducing our carbon footprint"* (WOOD1).

A significant challenge highlighted in the interviews was the slow pace of technological adoption in the Slovenian wood industry. Despite the necessity of modernisation, many companies still rely on outdated equipment, which affects their productivity. *"Our production lines are efficient, but without adopting more advanced digital technologies, we will not be able to keep up with competitors abroad"* (WOOD16). The reliance on older machinery hinders the industry's ability to compete in global markets, underscoring the need for investment in newer technologies and digital tools.

Workforce development is another challenge, as employees often excel in traditional craftsmanship but lack digital skills. *"We are struggling to implement digital transformations that are common in other European countries"* (WOOD5). Companies are beginning to address this gap through training programs. *"The lack of digital skills is a significant barrier; hence, we have established continuous learning programs to upskill our workforce and prepare them for future technological demands"* (WOOD12). Smaller companies often find it challenging to afford the required training programs and technological upgrades, putting them at an even greater disadvantage. *"We want to invest in modern technologies, but the costs of both the equipment and the necessary training are often too high for smaller businesses like ours"* (WOOD14). This issue underscores the need for greater governmental support and funding to help smaller firms in the sector make these crucial upgrades.

In response to these challenges, there has been a growing focus on partnerships between industry and educational institutions to develop specialised training programs to address the skills gap in the workforce. *"We are collaborating with local technical schools to develop training courses that focus specifically on digital manufacturing processes"* (WOOD15). Such initiatives are essential for building a future-ready workforce capable of driving technological innovation. Digital training and technological upgrades are critical for enhancing productivity and competitiveness. However, without a coordinated effort from companies and government bodies to facilitate these changes, the industry risks falling further behind its international competitors.

5.2 Adapting to market volatility with niche strategies

Market volatility poses a significant challenge, with fluctuating demand making long-term planning difficult. *"The demand for wood products can fluctuate widely, often influenced by external economic factors we cannot control"* (WOOD2). To mitigate these risks, many companies are pivoting toward niche markets. By focusing on specialised products, businesses can target more stable, high-margin segments where customisation and quality are prioritised over volume. This shift allows them to differentiate themselves in the marketplace and gain a competitive edge during periods of economic uncertainty. *"By specialising in custom-made wooden elements, we can maintain higher profit margins and build stronger relationships with a dedicated customer base"* (WOOD9).

These niche strategies effectively buffer against market instability by catering to specific customer demands and creating unique value propositions for stable segments. *"Our business thrives on customisation. By focusing on niche markets, we can offer more specialised products that meet specific customer demands"* (WOOD11). This strategic focus on high-quality, bespoke products has enabled companies to explore new revenue streams, allowing them to become more resilient in the face of market fluctuations.

Furthermore, companies that invest in premium craftsmanship often find themselves accessing exclusive markets where quality is valued over volume, offering them a sustainable growth path. *"Our commitment to premium craftsmanship has opened doors to exclusive markets where quality is more important than volume"* (WOOD7). This shift has safeguarded companies from the volatility of mass-market demand and positioned them for long-term growth in more secure market segments.

Additionally, the flexibility of niche strategies enables companies to swiftly adapt to changing customer preferences or economic conditions. *"By keeping our production flexible and focusing on niche markets, we can quickly adapt to shifts in demand without compromising on quality"* (WOOD8). Agility in a rapidly changing environment is key to maintaining competitiveness in both domestic and international markets.

Government support in the form of grants or subsidies targeting innovation and market diversification has also played a crucial role in helping companies adopt these niche strategies. *"Government programs aimed at encouraging innovation in product development and supporting market diversification have been essential in our transition to niche markets"* (WOOD13). Such initiatives provide companies with the necessary resources to explore new market opportunities and invest in product development that meets specific customer needs.

By embracing niche strategies, Slovenian wood companies are not only mitigating the risks posed by market volatility but also creating sustainable pathways for growth. This focus on specialised products and premium quality has enabled them to differentiate themselves in an increasingly competitive marketplace while tapping into more stable, long-term revenue streams.

5.3 Comprehensive sustainability strategies

The push toward sustainability has become a cornerstone of Slovenia's wood industry, driven by regulatory requirements and consumer demand. As global awareness of environmental issues rises, companies are under increasing pressure to demonstrate their commitment to sustainability. Certifications like FSC (Forest Stewardship Council) and PEFC (Programme for the Endorsement of Forest Certification) are crucial for international market access, where sustainability standards are often non-negotiable. *"Achieving certifications can be a substantial financial burden, particularly for smaller firms, yet these are often prerequisites for entering certain markets"* (WOOD4). Despite the costs, these certifications are critical for market access and building consumer trust, which has become essential to brand reputation in today's marketplace.

However, some companies face additional challenges competing with uncertified businesses, which avoid sustainability audits and international regulations, allowing them to offer lower prices. *"It is difficult to compete with companies that do not have certifications because they can offer lower prices, while we have to invest significant resources into maintaining compliance"* (WOOD14). This issue presents a major challenge, particularly for smaller certified firms, which may find it harder to maintain price competitiveness while upholding sustainability standards. *"For us, the cost of certification is not just a one-time expense. The ongoing audits and compliance checks require continuous investment"* (WOOD14). However, failing to meet international sustainability standards could limit growth, especially in export markets where environmental credentials are crucial.

Waste reduction is another key aspect of comprehensive sustainability strategies. *"Minimising waste and optimising logistics are critical steps toward a greener operation"* (WOOD8). Companies are increasingly focusing on improving production efficiency, reducing material waste, and streamlining transportation processes to minimise their carbon footprint. This approach benefits the environment and contributes to operational efficiency, helping companies save costs in the long run. Additionally, some companies are exploring innovative ways to repurpose waste materials, turning production by-products into new, marketable products. *"We have started looking at ways to repurpose our wood waste into secondary products, such as pellets or bio-based materials"* (WOOD11). This approach reduces waste and creates new revenue streams, contributing to environmental and economic sustainability.

Moreover, government incentives and support for sustainable practices have encouraged companies to invest more in eco-friendly technologies. *"Government grants aimed at supporting sustainable innovation have been instrumental in helping us adopt new technologies and reduce our environmental impact"* (WOOD15). These incentives are particularly important for smaller firms, helping them offset the high initial costs of adopting sustainable technologies.

5.4 Innovation, R&D and government support

Innovation and R&D are crucial for the future success of Slovenia's wood industry. Companies must continually innovate in an increasingly competitive global market to remain relevant. This innovation extends beyond product development into production processes, where companies seek to improve efficiency, sustainability, and overall performance. *"Innovation is not just about creating new products but about fundamentally changing how we approach production processes to be more sustainable and efficient"* (WOOD15). By investing in R&D, companies are developing advanced materials and techniques that offer a significant competitive edge, particularly in sustainability, design and aesthetics.

One of the most promising areas of innovation is the development of new materials that are both functional and visually appealing. *"Our focus on R&D has allowed us to develop unique materials that provide competitive advantages* *in both aesthetics and functionality"* (WOOD11). This commitment to R&D is helping companies create products that stand out in the market and aligning them with growing consumer demand for eco-friendly, high-performance materials.

Another key aspect of innovation is adopting new technologies, such as digitalisation and automation, which are critical for improving production processes. Companies are increasingly turning to advanced manufacturing technologies to reduce waste, increase efficiency, and improve product quality. *"The introduction of automation has significantly improved our production flow, reduced errors and allowed us to scale more efficiently"* (WOOD8). This shift toward more automated processes is essential for companies looking to maintain competitiveness in a fast-evolving industry.

Collaboration with academic institutions plays a pivotal role in advancing these R&D efforts. By partnering with universities, companies gain access to cutting-edge research, which can be applied directly to industrial processes. *"Partnering with universities has enabled us to develop groundbreaking products that are both innovative and sustainable"* (WOOD15). These collaborations give companies valuable insights into new technologies, materials, and methods they might not have developed in-house. This exchange of knowledge is particularly important for smaller companies that may lack the resources to conduct extensive R&D on their own.

In addition to product development, companies must focus on process innovation to optimise efficiency and reduce costs. *"We have invested heavily in R&D to develop new, innovative wood finishes, but we also need more support from the government to push these innovations into the market"* (WOOD16). This statement highlights the industry's need for greater collaboration with government bodies to support research and development initiatives, ensuring Slovenian companies stay ahead in global markets.

However, the industry also requires more consistent and long-term support from the government to facilitate this transition. While some companies have benefited from government grants aimed at promoting innovation, many argue that these initiatives need to be expanded and made more accessible. *"The government needs to provide more consistent and long-term policies to help the wood industry transition to more sustainable practices"* (WOOD6). This call for enhanced government support is echoed by other industry leaders, who point out that many companies will struggle to make the necessary investments in innovation without strong policy frameworks and financial incentives. Government-backed programs that provide funding for sustainable projects or that support collaborative research between industry and academia are essential for driving innovation. *"We have received government support for several R&D projects focused on sustainability, which has been crucial for our ability to innovate"* (WOOD13). Such programs not only help companies develop new products but also assist them in meeting the increasing global demand for sustainable, high-value products.

5.5 Collaboration and networking in a fragmented market

Slovenia's wood industry is highly fragmented, with many small and medium-sized enterprises (SMEs) operating independently. This fragmentation leads to inefficiencies and duplicated efforts as each company navigates challenges on its own without the benefit of shared resources or knowledge. The lack of coordination among firms makes it difficult for the industry to achieve economies of scale, which are crucial for reducing costs and improving competitiveness. *"The market's fragmented nature means that many firms are duplicating efforts and not leveraging potential economies of scale"* (WOOD10). This issue is particularly problematic in a globalised market, where large international competitors can lower production costs by maximising efficiency through economies of scale.

Without collaboration between firms, Slovenian wood companies miss out on significant opportunities to pool resources, share knowledge, and optimise production processes. In an industry where innovation and cost-efficiency are key to survival, these missed opportunities can put smaller firms at a severe disadvantage. *"Many companies are reluctant to collaborate because of the competitive nature of the market, but by working together, we could significantly reduce costs and improve our overall competitiveness"* (WOOD11).

To overcome these challenges, greater collaboration and networking among companies, both domestically and internationally, is essential. Firms collaborating on joint ventures, research, and strategic alliances can access shared resources and knowledge, allowing them to compete more effectively in domestic and global markets. *"Collaboration is the key to unlocking new opportunities, especially regarding research and innovation"* (WOOD12). By forming alliances with other companies within Slovenia or abroad, firms can diversify their market reach, reduce costs through shared investments, and increase their innovation capacity by exchanging ideas and technologies.

However, one of the barriers to greater collaboration is the mistrust built up over years of competition within the industry, with many companies seeing each other as rivals rather than potential partners. *"The mistrust built over years of competition makes collaboration difficult, but without it, we cannot hope to compete globally"* (WOOD12). Overcoming this mistrust will require a cultural shift within the industry, with companies recognising the value of collaboration, especially in research and development.

International partnerships are also vital for expanding market reach and accessing innovations from other countries. Through collaboration with foreign companies, Slovenian firms can tap into new markets, gain access to advanced technologies, and learn from global best practices. *"Collaborative international projects have opened new avenues for us to expand our market reach"* (WOOD9). These partnerships enable companies to diversify their product offerings, reduce dependence on the domestic market, and increase their exposure to international customers.

Government initiatives aimed at fostering collaboration and networking among companies could also play a significant role in overcoming fragmentation. "We need more support from the government to encourage collaboration, whether through grants or networking events that bring companies together" (WOOD13). These initiatives could help facilitate the partnerships that are essential for creating a more unified and competitive industry.

5.6 Challenges in B2B operations abroad

Expanding into foreign markets presents significant growth opportunities for Slovenia's wood industry by diversifying customer bases and increasing revenue streams. However, managing B2B (business-to-business) operations abroad, such as supply chain adaptation, regulatory compliance, and logistics, presents challenges. *"Entering new markets is not just about selling a product but also about managing the entire supply chain, which can be exceedingly complex in unfamiliar markets"* (WOOD8).

Navigating these complexities requires an in-depth understanding of each market's unique legal and logistical frameworks. Differences in regulations, taxes, and import and export requirements can vary significantly from one country to another, making it essential for companies to invest in dedicated teams that specialise in these areas. *"Navigating different regulatory landscapes requires dedicated teams familiar with local laws and customs to ensure compliance and* *smooth operations"* (WOOD13). Without this localised knowledge, companies can face costly delays, fines, or even the inability to operate in certain markets.

Building trust with local partners is another crucial factor in succeeding abroad. Establishing effective networks in new markets is essential for overcoming logistical and operational obstacles. *"Forming reliable partnerships with local distributors and suppliers is essential for ensuring that our products reach customers efficiently"* (WOOD9). These partnerships allow companies to navigate the complexities of foreign markets more smoothly, ensuring that products are delivered on time and in compliance with local regulations.

One of the most critical challenges in expanding abroad is the shortage of skilled labour, particularly for assembly and production processes in foreign locations. Slovenian wood products are renowned for their high level of craftsmanship, which requires specific skills that are often difficult to replicate without thorough training. *"Our products require precise craftsmanship, which can be difficult to achieve with labour that has not been specifically trained in our methods"* (WOOD9). This shortage creates a significant barrier for companies that need to maintain the same level of quality in foreign markets as they do domestically.

To mitigate these challenges, companies are advocating for greater government support through international training programs. These programs would help standardise labour practices and ensure that Slovenian companies maintain their reputation for quality craftsmanship in foreign markets. *"Government programs that support training initiatives abroad could significantly ease the burden on companies trying to expand"* (WOOD6). Such initiatives would facilitate smoother operations and provide consistent skills and craftsmanship, ensuring high-quality standards across all locations. In addition, some companies have developed in-house training programs for foreign workers. *"We have established an internal training program for our assembly workers abroad to ensure that they meet our standards of craftsmanship"* (WOOD15). This approach allows companies to maintain greater control over product quality while also adapting to local labour market needs.

5.7 Challenges and strategies in B2C operations and brand building

The Slovenian wood and furniture industry faces significant challenges in the B2C (business-to-consumer) markets, particularly against large foreign retailers. These foreign companies dominate the market with extensive product offerings, often relegating Slovenian-made products to a minority position. *"Foreign retailers offer up to 16 kitchen designs, yet only one or two of them are Slovenian, making it incredibly difficult for local producers to compete"* (WOOD3). This circumstance highlights a critical issue for Slovenian companies as they struggle to achieve visibility in a crowded marketplace dominated by global brands.

One of the main barriers for Slovenian furniture companies is the high cost of establishing their own sales showrooms, which would allow them to compete directly with these large foreign retailers. In response, some companies, in collaboration with the government, are exploring the development of stores dedicated exclusively to Slovenian-made furniture. *"We are working closely with the government to establish a retail concept where only Slovenian furniture would be sold. This concept could significantly increase our visibility in the local market and, if successful, could be replicated abroad"* (WOOD13). Such initiatives aim to boost the competitiveness of domestic companies by providing a platform to showcase their products directly to consumers.

One of the most significant challenges for Slovenian companies, particularly those involved in housing and windows, is establishing a brand and competing with domestic manufacturers in foreign markets. *"Competing with established local brands can be difficult, as they have better market recognition and often have the advantage of lower production costs"* (WOOD14). Companies must invest in expanding operations and building a brand that resonates with foreign consumers, which requires a long-term strategy. *"Creating a recognisable brand in foreign markets is a long-term effort, particularly when competing against well-known local manufacturers"* (WOOD11).

The B2C market for wooden houses and windows also presents challenges, particularly when establishing a recognisable brand. Slovenian companies face strong competition from well-established local brands in foreign markets. The process of building a brand is often slow and resource-intensive, requiring sustained investment in marketing and product differentiation. Moreover, the market for wooden houses is primarily limited to nearby international markets due to the high costs of transporting large prefabricated structures and sustainability concerns. *"For wooden houses, we can realistically compete only within a 1000-kilometre radius due to high transport costs and the need for sustainable practices"* (WOOD9). In contrast, sawmill products and furniture have greater potential to reach the global market, but this requires companies to invest heavily in branding, design and technology. *"Our products have the potential to* *compete globally, but we need stronger connections to design and technology to develop a compelling brand that can stand out in the market"* (WOOD8).

Focusing on branding and positioning will be essential for Slovenian companies to succeed in both domestic and international B2C markets. By enhancing product visibility, refining branding strategies, and working closely with the government on initiatives that support domestic production, these companies can overcome some of the major challenges they face in the global marketplace.

Table 4 summarises the key findings, showcasing the essential data and trends identified throughout the study.

5.8 Transition to high-value and sustainable products

Despite challenges, Slovenia's wood industry is shifting toward high-value, sustainable products, driven by growing demand for eco-friendly solutions and a broader industry commitment to sustainability. Prefabricated wooden houses, modular furniture, and energy-efficient components are gaining popularity, especially among eco-conscious consumers who prioritise sustainability and energy efficiency. *"Moving towards sustainable and high-value products requires new technologies and a shift in industry mindset and consumer expectations"* (WOOD8). This shift reflects a broader global trend, where consumers are increasingly willing to pay a premium for products that align with their environmental values.

The move toward high-value products is crucial for maintaining and enhancing global competitiveness. Companies are investing heavily in innovation to meet sustainability goals and attract consumers who are willing to pay more for environmentally friendly products. *"Investing in high-value modular homes with a focus on energy efficiency has allowed us to capture a new segment of eco-conscious customers"* (WOOD14). These products are in demand domestically and in export markets, where sustainability and quality are key differentiators.

Focusing on high-value, sustainable products helps position Slovenia's wood industry as a leader in the global green economy. *"We have found that by focusing on sustainability, we are not just meeting market demand; we are setting ourselves apart from competitors"* (WOOD11). This focus on sustainability allows companies to build stronger brands, increase customer loyalty, and open new revenue streams.

The transition to high-value, sustainable products also aligns with broader EU environmental goals, which aim to reduce carbon emissions and promote the use of renewable resources. Furthermore, companies are leveraging government incentives and support to help finance these sustainability initiatives. *"We have been able to access government grants that support innovation in sustainable product development, which has been instrumental in helping us stay competitive"* (WOOD13). These grants provide critical financial support for companies transitioning to more sustainable business models, allowing them to invest in new technologies and processes that reduce their environmental impact.

Table 4. Summary of key empirical findings

Aspect	• Findings
Challenges in the wood industry	• Fragmented forest ownership • Outdated technology • Lack of skilled labour • Market volatility
Market dynamics	• Fluctuating demand • Need for market diversification • Need for product diversification
Skills gap and workforce limitations	• Shortage of digital skills • High labour costs • Competition with neighbouring countries' skilled workforces
Technological and operational barriers	• Outdated machinery • High costs of modernisation • Regulatory challenges
Sustainability and certification challenges	• High costs for certifications (e.g., FSC, PEFC) • Essential for international market access • Continuous compliance requirements
Strategic responses and opportunities	• Investment in modern technologies (AI, BI) • Need for government support and incentives • Emphasis on collaboration
Transition to high-value products	• Shift to sustainable products (e.g., prefabricated houses and modular furniture) • Investment in branding and innovation
Policy implications and recommendations	• Address fragmented ownership • Increase R&D support • Incentivise technology investments • Encourage market diversification

Source: Own work (2024).

6 Discussion and conclusion

Despite its rich forestry resources, Slovenia's wood industry faces significant challenges that hinder its ability to fully leverage its potential. Key obstacles include fragmented forest ownership, relatively high reliance on roundwood exports, especially compared to Austria and Germany, and outdated technologies, all limiting the industry's global competitiveness. In contrast to neighbouring countries like Austria and Germany, Slovenia has not yet fully embraced technological modernisation or organisational cohesion, which are critical to achieving economies of scale and driving productivity. Investment in modern equipment, digital skills, and industry-wide collaboration will be essential for the Slovenian wood industry to catch up and capitalise on opportunities in higher-value-added markets.

The industry's vulnerability to market volatility, driven by its dependence on raw timber exports and fluctuating global timber prices, further complicates the situation. To reduce this reliance, the industry must diversify into high-value, eco-friendly products such as prefabricated wooden houses, modular furniture and bio-based materials. However, this shift requires a change in mindset and significant investment in R&D to innovate and adopt sustainable production practices. Slovenia must align with global trends, such as the circular bioeconomy, to unlock the full potential of its wood resources and position itself as a leader in sustainable, value-added wood products.

Strategic policy interventions are also critical. The government can play a key role by incentivising technological investments, supporting market diversification, and addressing the issue of fragmented forest ownership through cooperative management models or land consolidation initiatives. Furthermore, enhancing the digital skills of the workforce through targeted training programs and fostering collaboration among industry stakeholders will be essential to scaling efforts and improving the industry's competitiveness.

However, this research is not without its limitations. The study relied on a small sample of 16 semi-structured interviews, predominantly with small and medium-sized enterprises (SMEs), which may not fully capture the diversity of experiences across the broader wood industry, particularly among larger firms. Additionally, the Slovenian focus limits the transferability of these findings to other regions with differing economic, social, and regulatory contexts. The use of self-reported data introduces potential biases, as participants may have presented their companies in an overly positive light. Moreover, the research offers only a snapshot of the industry's current state and lacks a longitudinal perspective that would account for the dynamic changes in technology, policy, and market conditions. Finally, the study did not explore consumer perspectives or delve deeply into the impact of regulatory frameworks, which are vital for a more comprehensive understanding of the industry's challenges and future prospects.

In conclusion, Slovenia's wood industry requires bold, transformative action to overcome its challenges and fully realise its potential. Slovenia can position itself as a leader in the global wood industry by embracing technological modernisation, sustainability, and value-added production, and with coordinated efforts from the government, industry stakeholders, and educational institutions. However, ongoing research will be needed to address the limitations of this study and provide a more nuanced understanding of the industry's evolution.

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PREFABRICATED WOODEN HOUSE MARKET: MARLES CASE STUDY

1 Introduction

The global housing industry is undergoing significant transformation, driven by technological advancements, sustainability concerns, and evolving consumer demands. Prefabricated housing, particularly in wooden construction, plays a key role in this revolution, merging traditional techniques with cutting-edge technology. Marles exemplifies these trends by integrating modern technologies into its operations, setting new standards for sustainable, friendly living (Marles, 2024).

This chapter aims to explore the development and impact of rapidly evolving technology and smart solutions on the Slovenian prefabricated wooden frame house market from the perspective of the Marles company. The focus is on Slovenian companies, including Marles, which utilise prefabricated frame construction systems. The analysis is based on a combination of primary and secondary data sources.

The chapter provides a comprehensive analysis of Marles' position within the Slovenian prefabricated housing sector, comparing it with key competitors and exploring best practices from leading global companies. Specifically, the text addresses three key research questions. First, it explores how Marles has integrated new technology into its prefabricated housing models. Then, it investigates the impacts of these technological advancements on Marles' market position, assessing whether these innovations have strengthened its competitiveness. Finally, the text compares Marles with its competitors in the Slovenian market, analysing how the company stands in relation to other key players in the industry.

The chapter begins with an overview of the timber housing market and the various construction systems used, followed by an exploration of the current state of the market in both Slovenia and Europe. The subsequent sections present a detailed comparison between Marles and its key competitors, focusing on financial performance, technological innovation, supply chain management, and the role of government. The chapter concludes with insights into future expectations for the industry, particularly concerning sustainability and smart home technologies, offering a forward-looking perspective on the evolving market.

2 Timber house market

Timber houses are a sustainable and eco-friendly alternative to traditional construction, using wood as the primary building material. They offer significant environmental benefits, including a reduced carbon footprint and improved energy efficiency, aligning with growing trends toward green building practices (Gustavsson & Sathre, 2011).

2.1 Different production systems of timber houses

Various methods are utilised to build timber homes, each with its own set of advantages and applications. Among the most prominent techniques are skeletal construction, prefabricated frame construction, and cross-laminated timber (CLT).

Skeletal construction is a traditional method where a wooden frame forms the house's skeleton, with components like insulation, electrical installations, and plumbing integrated at the construction site. The frame construction process is relatively quick, as all timber parts are pre-manufactured using advanced Computer Numerical Control (CNC) machines. It allows for design flexibility and reduces on-site construction time, labour costs, and weather delays (Lawson et al., 2014). Additionally, it supports sustainability goals by reducing material waste and enhancing energy efficiency (Mao et al., 2015).

Production of prefabricated frame construction is a more modern method, where a wooden frame forms the house's skeleton, with components like electrical installations, plumbing, and windows integrated at the factory. This variation of frame construction also integrates insulation materials during factory assembly, ensuring consistent application and enhanced performance (Lawson et al., 2014; Piroozfar & Farr, 2013). It is particularly useful in regions with strict energy efficiency standards and reduces on-site work, minimising errors and delays (Goodhew, 2016). This method promotes sustainable building by lowering energy consumption (Häkkinen & Belloni, 2011).

CLT is an advanced prefabrication method that uses multiple layers of wood bonded with adhesives to create strong, solid panels that are cut to precise specifications using CNC machinery (Brandner et al., 2016). CLT offers benefits such as lower environmental impact, improved thermal performance, and carbon sequestration (Brandner et al., 2016). It is suitable for multi-story buildings due to its strength and stability, and it enables faster construction by allowing quick on-site assembly (Churkina et al., 2020). Despite needing some additional on-site work, CLT is highly customisable and environmentally friendly (Gavric et al., 2014).

2.2 Current situation in the European timber house market

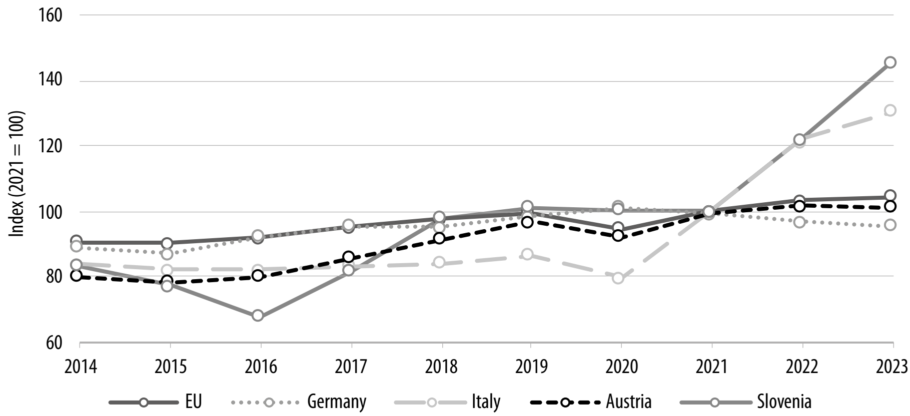
The timber house market in Europe has experienced substantial growth in recent years, driven by an increasing demand for sustainable, energy-efficient homes that incorporate modern technologies. The growing environmental consciousness among consumers and the push for renewable materials have aligned well with the timber housing sector, positioning it as a strong player in the broader construction industry. Timber houses, known for their low carbon footprint and high energy efficiency, have become increasingly popular as part of the shift towards eco-friendly construction (Ghobakhloo, 2020; Vestin et al., 2018). As of 2023, the European prefabricated timber buildings market is valued at approximately \$57.87 billion and is expected to grow at a compound annual growth rate (CAGR) of 5.41 percent, reaching around \$75.29 billion by 2029. This growth is fueled by the increasing demand for eco-friendly construction, coupled with favourable government policies supporting sustainable housing (Mordor Intelligence, 2023). The demand for timber housing is particularly strong in countries like Germany, France, and the UK, where regulations supporting renewable materials and energy-efficient construction are most stringent (IMARC Group, 2024).

Although timber construction is expected to represent a higher percentage of new buildings in the future, there is a negative trend in overall construction, based on the sector NACE F[1] data, in some European countries (Figure 1). The

1 NACE F refers to the statistical classification of economic activities in the construction sector, including general construction and specialised construction activities for buildings and civil engineering works.

index for the European Union has stagnated over the past three years, with several leading countries reporting stagnation or even decline. Slovenia is performing exceptionally well compared to Austria, Germany, and Italy and is significantly outperforming the EU average.

Figure 1. Production in construction index (NACE F sector), annual data



Source: Eurostat (2024).

Despite the overall stagnation and decline of construction in the biggest European country, Germany, the timber construction market remains dynamic, with no single company dominating the sector. Some of the key players include Stora Enso Group, Binderholz GmbH, and KLH Massivholz GmbH. These companies are leading innovations in prefabricated timber construction and custom timber solutions, helping drive the market forward (Virtue Market Research, 2023). Adopting CLT, particularly in residential construction, is another significant factor contributing to growth.

Despite the growing demand, price sensitivity remains a significant barrier for many consumers (Mergel et al., 2024). More price-sensitive customers are reluctant to buy wood-based houses because they are more expensive than brick ones (Hrdlicka et al., 2022). Concerns over value stability and durability also influence consumer decisions, particularly in regions where timber is not a traditional building material. Buyers often weigh the upfront costs of timber construction against long-term benefits. While many are motivated by sustainability, they may be deterred by fears of depreciation or high maintenance costs (Mergel et al., 2024).

The alignment of timber housing with smart home technologies is another significant market trend. Companies increasingly incorporate advanced systems such as integrated Heating, Ventilation, and Air Conditioning (HVAC) systems, smart lighting, and security features into their homes. These innovations enhance the sustainability of timber houses and cater to the growing consumer demand for technologically advanced, eco-friendly homes (Vestin et al., 2018). However, adopting these technologies faces hurdles, particularly due to a lack of digital maturity and skilled labour within the industry. As a result, the integration of smart technologies is progressing more slowly than expected (Mordor Intelligence, 2023).

2.3 Best practices from leading global companies

Leading global companies (mostly headquartered in Europe) in the timber housing market are adopting innovative strategies that focus on sustainability and incorporate advanced technologies to enhance production efficiency and meet the growing demand for eco-friendly housing (Vestin et al., 2018).

Sustainability is at the core of operations for many European timber housing companies, with Lignotrend in Germany as a prime example. Lignotrend emphasises using certified sustainable wood, such as the Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC), ensuring that their raw materials are sourced responsibly. Additionally, the company prioritises resource efficiency by minimising waste through advanced production technologies, aligning with regulatory requirements and consumer demand for environmentally friendly products (Vestin et al., 2018). These practices reduce the environmental footprint and enhance their products' marketability, particularly among eco-conscious buyers (Ghobakhloo, 2020).

WeberHaus in Germany is renowned for its use of modular construction systems that combine mass production with high levels of customisation. By utilising prefabrication in a controlled factory environment, WeberHaus achieves greater consistency in quality while significantly reducing on-site construction time and waste. This approach not only lowers costs but also improves energy efficiency. WeberHaus integrates smart home technologies, enabling homeowners to control aspects like lighting, heating, and security remotely, which enhances both convenience and energy savings. This combination of modular efficiency and customisation has positioned WeberHaus as a leader in the European timber housing market (Mordor Intelligence, 2023).

Companies like Moelven in Norway are pushing the boundaries of timber construction by integrating advanced technologies such as robotics, augmented reality (AR), and the Internet of Things (IoT). Robotics improve precision and reduce production errors, particularly in complex timber structures, while AR and IoT allow for enhanced customer engagement through real-time visualisation and customisation options. This level of technological integration enables companies to offer bespoke solutions tailored to individual customer needs while also improving production efficiency and reducing lead times (Vestin et al., 2018; Ghobakhloo, 2020).

3 Research methodology

To provide a more detailed analysis of the prefabricated housing industry in Slovenia and the position of Marles in the industry, six interviews with representatives from three companies in the sector were performed. The interviews covered a wide range of topics, including the industry's ecosystem, technological advancements, sustainability initiatives, key challenges, and the future potential of the prefabricated housing market. The interviews (Table 1) took place between August 23 and September 4, 2024, involving directors, heads of development, and quality management professionals. Each interview lasted between 35 minutes and 1 hour 35 minutes.

Table 1. List of interviewees

Code	Ownership structure	Markets of operations	Gender
MARLES1	Investment fund	Slovenia, Austria, Scandinavia, Russia, Ukraine, Central and Eastern Europe, USA, Tanzania, Aruba	Male
MARLES2	Investment fund	Slovenia, Austria, Scandinavia, Russia, Ukraine, Central and Eastern Europe, USA, Tanzania, Aruba	Male
MARLES3	Investment fund	Slovenia, Austria, Scandinavia, Russia, Ukraine, Central and Eastern Europe, USA, Tanzania, Aruba	Female
MARLES4	Investment fund	Slovenia, Austria, Scandinavia, Russia, Ukraine, Central and Eastern Europe, USA, Tanzania, Aruba	Female
COMPETITOR1	Private ownership	Slovenia, Croatia, Italy, Switzerland	Male
COMPETITOR2	Private ownership	Slovenia and a strong presence in Germany, Switzerland and Italy	Male

Source: Own work (2024).

4 Marles company case

The foundation of the Marles company dates back to 1899 when Ferdinand Potočnik opened a carpentry workshop in Limbuš, near Maribor, to produce quality wooden products. Over decades, Marles evolved from a traditional woodworking company into a pioneer in the prefabricated wooden building industry. Today, Marles is one of Slovenia's most advanced and largest manufacturers of prefabricated wooden houses, with the longest tradition in timber frame construction in the region and a global reach since 1942 (Marles, 2024).

4.1 Presentation of the company Marles

Marles is a company known for its commitment to sustainability, specialising in energy-efficient wooden homes. Using natural materials, with wood as the primary construction element, Marles combines environmental responsibility with the warmth and beauty of timber. They offer a variety of projects to meet diverse client needs, including custom-built homes through their individual solutions and pre-designed models under Marles solutions for those preferring a faster, streamlined process. Additionally, they cater to larger-scale projects like public buildings and modular, timber-based structures for apartments and business units. With a portfolio of over 30,000 homes and 400 public facilities, all produced at their facilities in Lovrenc, Slovenia, Marles continues to integrate sustainable practices into its wide-ranging construction projects (Marles, 2024).

Table 2. Key financial data of Marles for the past five years

Indicator	2019	2020	2021	2022	2023
Revenue (in €)	25,466,290	22,838,232	23,423,505	31,546,607	24,600,837
Average number of employees	118.06	119.47	118.84	128.2	120.57
Turnover per employee (in €)	215,450	191,162	197,101	246,073	204,037
Added value per employee (in €)	40,581	45,904	39,728	38,235	39,217

Source: Bizi.si (2023).

Over the past five years, Marles has experienced fluctuations in its key financial indicators (Table 2). Revenue peaked in 2022 at €31.5 million but saw a decline to €24.6 million in 2023. The average number of employees remained relatively stable, ranging from 118.06 in 2019 to a high of 128.2 in 2022. Turnover per employee followed a similar pattern, increasing to €246,073 in 2022 and dropping to €204,037 in 2023. Added value per employee showed a significant decline, with the highest figure in 2020 at €45,904 and the lowest in 2022 at €38,235. Despite fluctuations, Marles maintained overall stability in its workforce but has been reporting a decline in financial performance in recent years.

Marles' mission is to fulfil clients' dreams by merging innovative technologies with sustainable practices, creating nature-connected living environments. Their vision is to become a globally recognised brand for climate-smart living that enhances both human potential and environmental well-being. The company aims to provide every individual with a healthy, sustainable living environment that fosters happiness. Marles promises to deliver innovative, efficient, and comprehensive prefabricated solutions while building trust through reliable and enjoyable customer experiences (Marles, 2024).

4.2 Overview of Marles' position in the prefabricated wooden house market

Marles, one of the leading companies in Slovenia's timber housing industry, holds a unique position due to its strong commitment to sustainability and technological advancement. However, the company faces some challenges, particularly in sourcing materials, maintaining its position in international markets and expanding into new international markets.

One of Marles' primary strategies is rooted in its dedication to sustainability, which is reflected in its rigorous material sourcing standards. The company ensures that all materials, especially wood, are certified by credible organisations. As one representative emphasised, *"We ask suppliers for certificates like the European Technical Assessment. We are not allowed to buy materials without them, which ensures our products meet sustainability standards"* (MARLES3). The certificate requirement highlights Marles' proactive approach to aligning its operations with global sustainability trends. Yet, this commitment comes with operational costs, primarily due to the company's reliance on Austrian imports for raw materials. Despite Slovenia's abundant timber resources, the domestic sawmill industry has lagged behind. Another company's representative pointed out, *"Slovenia fell behind in the sawmill industry. This market has been taken over by the Austrians"* (MARLES1), illustrating a critical gap in Slovenia's industrial infrastructure. This dependency on external suppliers increases production costs and limits Marles' ability to fully capitalise on Slovenia's local resources.

From a technological standpoint, Marles has made substantial investments in automation and digitalisation to enhance precision and efficiency in manufacturing. The integration of CNC machines exemplifies this shift. However, Marles' emphasis on customisation complicates efforts toward full automation. *"We have integrated CNC machines, but the individualised nature of our products complicates full automation"* (MARLES2). While technological advancements have improved production efficiency, the customised nature of Marles' homes requires a level of craftsmanship that machines cannot easily replicate. This balancing act between technological innovation and maintaining a high level of customisation is a challenge Marles will continue to face as it strives to modernise its processes.

Moreover, Marles has struggled to establish itself in foreign markets, particularly in countries like Germany and Austria. Despite its strong domestic reputation, the company faces difficulties abroad due to entrenched consumer loyalty to local brands and very low brand recognition. One representative acknowledged that despite having a subsidiary in Austria since 2003 and also in Switzerland, they are still struggling to gain full acceptance in the market. *"In Austria, we are still viewed as an outsider, and customers prefer domestic brands. The consumers trust the supplier or the seller more if they see that you are locally present"* (MARLES1). This challenge indicates broader issues related to international market penetration, where nationalistic preferences and brand loyalty create barriers for foreign competitors. Marles is the brand with the longest tradition. Before the revitalisation of the brand, the company was more attractive to mature buyers. With new ownership and a new management team, the ambition is to change the perception of the brand, focusing the most on the younger population, as they are future potential customers. The goal to be perceived differently in the eyes of young clients recently led them to the rebranding of the company. *"While we were sharpening the positioning of the brand, improving the look and feel of Marles, and developing new communication, we also re-developed the existing product portfolio"* (MARLES4).

Internally, Marles prides itself on fostering a positive work environment, which has been instrumental in maintaining employee satisfaction. *"If you give people security and a vision, if they understand that they are contributing, that their effort is appreciated, then I truly believe they will also stay in the company because they feel good. They feel good for themselves, they feel good in the organisation, and they feel safe"* (MARLES1). However, the company is facing a shortage of skilled labour, particularly in production roles. *"We are struggling to attract skilled workers, particularly in production roles, and this will be a* *major challenge for our future expansion"* (MARLES1). This labour shortage is not only a constraint on production capacity but also impacts Marles' ability to scale operations efficiently.

4.3 Marles in practice: Dom24h house

One of Marles' most innovative projects is the Dom24h house, completed in 2022 and recognised as the smartest house in Slovenia. This groundbreaking project integrates living, working, and leisure into a net-zero energy house, demonstrating a significant leap in smart home technology. According to Marles, *"This is a development project, co-financed by the ministry, which is definitely one of the advantages I mentioned earlier. The project started in 2018. There was a call for applications, and we applied along with 13 other progressive Slovenian companies"* (MARLES2). The goal was ambitious: *"The idea was to create a carbon-negative building, using materials that reduce the building's footprint by at least 5 percent, while keeping the same usable area. The goal was also for it to be a smart building, interconnected with other systems, and equipped with smart devices that make it energy-negative, which means generating more energy than it consumes"* (MARLES2).

The Dom24h house assembled just before the pandemic, proved remarkably forward-thinking in its design. Marles highlighted its dedicated 30-square-meter workspace, including a kitchenette and toilet, allowing for independent work from home. This space can also serve as a studio apartment for family members, offering flexibility for modern families. During the COVID pandemic, the house's relevance became even more apparent as many families struggled with remote work and online schooling. *"Dom24h addresses these challenges with its dedicated work area and smart features, which allow the entire house to be controlled via a tablet and monitored through 170 sensors"* (MARLES2).

While the house's design is visionary, especially in the context of the pandemic, its future success depends on addressing affordability concerns. Dom24h sets a high standard for energy efficiency and remote work solutions.

5 Comparison of Marles with main competitors

This section provides a comparative analysis of key players in Slovenia's prefabricated housing industry, focusing on financial performance, technological innovation, supply chain management, workforce strategies, sustainability practices, and interactions with government regulations. The insights highlight how Marles and its competitors navigate industry challenges while employing different strategies to maintain competitiveness in a rapidly evolving market.

5.1 Financial performance

A comparative analysis of the four leading companies in the prefabricated frame construction sector with integrated insulation systems in Slovenia – Marles, Lumar, Jelovica, and Rihter – reveals variations in financial performance for the year 2023 (Table 3).

Table 3. Financial comparison among competitors and industry average in 2023

Indicator	Marles	Lumar	Jelovica	Rihter	Industry average
Revenue (in €)	24,600,837	29,909,300	13,629,643	9,670,452	19,452,558
Revenue growth (in percent)	-22.84	13.3	-1.44	-11.78	-5.69
Share of sales on foreign markets (in percent)	52.82	16.08	62.95	17.69	37.39
Average number of employees	120.57	94.62	73.43	45.32	83.49
Added value per employee (in €)	39,217	82,538	66,532	40,084	57,092

Source: Bizi.si (2023). Own analysis.

Financial analysis indicates that Lumar leads the competition with the highest revenue. It is also the only company with positive revenue growth in the last financial year, positioning itself as a strong market player. In contrast, Marles, Jelovica, and Rihter faced revenue declines, largely due to challenges in foreign markets (MARLES2). Jelovica, despite its smaller overall revenue, has the strongest foreign revenue share at 62.95 percent, highlighting its strong international presence. Despite its big reliance on foreign markets, Jelovica was able to keep revenue decline relatively low, perhaps as their exports are oriented on the B2B sales, which is not true for other competitors. Lumar is gaining a share of the Slovenian market, which may also be why other competitors record a decline in domestically generated revenue. Despite this, Marles remains competitive, with the second-highest revenue of €24.6 million. Companies can also be compared from the standpoint of the workforce. Marles has the highest number of employees, but compared to other companies, it has the lowest added value per employee. The industry average is well above its performance.

When examining asset and capital growth, Marles has outperformed its competitors in recent years, showing the most robust growth in these areas. While most companies reported gains in assets and capital, Jelovica saw a reduction, standing out as an exception to the overall growth trend within the sector (Bizi.si, 2023).

5.2 Technology and innovation

In the Slovenian prefabricated housing market, companies are increasingly focusing on balancing technological advancements with the need for highly customised solutions. Despite the potential benefits of automation, the complexity of individualised projects makes it difficult to fully adopt these innovations.

Marles has consistently emphasised its investment in digitalisation and technology, particularly in improving efficiency and processes, while acknowledging the challenges of full automation due to the highly individualised nature of housing in Slovenia. Marles pointed out, *"We cannot fully automate the process because each project is unique, and customisation is our strength"* (MARLES1). They recognise the importance of maintaining flexibility to meet client demands, limiting the degree of automation they can adopt.

However, COMPETITOR1 takes a slightly different approach. While they agree that individualisation complicates processes, they place a strong emphasis on managing the complexity. *"The more combinations there are, the harder it is to manage processes"* (COMPETITOR1). Despite customisation challenges, it has invested heavily in process management to ensure smoother operations. Their competitive edge lies in offering comprehensive, highly customised services, from design to turnkey construction.

In contrast, COMPETITOR2, while also focused on craftsmanship and individualisation, is more traditional in its approach. It has not yet fully embraced technological advancements like Marles. The company remains rooted in manual processes and traditional methods. *"Our strength lies in our longstanding expertise in production, and we rely more on the craftsmanship that has defined us for decades while we are gradually investing in automation and digitalisation"* (COMPETITOR2). This reliance on tradition may limit their ability to innovate and scale, positioning Marles ahead in terms of integrating technology into their operations.

Regarding smart home technology, Marles has recognised that while the technology is available, the demand from clients is not yet strong enough to justify large-scale investment in this area. As noted, *"People are not yet willing to invest in smart homes; they do not see the added value"* (MARLES1). COMPETITOR1 observed a decline in the demand for smart home installations, stating, "*Interestingly, there were significantly more smart home constructions in the past than there are today"*. In this context, none of the competitors, including Marles, have fully embraced smart home technology, as the market is not yet ready for widespread adoption.

5.3 Supply chain management

In Slovenia's prefabricated housing industry, effective supply chain management is critical, particularly due to challenges related to raw material sourcing, production capacity, and infrastructure. One significant issue across the industry is the reliance on foreign suppliers for processed wood, which is driven by insufficient local resources.

Marles has acknowledged the current state of its supply chain, emphasising the dependence on foreign suppliers, especially from Austria, for high-quality wood. *"We do not see any big weaknesses in the supply chain, but we see the potential for improvement, especially for the Slovenian industry"* (MARLES1). The representative further explained, *"30 percent of the wood is bought in Slovenia, but 70 to 80 percent is bought from Austria"*. They highlighted that Austria's advanced wood processing capabilities provide a significant competitive advantage. *"The level of the optimisation and usage of their wood is extreme. To the last drop of the wood, they are using everything. And out of that, of course, their competitive advantage over the Slovenian companies is enormous"* (MARLES2).

This situation is mirrored by COMPETITOR1, which faces similar local supply constraints and relies heavily on foreign sources. *"Mostly, we do not source from local suppliers. In Slovenia, everyone complains that the wood supply chain is completely wrong. This market was taken over by the Austrians, who still buy a lot of Slovenian wood and process it into semi-finished products. We then buy these semi-finished products, partly because they are certified. By this logic, the wood circles from Slovenia to Austria and then back to Slovenia. However, we also have some local wood and strive to increase this share"* (COMPETITOR1). COMPETITOR2 also relies on Austrian suppliers. They noted, *"We buy all the wood from there, and they can supply us. The prices are always good. Slovenian companies are simply too small now"* (COMPETITOR2).

The industry's shared concern lies in Slovenia's underdeveloped wood processing infrastructure. Marles' representative expressed this concern: *"We are the third woodiest country in Europe, but only 50 percent of our wood is used efficiently. So, there we are losing. And it is not Marles that is suffering, but the whole economy surrounding it is suffering because we cannot have more added value in Slovenia from this excellent material that is given to us directly from nature"* (MARLES1).

Overall, while the Slovenian prefabricated housing industry acknowledges the reliability and quality of Austrian wood suppliers, there is a shared desire to increase the use of local resources. However, the limitations in Slovenia's wood processing infrastructure and supply chain make this goal difficult to achieve, leaving companies dependent on foreign suppliers for the foreseeable future.

5.4 Governmental support and barriers

Like its competitors, Marles faces significant challenges in obtaining building permits, which delays project timelines and increases costs. Marles' representative noted, *"Currently, one of the biggest challenges in the Slovenian market is obtaining building permits. The process is relatively slow. We have been waiting for a building permit for one of our clients at the Sežana administrative unit since last December"* (MARLES1). COMPETITOR1 highlighted an even more specific issue: *"The government's inefficiency in handling permits is paralysing smaller businesses, especially when we need to expand or innovate. It is exhausting."* In contrast, COMPETITOR2 pointed out, *"The process could be improved significantly if the government reduced the bureaucracy. It is not just a matter of permits; every aspect of dealing with the government is slow."*

Both Marles and its competitors agree that regulatory complexity is a persistent issue. *"From past experience, I have to say that things tend to get more complicated rather than simpler. New regulations are often introduced, so they do not improve the process, but actually make it worse"* (MARLES1). COMPETITOR1 shared, *"Navigating the endless regulations is a daily battle for us. Every year, something new comes up that slows us down."* COMPETITOR2 mirrored this sentiment: *"Our biggest challenge is not production. It is the constant regulation changes we have to follow. It eats up time and resources."*

Regarding subsidies, Marles recognises the potential benefits but acknowledges the complexity of applying for them. They stated, *"We must praise the* *government for providing something good. Support is available if the company is mature enough to accept it. If you are not prepared enough to accept it, you cannot use it"* (MARLES1). COMPETITOR1 took a stronger stance: *"Grants and subsidies are theoretically helpful, but the hoops you have to jump through make them inaccessible for most smaller companies."* COMPETITOR2, while agreeing with the value of subsidies, also pointed out, *"We spend more time and resources applying for these funds than we gain from them in the end."*

6 Future expectations for the wooden house market in Slovenia

Marles sees the smart house market growing rapidly but adopts a balanced approach to technology. While smart systems such as automated lighting and climate control can enhance daily living, Marles does not believe every new technology is essential for a comfortable home. *"We are not selling smart houses. We support smart choices. Even though we do not believe that all the technology built into a house is necessary for comfort, we can show what we can do and what is currently on the market"* (MARLES1). Marles acknowledges that technology evolves quickly and that what is new today might soon be outdated. *"Tomorrow it will be something else; maybe this is already obsolete, but the customer can see how the technology can support modern life"* (MARLES1). Rather than promoting every new tech feature, Marles focuses on demonstrating the current offerings while being transparent about the rapid pace of technological change (MARLES1).

For example, Marles points out how homes are moving from traditional wiring to wireless systems like Wi-Fi-controlled switches, allowing more flexibility. In the next decade, they predict that homes will no longer need as much wiring as wireless technology will handle more tasks. However, Marles does not just follow trends for the sake of it. They encourage homeowners to plan ahead and install basic wiring for future smart systems, even if they do not plan to use them right away. This approach ensures homes stay adaptable for later upgrades without the need for future major adaptations (MARLES1).

Looking to the future, Marles expects smart home technology to keep evolving, driven by both innovation and growing consumer interest. In five to ten years, they believe homes will be more connected with smart systems, but they also see a stronger focus on sustainability. *"Our vision is to be number one in sustainability. We want our buildings to be made as much from natural materi-*

als as possible, striving towards 100 percent if possible. Our commitment is not only to provide healthy living environments but also to ensure that our building practices do not harm the environment" (MARLES1). *"We are pushing for climate-positive living with advanced, sustainable timber-based housing and believe that homes will increasingly use renewable energy sources to become more sustainable"* (MARLES4). By 2035, Marles hopes to be recognised globally as a leader in climate-positive living, not by expanding into new markets but by inspiring and educating others. Their mission is to make homes smarter and greener, showing that these two goals can go hand in hand. A summary of key findings is presented in Table 4.

Table 4. Summary of key findings

Topic	Key findings
Technological integration	• Heavy investment in digitalisation (CNC machines). • Limited full automation due to customisation needs.
Supply chain management	• 70 to 80 percent of the wood is sourced from Austria. • Underutilised local resources (Slovenian sawmill industry is underdeveloped).
Revenue and market performance	• Lumar leads the market in revenue and growth. • Marles ranks second, with revenue decline but strong asset growth.
International market presence	• Over 50 percent of revenue is from foreign markets. • Struggles in Austria due to local competition.
Workforce and efficiency	• Largest workforce but the lowest added value per employee.
Smart home technology adoption	• Low consumer demand; companies are reluctant to invest in advanced smart systems.
Customisation vs automation	• Customisation limits full automation. • Automation is used selectively without sacrificing flexibility.
Government challenges	• Delays in building permits. • Regulatory issues are becoming more and more complex.

Source: Own work (2024).

7 Conclusion

The Slovenian prefabricated wooden house market is characterised by a delicate balance of tradition, innovation, and sustainability. Marles, one of the key players, has made significant strides in adopting advanced technologies and promoting sustainable living and wood as a main construction material. However, its reliance on foreign suppliers for key materials, particularly wood, poses a clear challenge, highlighting vulnerabilities in the local supply chain.

While Marles invests heavily in digitalisation and process improvements, the high level of customisation in its projects limits the potential for full automation, affecting production efficiency. Competitors face similar challenges, though some excel in specific areas like workforce efficiency and process management. While promising, smart technology integration faces slow consumer adoption and cost barriers.

Overall, Marles' future growth will depend on addressing supply chain constraints, enhancing operational efficiency, and managing the complexities of customisation. By refining its strategy in these areas, the company can strengthen its position in domestic and international markets, continuing to contribute to the evolving landscape of sustainable construction.

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POSITIONING THE NORTH ADRIATIC HYDROGEN VALLEY ON THE EMERGING EUROPEAN HYDROGEN ECOSYSTEM

1 Introduction

A recent increase in floods, droughts, wildfires, irregular temperature variations, and rising sea levels is only one of the many consequences of excessive exploitation of planetary resources. They come as consequences of a triple planetary crisis: climate change, pollution, and biodiversity loss, and society is responsible for tackling them. One of the solutions proposed in the Agenda for Sustainable Development 2030 promotes sustainable energy development, which is crucial for reducing greenhouse gas emissions and eventually mitigating climate change (United Nations, 2024). This goal was addressed in part by introducing the use of green hydrogen[1] produced from renewable sources. According to the EU Hydrogen Strategy (2020), the European Union (EU) should produce 10 million tonnes and import the same amount of hydrogen by 2030 to successfully transit to renewable energy sources and come closer to the overarching goal of decarbonising its economy and demonstrating trust in the future hydrogen market (European Commission, 2024). Assisting in the re-industrialisation of the EU economy and its electrification process, the transition to hydrogen is used as a medium for many different practices and for decarbonising the sectors, especially in hard-to-abate industries and commercial transportation. Although hydrogen-related technologies are still in the development phase, it is proven that hydrogen can be used as a feedstock, energy carrier and storage. Moreover, it also has many applications across various

1 From here on, green or renewable hydrogen will be referred to as hydrogen.

sectors like transport, industry, power, and buildings (European Commission, 2020). Technical readiness level of production and technologies related to green hydrogen that assure standardisation, proper regulation and safety are some of the main challenges the EU Hydrogen Strategy is still addressing (European Commission, 2020). All these factors contribute to the current market price of hydrogen, which is still not competitive compared to other energy sources.

Many coordinated hydrogen initiatives on a regional level have been arising as hydrogen valleys, such as the North Adriatic Hydrogen Valley (NAHV), aiming to boost the hydrogen market and provide a proper environment for emerging technologies to evolve and mature faster. Private initiatives in the hydrogen sector supported by EU funding will significantly change the industry, and those who take the risk might be the first to lead in the future.

This chapter aims to analyse the unique value proposition (UVP) of the NAHV compared to other EU hydrogen valleys in the early stage of the emergence of the EU-supported hydrogen ecosystems. The analysis is based on the acquired learnings structured around the Quadruple Helix model (industry, government, academia, and civil society), aiming to define potential benefits for citizens in the target territories and focusing on potential long-term economic progress and recommendations for regional development policies. The main threats related to NAHV are also addressed, and risk mitigation actions from NAHV and other hydrogen valleys have been explored.

The chapter is divided into three parts. The first part explains the main findings about the NAHV and helps tackle the research questions, utilising different perspectives from the research. The second part tackles the position of NAHV in more detail in relation to other selected hydrogen valleys. For that purpose, strategic benchmarking was done alongside qualitative analysis. Finally, the third part analyses the specific risks in hydrogen systems.

2 Geopolitical and regulatory context, strategic initiatives and risks in EU's hydrogen economy

The EU is facing many challenges regarding resources and energy management, and one of its new goals is a complete transition towards climate neutrality and green energy production, import, storage, and usage in Europe (European Parliament, n.d.). Some main acts supporting this transition are the European Green Deal, the Fit for 55 package and the REPowerEU plan. The transition towards climate neutrality by 2050 is tackled in the European Green Deal, emphasising reducing emissions by at least 55 percent by 2030, compared to 1990 levels and reaching net zero emissions by 2050 (European Commission, 2024). The Fit for 55 package, introduced in 2021, established legislative proposals to integrate the European hydrogen strategy into policy (European Commission, 2024). This package includes setting targets for hydrogen use in industry and transport by 2030, supported by infrastructure development and an efficient hydrogen market. Hydrogen is also described as key for decarbonising hard-to-abate sectors, which are known to produce the highest amount of greenhouse gases.

Following the geopolitical consequences of the war in Ukraine on the energy market and prices, the EU launched the REPowerEU plan, which should deploy more renewable energy, save energy and diversify energy supplies in the EU. In 2023, this plan gained additional legislation to increase its renewables capacity by raising its binding target to a minimum of 42.5 percent, up from the current 32 percent target, aiming to reach 45 percent by 2030 (European Commission, 2024). For this reason, the EU has been facilitating the large-scale deployment of hydrogen. The Hydrogen Strategy was adopted by the EU in 2020 and backed up by REPowerEU. By the first quarter of 2022, the Fit for 55 package managed to have all of its 20 action points implemented and delivered (European Commission, 2024).

Clean Hydrogen Partnership Joint Undertaking or Clean Hydrogen Partnership was founded in 2021, and it is composed of the European industrial association Hydrogen Europe, Hydrogen Europe Research, and the EU Commission. They play a central role in the further implementation of the EU Hydrogen Strategy, which is a unique public-private partnership that supports research and innovation (R&I) activities in hydrogen technologies in Europe (Hydrogen Europe Research, 2024). Expanding on the initiatives, hydrogen valleys were born. They are crucial for advancing Europe's hydrogen economy since these valleys integrate clean hydrogen production, storage, and distribution to end-users, fostering regional value chains (Clean Hydrogen Partnership, 2024). This process is carried out through the Quadruple Helix model, which includes four main components: industry, government, academia and civil society. The model highlights the crucial role of collaboration among these components to foster innovation and tackle complex societal issues. The inclusive approach ensures all stakeholders are actively and equally involved in the transformation process: the industry formulates business strategies, the academia conducts research and takes entrepreneurial roles, and the government enacts policies. Civil society's support is also essential for adopting and utilising new technologies (Carayannis & Campbell, 2019).

There are 32 hydrogen valleys in Europe now, of which most are regional and exclusive to one country. Only a few are international, joining multiple countries in one hydrogen valley (Hydrogen Valleys, 2024). The North Adriatic Hydrogen Valley (NAHV) is a unique transnational initiative bringing together Slovenia, Croatia, and Friuli-Venezia Giulia, an autonomous region of Italy. These valleys were formed to provide the ground for further hydrogen market development to make these new technologies widely available and used (Hydrogen Valleys, 2024).

Though a promising clean energy source, hydrogen presents several risks and challenges. One major issue is the development of infrastructure, which is both costly and complex. This development includes building pipelines, refuelling stations, and storage facilities. Production of hydrogen, especially hydrogen made from renewable sources, is currently costly in the EU, so reducing the cost of electrolysis is essential for improving its competitiveness. There are also efficiency concerns, as green hydrogen can be less energy-efficient than directly using electricity from renewable sources or other fuels. Safety is another significant risk since hydrogen is flammable and requires safety measures to prevent leaks and explosions. Various barriers must be overcome to achieve widespread market adoption of hydrogen technology, including the need for government incentives, industry collaboration, skill match, and consumer acceptance (European Commission, 2020).

3 Unique value proposition of the NAHV and the Quadruple Helix model: Regional benefits and risks

This section examines the unique value proposition (UVP) of the NAHV compared to other EU hydrogen initiatives and the Quadruple Helix model. It explores the potential benefits for citizens in its three target territories, focusing on long-term economic progress and regional development policies. It also identifies main threats and risk mitigation strategies, using examples from NAHV and other hydrogen valleys.

3.1 Research methodology

The research was conducted in August and September 2024. Given that hydrogen valleys are a relatively new phenomenon in the EU, with no completed life cycles of related EU-funded Horizon Europe initiatives, there is limited available evidence on their lifecycle. As a result, the methodology relies heavily on secondary sources, expert opinions, and early experiences.

The empirical analysis was conducted through 11 in-depth interviews with experts involved with the EU hydrogen valleys or otherwise informed about the use of green hydrogen. The sample characteristics are provided in Table 1. Selected interviewees shared insights from different perspectives, covering topics about all four parts of the Quadruple Helix model to help develop a holistic overview. The semi-structured interviews allowed flexibility to explore interesting topics that arose during the conversations.

The valleys chosen for strategic benchmarking were selected based on specific criteria, including demonstrated best practices referring to at least one of the four Quadruple Helix components and in connection with risk mitigation. The four selected valleys are NAHV, BalticSeaH2 (Baltic Sea Hydrogen Valley), HEAVENN (H2 Energy Applications in Valley Environments for Northern Netherlands), and eFarm Hydrogen Valley in Germany. More information about the selected valleys is presented in the section dedicated to the benchmarking analysis.

Table 1. Sample characteristics

Organisation	Role in Quadruple Helix	Interviewees	Gender	Code
Association 1	Mostly academia	President	Male	NAHV1
Association 2	Mostly industry	Analyst for regions and development policies in the hydrogen sector	Male	NAHV2
Institution 1	Government	Secretary	Male	NAHV3
Company 1	Industry	Head of Finance	Male	NAHV4-1
		R&D engineer	Male	NAHV4-2
		President of the Board	Male	NAHV4-3
Company 2	Industry	COO	Male	NAHV5
Institution 2	Civil society	Professor	Male	NAHV6
Company 3	Industry	RDI project manager	Female	NAHV7
Institution 3	Industry	Strategic coordinator	Male	NAHV8
Company 4	Industry	Founder of a leading EU hydrogen technology provider	Male	NAHV9

Source: Own work (2024).

3.2 Results

The main results obtained from the research are classified into three groups: integrated hydrogen ecosystem development (collaborative innovation, policy support, and sustainable funding), driving hydrogen adoption (cost, market demand, and industry innovation) and community engagement and workforce training in hydrogen projects.

3.2.1 Integrated hydrogen ecosystem development: Collaborative innovation, policy support, and sustainable funding

The insights collected from the "government" dimension of the Quadruple Helix model are used to present selected findings related to future policy-making and risk mitigation. First, hydrogen valleys are typically conceived as bottom-up initiatives meeting the support of the **Clean Hydrogen Europe Joint Undertaking**, representing the top-down policy-steering coordination and financing support to expand the European value chain for safe, sustainable, clean hydrogen technologies. *"This approach comes from the complexity of hydrogen projects, which need the involvement of entire socioeconomic systems to adopt new technologies and scale them up to industrial levels"* (NAHV9). NAHV exemplifies this approach. Spanning three areas (two countries and one region), it fosters **innovative regulatory collaboration** between governments and the Clean Hydrogen Europe Joint Undertaking. To address this specific framework, NAHV plans to establish a **Special Purpose Vehicle**, a non-profit association under Belgian Law, so that all partners and interested stakeholders of the NAHV can participate in the outcomes of this initiative and its further outgrowths even after the expiry of the EU funding. *"The next phase of the evolution of the NAHV will be the constitution of an AISBL[2]. The association will be open to all members from the Quadruple Helix"* (NAHV8) and essentially connected to all hydrogen-related projects in the region.

Focusing on **system-wide innovation**, NAHV uses the Quadruple Helix approach tailored to each ecosystem's socioeconomic and industrial characteristics. *"Hydrogen valleys are projects developed within the context of a particular region, port or other location; therefore, they have specific characteristics that determine the hydrogen technologies used. However, their best practices should be replicable across different projects"* (NAHV2). It is about

2 Association internationale sans but lucratif – (AISBL): An international non-profit association is a group of individuals or legal entities that pursues a disinterested goal of international utility with a head office in Belgium. More on: https://justice.belgium.be/fr/themes_et_dossiers/societes_associations_et_fondations/associations/aisbl

individual advancements and creating an integrated hydrogen strategy across all NAHV regions. *"It is always beneficial to work together with others at the end of the day"* (NAHV4-3). By involving representatives from each country's four main Quadruple Helix parts and managing 17 testbeds on the whole territory under the same umbrella, NAHV ensures the project is **innovative and practical**. This collaborative model drives success and can serve as a blueprint for other regions developing cross-border hydrogen initiatives. *"When finished, this will represent a regulatory framework applicable on the Pan-European level"* (NAHV5).

The three governments involved in the NAHV support hydrogen ecosystem development, a transnational collaboration that, among others, aims for regulatory harmonisation. More broadly, the role of the government is to facilitate collaboration, knowledge sharing, and **policy development**, all of which are essential for the success of the NAHV. *"We must prepare these policy guidelines together with a common hydrogen strategy between three countries"* (NAHV3). The early stages of the project have already revealed **significant challenges**, particularly related to funding and infrastructure. Still, the Ministry is committed to overcoming these through continued collaboration with national and international partners. *"It is our task to make further connections with Brussels and other countries to create the infrastructure"* (NAHV3). One of the primary focuses is establishing a clear **regulatory framework** that would provide clarity and stability for all stakeholders in the project. The industry acknowledges the government's role in the projects; however, they also see room for improvement. *"Second-level policymakers, like those in the Ministry, struggle with the necessary knowledge. They need to create the right environment for us. If there is no business case, the idea dies. We need someone to help us"* (NAHV4-3).

Sufficient **follow-up funding** is essential for the success of hydrogen projects. For example, the Baltic Sea Hydrogen Valley operates under the EU umbrella for the creation of the hydrogen valley and regulatory support. *"The EU project creates an umbrella that brings various investment cases and stakeholders of the Quadruple Helix model together and strengthens the collaboration"* (NAHV7). It distinguishes itself by investing heavily in its own projects, believing that sustainability will yield better results through direct investment in R&D and project development. *"To ensure the long-term operation of the valley and significant growth, additional external funding and financing will be secured during the project. The project will create a strong basis for the future positive investment decisions and growth"* (NAHV7). It is common across other valleys that besides the initial funding of the valley, additional investments are necessary, deriving from the public sector, the industries and financial intermediaries. *"Due to their nature, hydrogen valleys require massive investments, meaning that funding from the Clean Hydrogen Partnership needs to be complemented with other public and private funding sources to ensure the success and sustainability of a project"* (NAHV2).

3.2.2 Driving hydrogen adoption: Cost, market demand and industry innovation

The industry is one of the main actors that push the production and development of the economy based on Quadruple Helix. Insight into the UVP of NAHV, the future of this sector and its regulations, as well as risks are further discussed. Firstly, the **cost of hydrogen**, being a crucial determinant for its uptake, is determined by **natural advantages** and **geopolitical circumstances**, depending mostly on renewable energy generation capabilities, transportation and storage. *"If you produce hydrogen at €3 per kilogram in Tunisia and want to bring it through pipelines in Germany, so 1,500 kilometres, the marginal additional cost for transport is around €0.4 per kilogram. It is a very small marginal cost compared to hydrogen produced in Germany. In Germany, hydrogen will cost more than €10 per kilogram"* (NAHV1). Prices for hydrogen production in various EU countries are higher mainly due to higher electricity prices: *"The cost of electricity is much, much lower (outside of EU). The cost of electricity is one big factor in the total cost of ownership of hydrogen"* (NAHV1), and this gap presents a real issue. *"The cost of producing renewable hydrogen at some locations in the EU is significantly higher than what end users, who currently use natural gas, gasoline, diesel, or grey hydrogen, are willing to pay. This price gap is substantial"* (NAHV1). Thus, *"The NAHV project, with 37 partners, has positioned the North Adriatic region as a future European hydrogen hub. Its success is built on three pillars: pioneering an offtake market for 16 million inhabitants, enabling storage and transport of hydrogen through unique innovation, making its usage affordable, and establishing a leading European clean hydrogen import destination"* (NAHV9).

To make one large hydrogen market, creating sufficient market **demand for hydrogen** is essential. Ratios in demand and supply of hydrogen are very different between countries. While some can satisfy their own demands, many will not adopt hydrogen until the market is ready with price and infrastructure. *"Our approach involves creating demand from the offtake market first in the form of a hydrogen valley, but not forgetting to simultaneously create the entire value chain. This strategy, combined with support from multiple governments, helps* *us overcome challenges and create a robust market for hydrogen. It is a complex process, but with collective effort, we are making significant progress"* (NAHV5).

The industry is the main driver of innovation and creates demand for hydrogen through various green and zero-emission projects. With the new regulatory framework arising from the Green Deal and the overall plan for decarbonising the industrial sector in Europe, many companies, especially in the hard-to-abate sector, are willing to invest in alternative and green energy sources. *"Some construction companies are also struggling with ECG and not meeting the sustainability criteria"* (NAHV4-1). This decision comes from wanting to align with EU goals and avoid pollution penalties. For example, some companies plan to switch to hydrogen-fueled transportation to solve the problems with emissions. *"We can solve all the transportation (using hydrogen)"* (NAHV4-2). Others are using hydrogen during production instead of other gases, developing their own hydrogen-based solutions. The demand for hydrogen in this sector is real, and *"there are no specific safety concerns"* (NAHV4-2) regarding its use in industry as long as R&D is working on it constantly. Additionally, the willingness of industry representatives and other partners to collaborate in hydrogen valleys signals the market where to focus.

3.2.3 Community engagement and workforce training in hydrogen projects

To tackle future challenges and risks connected to academia and civil society, the engagement of local communities has been proven essential to convey future opportunities and address the safety and environmental concerns of hydrogen projects. Increasing community awareness and involvement is crucial for the success of hydrogen projects. *"The general public in the region is less aware of the latest developments on a technological level but is very aware of anything that goes wrong in any hydrogen plant"* (NAHV8). Often, local communities have low initial awareness, and their involvement is typically indirect through officials, industry, and academia. Direct participation through public consultations and advisory boards can bridge this gap, allowing communities to voice concerns about safety and environmental impact. *"Building trust requires consistent, open communication and tangible benefits that the community can see and experience"* (NAHV6). Safety concerns are present in local communities, particularly regarding hydrogen's flammability and high-pressure storage. Addressing these concerns requires clear, accessible communication and practical demonstrations of safety protocols. Establishing advisory boards that include local residents enables direct community involvement in decision-making processes, ensuring that projects are aligned with local values and fostering trust. *"Civil society should be seen as a co-developer in the hydrogen valley's long-term evolution, not merely a beneficiary or passive observer"* (NAHV6).

Education and training programmes about the hydrogen valleys are being developed to ensure a skilled workforce for the hydrogen sector. Collaborations with local academic institutions and professional training centres aim to equip the current and future workforce with the necessary skills to support the hydrogen industry's growth. By investing in education and training programs, workers from related sectors, such as oil and gas, can be reskilled or upskilled to transition into the hydrogen sector, ensuring smooth and efficient energy shifts. *"In the specific territory, if there is an excellent workforce, industries are more interested in developing the business"* (NAHV1). These initiatives address the immediate technical needs and foster long-term employment growth and sustainability within local communities, thereby supporting the broader goals of the hydrogen valleys. A working group has been set up to discuss and address the skills needed in the hydrogen sector. Additionally, educating students as future leaders in the hydrogen transition is important, with various programs supporting this effort.

3.2.4 Position of the NAHV in relation to other selected hydrogen valleys

Based on the expert judgements and the key findings above, strategic benchmarking was conducted using selected key performance indicators (KPIs) and qualitative observational components to demonstrate the UVP of the NAhv and address the potential risks. It must be mentioned that general benchmarking is not a meaningful solution for comparing the valleys since the systems in which valleys operate are still too complex and quite dissimilar. However, looking from a strategic point of view, interpreting the different valleys by exhibiting their main characteristics (scope and influence) and best practices that helped them mitigate specific risks that are universal for all valleys can help spot the same risks for the NAHV and propose potential solutions for risk management in all four dimensions of the Quadruple Helix. This analysis can also provide a new perspective on how the NAHV is positioned based on its own scope and influence compared to the other three valleys.

BalticSeaH2 is a transnational valley like the NAHV, and funding was granted in the same year. This initiative follows a different approach in terms of the initiation of the valley. While the NAHV is a result of a bottom-up approach,

Table 2. General key performance indicators of the valleys

Key performance indicators	NAHV	HEAVENN	BalticSeaH2	eFarm
Positioning	• Cross-border valley • Ideal position for a hydrogen hub • Low renewables	• Abundant wind and solar energy • Strong industrial base • Excellent port facilities	• Abundant renewable energy from wind power • Exports of the surplus via cross-border hydrogen pipeline transmission infrastructures	• Wind energy • Close to local industries and transportation networks • Not optimal for large-scale distribution
Geographical location	Slovenia, Croatia, and the Friuli-Venezia Giulia	Northern Netherlands	Main Valley between Finland and Estonia, connected valleys around the Baltic Sea	North Frisia, Germany
Target production	5,000 T/year	36,500 T/year	100,000 T/year	126 T/year
Funding	• EU: €25 million • Public-private co-funding: over €300 million	• EU: €20 million • Public-private co-funding: €70-80 million	• EU: €25 million, • Project partners: €8 million • Total value of investments: over €4billion	€17.60 million
Project duration	1 Sep 2023 - 31 Aug 2029	1 Jan 2020 - 31 Dec 2025	1 June 2023 - 31 May 2028	2020 - 2035
Number of partners	37 partners and their associated companies	31 public and private partners from 6 EU countries	40 from 9 countries in the Baltic Sea region	20 regional partners
Long-term sustainability	• Established Special-Purpose Vehicle (SPV) • International non-profit association (AISBL) in Brussels	• Replicable model for green hydrogen operations • Established SPV, which unites over 30 partners	• Strategic growth plan for the cross-border hydrogen economy and replication tools • Social awareness and acceptance activities and practices to engage the community	Effective community engagement and strategic de-risking
Focus of innovation	• Decarbonizing hard-to-abate industries • 17 industrial testbed pilots across three sectors • regulatory framework	Multiple projects aimed at integrating hydrogen technologies into the energy system	Innovate across all sectors, with a focus on fuel cell technology and heating solutions	Complete value chain of green hydrogen on the mobility path
Education and training	• H2 student program • Educational workshops • Public events	• Training programs • Workshops • Academic collaborations	• Educational glossary at the main website • Workshops, public events and social awareness activities	Including local communities in the development processes

Source: NAHV (2024); HEAVENN (2024); BalticSeaH2 (2024); GP-joule (2024); Clean Hydrogen Partnership (2024).

the BalticSeaH2 started top-down. This valley represents a useful comparison since it is also a cross-border valley and has one of the best practices related to the industry sector (Baltic Sea Hydrogen Valley, 2024).

HEAVENN is an example pointed out by many European hydrogen websites and articles as one of the best-implemented practices of hydrogen valleys in Europe, especially in terms of exceptional collaboration with the government. (Roland Berger & INYCOM, n.d.).

The third valley is **eFarm**, which is comparably smaller but represents a unique example of how small-scale valleys that follow a focused strategic approach can bring the civil society from the target region and the project together in a unique collaboration. Moreover, this valley effectively managed public acceptance risks by using a successful strategic approach (GP Joule, 2024).

General characteristics are defined as general KPIs of the valley during the project (Table 2). In addition, the differences in approach, scope and width are presented (Table 3).

NAHV, based on its position, is behind in terms of renewable energy production. Still, as a potential port for importing cheaper hydrogen to the EU, it is definitely in the strategic lead (Table 2). Moreover, the structure that already works as a cross-border structure provides significant reassurance to the market regulation frameworks for the future. Since one of the focuses is on hard-to-abate industries, demand for hydrogen will be present. In this case, the infrastructure, led by bottom-up initiatives, will be prioritised for development. Creating a separate governance structure as a non-profit SPV is a safe initiative, which was also done by the famous HEAVENN project. Regarding education, NAHV has a versatile profile dominated by the unique H2 student programme (Table 2).

Choosing the top-down vs bottom-up approach highlights decision-making dynamics and flexibility. The bottom-up approach fosters local innovation, while the top-down ensures strategic alignment. The industry-focused vs industry-agnostic criterion shows if the project is tailored to specific industries or versatile across sectors. Most of the larger-scale hydrogen valleys are focused on covering the whole value chain and multiple industries. Industry-focused offers specialised solutions, while industry-agnostic provides broader applicability. Evaluating the narrow vs broad scope reveals if the project targets specific areas or addresses a wide range of issues, with narrow projects achieving deeper expertise. eFarm is an example of a narrow-scoped project with its mobility innovation system. At the same time, Baltic Sea Hydrogen Valley is a broad project offering comprehensive solutions that address the issues of mobility, infrastructure, production and many more (Table 3). In short, the valleys are very complex systems influenced by their own regional policies, state regulations, the involvement of different partners from industry and academia and essentially different civil societies with different needs and concerns.

Table 3. Differences among the hydrogen valleys

Key areas	NAHV	HEAVENN	BalticSeaH2	eFarm
Approach	Bottom-up	Bottom-up	Top-down	Bottom-up
Scope	Industry-agnostic	Industry-agnostic	Industry- agnostic	Industry- focused
Width	Broad	Broad	Broad	Narrow
A good practice from specific Quadruple Helix actor	Academia: H2 Student Program by Ecubes	Need for governmental support	Industry: Helen's Green Hydrogen Production Plant	Civil Society: Community Engagement Strategy in the eFarm
Risk detected and addressed	Insufficient knowledge of hydrogen	Need for government support in realisation	Inefficient hydrogen utilisation in the industry sector	Resistance to change imposed by civil society

Source: Own work (2024).

3.3. Specific risks detected in different dimensions of the Quadruple Helix

Firstly, the risk present in each hydrogen valley is insufficient knowledge of the change that takes place or will take place, which might cause panic and resistance in the future. To address such risks in the NAHV, the **H2 Student Program (Academia)** was conducted. The future relies on educating young people, who are more open to new ideas. Changing the mindset of someone who has been in the same job for 30 years is tough, but teaching new concepts to young people is much easier. That is why the H2 student program was developed. This program introduces young students to energy transitions and hydrogen through interactive activities. It includes a **mix of theory and hands-on learning**.

The program is structured as a one-day event. The first half focuses on theory, where students learn about hydrogen, energy transitions, and electrolysis. Lectures are designed to be interactive and easy to understand. The second half is more practical, involving quizzes and competitions. Students build

Lego cars with **electric motors powered by small hydrogen fuel cells**. They program and control these cars using apps on their phones. This hands-on approach makes learning fun and engaging. During the races, students learn the importance of efficient resource use. They cannot just use maximum power; they must manage their resources wisely to win. They can earn credits by answering quiz questions about hydrogen, which they can use to upgrade their cars with better tyres, bigger tanks, or more efficient motors. The program encourages collaboration and competition among students. Typically, 10 to 15 students work together in groups, fostering teamwork and problem-solving skills. It is not rare to see students who might not usually interact, working together and having fun.

The H2 student program is **free of charge** as an investment in the future. Hosted also globally, it spreads awareness and understanding of hydrogen technologies. Students leave excited about learning new things and sharing their knowledge with families. This unique initiative successfully promotes a healthy energy mindset among young people, aiming to inspire the next generation to embrace sustainable energy solutions (Ecubes, 2023).

A second risk that is also very common among the valleys is the **inefficient hydrogen utilisation in the industry sector**. This one was very successfully solved by **Helen's Green Hydrogen Production Plant**. Helen, a Finnish energy company, is pioneering Helsinki's first green hydrogen production plant, the 3H2 – Helsinki Hydrogen Hub pilot project, in Vuosaari. This 3 MW plant will produce hydrogen using renewable electricity, ensuring an emission-free process. The project aims to enhance Helen's expertise in large-scale hydrogen production and contribute to the flexibility of the entire energy system. A key feature is its integration with existing infrastructure. Located near Helsinki's district heating network and Vuosaari Harbour, the plant will utilise waste heat generated during hydrogen production in the district heating network, achieving over **90 percent energy efficiency**. This feature maximises resource use and exemplifies circular economy principles.

The hydrogen produced will primarily be used at a fuelling station for heavy transport, with additional container delivery options. This initiative is expected to reduce CO_2 emissions by 3,700 tonnes per year by replacing fossil fuels in heavy traffic and utilising waste heat, significantly contributing to Helsinki's sustainability goals. The project fosters collaboration among various sectors and stakeholders, including local authorities, research institutions, and the general public, showcasing the potential of green hydrogen (Helen, 2024).

The third risk refers to the need for **governmental support** to realise the project. HEAVENN is one of the very first serious hydrogen valleys in Europe, and its government managed to back up this initiative and allow the usage of existing infrastructure for the transition to the hydrogen system. The Northern Netherlands has successfully transitioned from natural gas to green hydrogen, leveraging decades of natural gas expertise. A key factor in their success is strong governmental support (New Energy Coalition & Impact Hydrogen, 2023), which fostered innovation and facilitated **upgrading existing infrastructure** for hydrogen transport, including adapting existing pipelines and developing hydrogen storage (using salt caverns) (Reitsma, 2023). Recognised as Europe's first hydrogen valley by the Clean Hydrogen Partnership (New Energy Coalition & Impact Hydrogen, 2023), the region's HEAVENN project secured EU Horizon 2020 funding with additional support from public and private partners (Reitsma, 2023). Political backing, particularly from the National Hydrogen Strategy and European Commission, has positioned the region as a leader in hydrogen development (New Energy Coalition & Impact Hydrogen, 2023).

Resistance of civil societies to the change represents an even higher threat, especially when the change takes place in their region. The eFarm hydrogen valley in Germany in North Frisia is an example where the public exhibited strong resistance to change. This valley, initiated by GP JOULE, is one of the country's largest green hydrogen mobility projects. The project is an outstanding example of how effective community engagement and strategic decreasing of risk can drive the success of a renewable energy initiative (GP Joule, 2024). The project leaders understood early on that for eFarm to thrive, they also needed the active participation of the local residents and businesses. The project team undertook community outreach efforts, holding informational sessions and workshops to educate locals about the benefits of green hydrogen and the specifics of the eFarm initiative. Sessions were designed to inform and foster a sense of ownership and pride among the community members. They believe that if the community feels invested in the project, both emotionally and economically, they are more likely to support it actively and advocate for its success (Hannover Messe, 2024). Moreover, eFarm provided financial incentives for locals to adopt hydrogen vehicles, creating demand and assuring investors of a strong local market for green hydrogen (GP Joule, 2024). In addition, the project prioritised using local workers, creating meaningful jobs and stimulating economic growth in North Frisia (Now.GMBH, 2024). By developing a local supply chain for hydrogen production and distribution, eFarm reduced its dependence on external suppliers, lowering costs, increasing the project's resilience to potential disruptions, and contributing to its sustainability (GP Joule, 2024).

4 Conclusion

The North Adriatic Hydrogen Valley represents a significant step forward in Europe's energy transition, uniting Slovenia, Croatia, and Friuli-Venezia Giulia in a cross-border collaboration. The initiative's strengths lie in its strategic location, high demand for hydrogen, and the balanced involvement of academia, industry, government, and civil society in decision-making and knowledge sharing.

While the long-term economic benefits for the three regions are not precisely defined, the NAHV has the potential to serve as a catalyst for regional development policies, promoting sustainable economic growth and technological leadership. The project's collaborative nature, with multiple countries and sectors, can position the NAHV as a frontrunner in Europe's hydrogen ecosystem in terms of regulatory frameworks between different states and with the capacity to significantly influence the broader European hydrogen market. Moreover, the valley's future is additionally secured with follow-up initiatives such as forming the NAHV's Special Purpose Vehicle (SPV), which will provide a structured framework for collaboration, funding, and risk management, fostering innovation and regulatory compliance throughout the project's lifecycle. This approach helps create resilient and scalable hydrogen ecosystems that can attract ongoing investment and support even after the project officially ends.

The NAHV faces several key threats, including safety and environmental risks associated with hydrogen's technological readiness for safe and standardised usage, economic challenges due to the high cost of hydrogen production, regulatory uncertainties, and concerns about community benefits. To manage these risks, the project should prioritise transparent communication and community engagement, invest in research and development to improve technology and reduce costs, collaborate with governments and international bodies for supportive policies and financial aid, foster public-private partnerships to share risks and benefits and ensure tangible local benefits like job creation and economic revitalisation. These strategies will help mitigate risks and ensure the project's success and sustainability.

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POWERING THE FUTURE: HYDROGEN TECHNOLOGIES IN INDUSTRIAL APPLICATIONS

1 Introduction

The production and consumption of energy currently account for over 85 percent of global carbon dioxide (CO_2) emissions (IEA, 2019). Hydrogen has gained increasing attention as a versatile energy carrier and a key player in the transition to a low-carbon economy. Its potential to serve as a sustainable energy solution for various sectors, particularly those that are "hard to abate" and can use limited methods to decarbonise, such as cement, heavy industry, and transportation, makes it a promising candidate for future energy systems. Global hydrogen use reached 95 million tonnes in 2022, with strong growth in all major consuming regions. Hydrogen's ability to store and transport energy, especially in combination with renewable sources like wind and solar energy, could be crucial in addressing the intermittency challenges associated with these energy sources (IEA, 2019). Maximising the long-term potential of hydrogen depends on efforts made to move beyond its existing industrial uses and expand its use as a versatile fuel in various new sectors. However, scaling hydrogen infrastructure and production remains one of the key challenges. Less than one percent of global hydrogen production currently comes from low-emission processes (Krishnan et al, 2024). It accounts for 3 percent of the final global energy demand, equivalent to Germany's annual energy consumption. Hydrogen production from renewable sources could reach 38 mega tonnes by 2030 if all announced projects are realised (IEA, 2023).

This chapter examines the potential of hydrogen as a solution for sustainable energy transition, identifies the key barriers to widespread hydrogen adoption, explores how it can be integrated into sectors such as cement, transportation, and heavy industry, and provides insights into how one of the most prominent players in this industry in Slovenia is contributing to the transformation, based on empirical evidence.

First, the chapter discusses hydrogen's potential as an energy carrier and its challenges in renewable energy integration. It examines hydrogen's applications in "hard-to-abate" sectors like cement, heavy-duty transport, and heavy industry, exploring the motives, drivers, and challenges of adoption. Then, it focuses on Slovenia's leading cement company, Alpacem Cement, d.d. Finally, the empirical section examines how Alpacem Cement is transitioning to hydrogen-powered fuels, focusing on economic and technological viability.

2 Hydrogen as a missing market: Potential, challenges and future path

A missing market in economic theory occurs when supply and demand for a specific good or service fail to materialise due to factors like high transaction costs, externalities, or the public good characteristics of certain products (Berta, 2016). Hydrogen as a clean energy source exemplifies this, as its market remains underdeveloped due to gaps in infrastructure, technology, and economic incentives. Government intervention is essential to address these challenges. By implementing policies, providing subsidies, and investing in innovation, governments can create the conditions needed for the hydrogen market to expand (Berta, 2016).

Developed and developing nations now recognise hydrogen as a key energy carrier for achieving global sustainable growth (Vengatesan et al., 2024). It also offers a solution for long-term energy storage, addressing renewable energy integration challenges. Hydrogen can convert surplus electricity from renewable sources like wind and solar through electrolysis, smoothing out fluctuations in supply and demand. This capability positions hydrogen as a valuable energy carrier with applications across various sectors (Scita et al., 2020).

Yet, hydrogen's energy efficiency poses significant challenges, with substantial losses at each stage of production, storage, and use. Electrolysis operates at 60 to 70 percent efficiency, and converting hydrogen back into electricity further reduces efficiency to 40 to 60 percent. The overall hydrogen cycle efficiency ranges from 25 to 30 percent, much lower than batteries, which exceed 90 percent. R&D is needed to enhance electrolysis efficiency and reduce costs (Scita et al., 2020). Hydrogen's low energy density also complicates storage, requiring high-pressure systems or liquefaction, which demands costly infrastructure investments (Worku et al., 2024).

The high cost of hydrogen production presents another significant barrier. Unlike fossil fuels, hydrogen must be manufactured, making it about three times more expensive (Vengatesan et al., 2024). The process involves expensive electrolysis equipment and renewable electricity, which further increases costs (Scita et al., 2020). Even though renewable energy prices are dropping, they remain a significant part of the expenses (Martin et al., 2023).

The European Union has launched initiatives supporting hydrogen adoption to overcome these challenges. Since 2018, the Commission has approved multiple Important Projects of Common European Interest (IPCEI) worth over €91 billion, focusing on R&D and infrastructure. In May 2024, the fourth IPCEI on hydrogen research and innovation, worth €1.4 billion, was approved. This initiative aims to reduce emissions from the mobility and transport sectors by 90 percent as part of the EU's 2050 climate-neutral goal (European Commission, 2024). Hydrogen-focused IPCEIs support large-scale projects like production plants and refuelling stations, promoting economies of scale and collaboration between member states. Additionally, IPCEI funding accelerates electrolyser production, lowering costs and aligning hydrogen with renewable energy (European Commission, 2024).

3 Application of hydrogen in "hard-to-abate" sectors

Applying hydrogen in the "hard-to-abate" sectors, where it is difficult to lower greenhouse gas emissions, opens new dimensions for coping with the problem of CO_2 emissions in these sectors. Key findings on the sectors are presented in Table 1.

Table 1. Key findings on motives, drivers and challenges of hydrogen adoption in selected sectors

Sector	Motives and drivers	Challenges	Examples
Cement	Regulatory pressure, CO_2 reduction	Kiln retrofitting, high demanded quantity, high costs, storage and transportation difficulties, price uncertainty	Alpacem, HeidelbergCement
Heavy-duty transport	FCEV range, payload, cold performance	High hydrogen costs, expensive trucks	Scania, Volvo
Heavy industry	Emission reduction in steel and ammonia	Investment costs, lack of global policies	H2 Green Steel, SSAB

Source: Own work (2024).

3.1 Cement industry

The cement industry is crucial for global infrastructure, but it is also a major CO_2 emitter, accounting for approximately 7 percent of global emissions (IEA, 2018). Its "hard-to-abate" status stems from the calcination of limestone ($CaCO_3$), which releases CO_2 and contributes to 60 to 70 percent of the industry's emissions, with another 30 to 40 percent arising from the burning of fuels in kilns (IEA, 2019). Cement production is an energy-intensive process, requiring temperatures up to 1,450°C, making solar energy with batteries impractical, as solar power is intermittent and cannot meet continuous, large-scale energy demands (Jayachandran et al., 2024). Companies in the sector face regulatory pressures to reduce emissions or risk shutdowns, prompting many to explore carbon capture technologies. As cement demand is expected to rise by 12 to 23 percent by 2050, driven by urbanisation and infrastructure needs, it is critical that producers invest in clean energy to lower emissions (IEA, 2019).

Motives and drivers for hydrogen adoption. New environmental regulations and international agreements, such as the Paris Agreement, impose significant regulatory pressure on the cement industry. Introducing carbon pricing schemes has provided a pathway for investing in low-carbon technologies like hydrogen. However, this approach has also presented substantial challenges for industries striving to stay cost-competitive (IEA, 2018). Due to their localised nature, cement producers may find it somewhat easier to adapt and balance these investments with economic survival. In Europe, for example, the cost of EU Emissions Trading System (EU ETS) carbon permits can account for 8 to 10 percent of total production costs for cement plants, with permit prices fluctuating between €50 and €80 per ton of CO_2 (CEMBUREAU, 2021), also in 2023 and 2024. Early adoption of hydrogen as an energy source could give cement producers a competitive edge in a market that increasingly prioritises sustainable practices and renewable energy (Jayachandran et al., 2024).

Challenges in hydrogen adoption. Like any major transition, adopting hydrogen in the cement industry brings both opportunities and challenges. Key obstacles are technical, economic, and regulatory.

Technically, retrofitting cement kilns – currently designed for fossil fuels – to operate on hydrogen requires overcoming combustion differences and maintaining consistent high temperatures, both critical for cement production (IEA, 2018). Hydrogen's low density makes storage and transportation difficult, necessitating high-pressure or liquefied systems and requiring new infrastructure (Jayachandran et al., 2024).

Economically, high initial investment costs and market uncertainty pose barriers. Governments play a crucial role in ensuring hydrogen's potential is realised by offering the necessary support to prevent stagnation (IEA, 2019). The hydrogen market is still developing, making future prices and supply unpredictable, increasing the adoption's financial risk (Jayachandran et al., 2024). Beyond policy and regulation, significant investments in hydrogen infrastructure are also needed, and government incentives, such as subsidies and tax breaks, are set to encourage these investments (IEA, 2018).

Examples of the industry. Hydrogen technologies are moving beyond theoretical concepts and are being actively developed within the European cement industry. Alpacem, a cement company, is working to integrate hydrogen into its operations, including installing a hydrogen charging unit to fuel transportation trucks, helping to lower CO_2 emissions. Similarly, HeidelbergCement is part of the H2Future project, funded by the European Union's Fuel Cells and Hydrogen Joint Undertaking, which uses green hydrogen produced through PEM electrolysis in industrial applications, including cement production. At HeidelbergCement's Ribblesdale plant in the UK, hydrogen trials in cement kilns have shown potential to reduce carbon emissions by 180,000 tons annually. These initiatives align with the company's broader goal to decarbonise its processes by 2030. Although hydrogen technology is still evolving and is not yet a full-scale solution, ongoing collaborations between governments, industry leaders, and research institutions aim to achieve commercial-scale integration in cement production by 2030 (H2Future Project, 2024).

3.2 Heavy-duty trucking and transportation

Transport represents around 23 percent of all global energy-related CO_2 emissions, and road transport accounts for about 70 percent of it, making it the largest contributor within the sector (IPCC, 2022). A large share of it holds a fleet of 1.5 billion internal-combustion engine vehicles (ICEs) (Krishnan et al., 2024). Heavy-duty trucks make up for a smaller percentage but disproportionately contribute about 40 percent of all road mobility global warming emissions, making them one of the largest global air polluters (IPCC, 2022). While forklifts and light- and medium-duty vehicles are already commercially available, the heavy-duty trucking sector is also increasingly supported by policies promoting hydrogen use (Energy Futures Initiative, 2021).

To achieve a sustainable transportation system, more than 150,000 vehicles worldwide are already leveraging electrification, either alone or in combination with hydrogen (Collins, 2023). Currently, two primary technologies are used: battery-electric vehicles (BEVs) and fuel-cell electric vehicles (FCEVs). While both produce zero tailpipe emissions during operation, producing the electricity or hydrogen that powers these vehicles can still produce emissions that contribute to global warming (Wilson, 2023).

Motives and drivers for hydrogen adoption. FCEVs are similar to BEVs but generate electricity onboard by converting stored hydrogen into electricity via a fuel cell. This process allows FCEVs to use smaller batteries, reducing vehicle weight (Vengatesan et al., 2024). For example, while a long-haul BEV truck requires a battery exceeding one megawatt-hour to travel several hundred miles before recharging, an FCEV's battery is about one-tenth of that size. This smaller battery enables FCEVs to carry heavier loads, making them comparable to diesel trucks in terms of freight capacity (Wilson, 2023).

While some manufacturers are exploring hydrogen combustion vehicles, these are less efficient and produce more pollutants than FCEVs, BEVs, and even diesel trucks (Wilson, 2023). Additionally, hydrogen's high energy density, measured by weight, is crucial for long-range transport and energy storage, with hydrogen-based fuels being up to 100 times denser than current batteries (Krishnan et al., 2024). FCEVs also offer shorter refuelling times than BEVs, making them more efficient for long-distance routes, especially in cold climates where they perform better (Vengatesan et al., 2024). These characteristics make FCEVs ideal for trade routes that require high payloads and long ranges, even in extreme conditions (Krishnan et al., 2024).

On the other hand, hydrogen technologies also present significant opportunities for decarbonisation across industries. Unlike traditional fuels, when produced through renewable sources, hydrogen offers the potential for virtually zero emissions, which positions hydrogen as a key player in achieving climate goals, particularly for hard-to-abate sectors like transportation and heavy industry, where complete electrification is not yet feasible. Its versatility, ability to store large amounts of energy, and potential to be integrated with existing infrastructure make it an attractive alternative fuel. Various pilot projects, such as the Hydrogen Valleys initiative, are already demonstrating the benefits of hydrogen adoption through collaborations between governments, industries, and research institutions (Giacomelli et al., 2024).

Challenges in hydrogen adoption. Despite their advantages, FCEVs face several challenges that limit their widespread adoption. While FCEVs typically emit less during production, a BEV powered by renewable electricity generates 13 percent fewer lifetime emissions compared to an FCEV running on green hydrogen (Bieker, 2021). Most hydrogen is produced from natural gas – called "grey" hydrogen – which contributes to air pollution, giving FCEVs a life-cycle climate impact similar to diesel trucks (Wilson, 2023). Additionally, FCEV trucks tend to have higher purchase prices than BEVs, but an even bigger economic hurdle presents high fuelling costs (Martin et al., 2023). Hydrogen fuel prices need to fall between €3 and €6.5 per kilogram by 2030 for FCEVs to compete with BEVs, which will likely have 25 percent lower per-mile costs due to cheaper energy sources (Wilson, 2023). At present, FCEVs are most viable in niche applications. For example, hydrogen is ideal in continuous operations where trucks require fast refuelling because it only takes 10 to 15 minutes to fill up a truck. It is also well-suited for payload-sensitive transport, such as tank trailers, where every kilogram counts. Also, hydrogen benefits regions without electrical grid infrastructure but with existing natural gas pipelines. Even with improved efficiencies over time, hydrogen fuel derived from natural gas will continue to resemble fossil fuels in terms of pollution (Wilson, 2023).

Examples from the industry. Scania is taking a measured approach to hydrogen, recognising its potential for specific markets where quick refuelling or limited electric infrastructure pose challenges. Currently, Scania is involved in a significant hydrogen initiative, working on a project to develop 20 fuel-cell electric trucks in collaboration with Cummins Inc. for the HyTrucks project in the Netherlands (Scania, 2022). These trucks, built on Scania's battery-electric platform, will run on green hydrogen, and the project aims to gather insights into hydrogen's real-world applications. Due to their higher uptime and lower costs, Scania views fully battery-powered vehicles as the primary strategy for most transport needs. Still, they acknowledge hydrogen's importance in certain regions and operations where battery-electric vehicles (BEVs) are not optimal. Hydrogen could play a key role in decarbonisation, especially if produced sustainably, and Scania's pilot projects aim to explore how hydrogen can complement BEVs. Unlike its Chinese competitors, which benefit from substantial government support, Scania finances its hydrogen and electrification investments through internal resources and partnerships without relying on state aid. However, given the current challenges in the European automotive industry, sustaining development solely from its own resources will be difficult. Despite the challenges of hydrogen's high cost, inefficiency, and storage difficulties, Scania is committed to learning more about its role in the future of sustainable transport through projects like HyTrucks and reducing its emissions by 20 percent until the next year to avoid penalties from the EU (Scania, 2022).

3.3 Heavy industry: Steel and chemicals

Heavy industry encompasses sectors like steel, power, and chemicals, which produce large, heavy products requiring significant machinery, facilities, and capital (Corporate Finance Institute, 2022). It significantly contributes to global pollution and climate change, accounting for approximately 22 percent of global greenhouse gas emissions and large quantities of other harmful pollutants, which contribute to air pollution and pose serious risks to human health and the environment. In the future, heavy industry will become the target of increasingly strict environmental regulations, which will raise already significant costs associated with the industry (Brangham & Dubnow, 2024).

Motives and drivers for hydrogen adoption. In efforts to reduce greenhouse gas emissions, green hydrogen is emerging as a key solution for decarbonising heavy industry, drastically cutting global emissions. For example, replacing traditional coke with hydrogen as a reducing agent in steelmaking can eliminate carbon emissions. Deploying hydrogen in steelmaking could reduce the industry's global CO_2 emissions by as much as 30 percent. In the chemical industry, hydrogen is primarily used as a feedstock to produce ammonia, which is mainly used as a fertiliser and in household cleaning products like ammonium hydroxide. Ammonia is also vital in industrial processes, serving as a refrigerant, purifier, and stabiliser. Moreover, hydrogen's role in heavy industries extends beyond direct decarbonisation as it offers a practical solution for sectors where electrification is not feasible due to the high temperatures required (The Hydrogen Podcast, 2024).

Challenges in hydrogen adoption. The adoption of hydrogen in heavy industry faces challenges, including technical, infrastructural, financial, and regulatory barriers. Key issues include the efficiency of green hydrogen production, though innovations like solid oxide electrolysis cells (SOECs) may help. Infrastructure for hydrogen transport and storage is also difficult due to its low density and the need for high pressure. Financially, the high initial investment is a major hurdle, but governments and international bodies are addressing this. Regulatory challenges arise from a lack of cohesive global policies, though collaborations like the Hydrogen Council and Clean Hydrogen Alliance are working to harmonise standards. Despite these barriers, innovation and supportive policies are crucial to making hydrogen a key element of decarbonisation in heavy industry (The Hydrogen Podcast, 2024).

Examples from the industry. H2 Green Steel is an innovative project in Boden, Sweden, aimed at producing 5 million tonnes of green steel annually by 2030. The project is partially funded with the help of the EU Innovation Fund. It uses hydrogen from renewable energy, cutting CO_2 emissions by 95 percent compared to traditional steelmaking. The project leverages local clean energy, iron ore, and infrastructure, integrating one of the world's largest green hydrogen plants with water as the primary byproduct instead of CO_2 (Stegra, 2024).

Another good example is SSAB's HYBRIT initiative, which is pioneering fossil-free steel production by replacing coal with hydrogen. SSAB aims for fossil-free steel by 2026 and plans to reduce Sweden's CO_2 emissions by 10 percent and Finland's by 7 percent by 2030. HYBRIT is a collaboration between SSAB, LKAB, and Vattenfall, with pilot facilities in place to scale up this green hydrogen technology (SSAB, 2024).

4 Strategic transformation through hydrogen adoption in Alpacem

4.1 About Alpacem

Alpacem Cement d.d. is a leading cement manufacturer in Slovenia, part of the Alpacem Group by Wietersdorfer from Austria, specialising in the production of high-quality cement and construction materials. Its market presence is significant, particularly in the Alpe-Adria region, where it serves major construction and infrastructure projects such as the Second rail track project from Divača to Koper. Alpacem Cement prioritises sustainability through energy-efficient practices to reduce CO_2 emissions (Alpacem, 2024). In the past 15 years, they invested €150 million in the development of the cement plant. On their 100th anniversary in May 2023, they presented a new development path to a carbon-free cement production plant. They announced the first cycle of investment worth €40 million, which has recently been postponed due to problems with obtaining permits. This first cycle will lead to a 15 percent reduction in the carbon footprint and, simultaneously, a reduction of other emission parameters (Alpacem, 2023a).

In 2023, Alpacem Cement d.d. produced around 900 thousand tons of clinker, which represents more than 60 percent growth of production achieved in the last ten years. Revenues have risen to €136 million in 2023, which means 16 percent growth compared to 2022. The number of employees grew from 225 in 2022 to 228 in 2023. Operating profitability also increased in 2023, with EBITDA growing to €45.7 million and EBIT rising to €37.4 million. In 2023, Alpacem's added value per employee was approximately 3.5 times higher than the Slovenian average (AJPES, 2024). These numbers reflect Alpacem's strong financial performance and continued growth momentum in 2023 (Alpacem, 2023b).

4.2 Research methodology

The core objective was to understand the inner workings of a company in the cement industry and its strategic view on hydrogen technology adoption, with an emphasis on motives, drivers and challenges in the widespread adoption of hydrogen-powered fuels. The research is based on in-depth interviews with Alpacem's management team and representatives from different fields of expertise (Table 2). The interviews were conducted on 28 August 2024 at their headquarters in Anhovo, Slovenia.

Table 2. Sample characteristics

Interviewee	Interviewee's position(s)	Interviewee's gender
ALPACEM1	Head of Finance	Male
ALPACEM2	R&D Engineer	Male
ALPACEM3	President of the board	Male

Source: Own work (2024).

The analysis focused on four main topics: decarbonising the cement industry, opportunities and challenges of hydrogen in cement production, collaborative efforts and strategic initiatives for hydrogen adoption and shaping the future of energy transition. Key interview findings can be found at the end of this chapter (Table 3).

4.3 Decarbonising the cement industry

The cement industry is widely recognised as a major emitter of CO_2, contributing significantly to global emissions. *"The cement industry emits 5 to 7 percent of CO_2 emissions globally. This is 3.3 gigatons annually, making it a very energy-intensive industry"* (ALPACEM1). In general, a significant portion of these emissions arises from the production of clinker, a key ingredient in cement. In Alpacem specifically, *"around 60 percent is process emissions"* (ALPACEM2) due to the heating of calcium carbonate and breaking down to calcium oxide and CO_2.

Alpacem aims to achieve carbon-neutral cement production by 2035, minimising its environmental impact. They aim to produce 30 to 40 percent of electricity from local carbon-free sources. As a significant player in Slovenia's circular economy, Alpacem's medium-term goal is to develop a processing capacity of around 500,000 tons of alternative raw materials and fuels each year.

The company's strategic plan focuses on energy efficiency, with thermal energy and electricity being its primary expenses. Alpacem has installed photovoltaic cells on all its roofs, *"which supply up to five percent of electricity needs"* (ALPACEM1). Another project underway is waste-heat recovery, which will eventually cover 25 percent of the plant's electricity needs. Another ongoing project is RTO-SCR, which would *"act as a catalyst and clean up all the emissions from the air"* (ALPACEM1). They also use alternative fuels. *"All modern* *cement production facilities use up to 100 percent of alternative fuels. We use alternative fuels like solid recovered fuel and waste tyres"* (ALPACEM1). While these initiatives are ongoing, the company plans to implement carbon capture and utilisation (CCU) technology, which is currently in pilot stages in different cement plants around Europe.

To mitigate this and reduce emissions, companies in the industry have been developing and exploring new strategies for decades, contributing to clinker content reduction. *"On average, we have a bit more than 70 percent of clinker in the cement composition. About 50 years ago, this was more than 80 percent"* (ALPACEM3). According to research findings, Alpacem is confident they will be able to reduce the clinker amount to 60 percent in the future without impacting the quality of the cement.

4.4 Opportunities and challenges of hydrogen in cement production

Hydrogen is often discussed as a potential alternative for reducing emissions in cement production. Still, significant challenges exist in the implementation of hydrogen at a scale needed to fully replace fossil fuels in such an energy-intensive industry. *"It is theoretically possible to use hydrogen for heat generation in the process of cement production. The problem is that it is not yet economically viable, and it is also, at the moment, impossible to supply so much hydrogen"* (ALPACEM2). The practicalities of producing vast quantities needed make it difficult also for Alpacem as they would need *"10,000 tons of hydrogen per year"* (ALPACEM2) to operate fossil-fuel-free with the combined use of alternative fuels and hydrogen. If Alpacem would want to fully transition to hydrogen use, then they would need *"another 15,000 tons of hydrogen per year"* (ALPACEM2), which brings them to 25,000 tons per year. *"As part of the NAHV project, with the installation of a 1 MW electrolyser, we will be able to produce between 50 and 145 tons annually"* (ALPACEM2).

The economic challenge from a cost perspective is also significant. The current cost of hydrogen production varies severely, depending on electricity prices and production scale, making it difficult to predict and achieve competitive pricing. *"With the price of electricity at €110 and fully utilised production of over 100 tons of hydrogen per year, our own equalised production cost of hydrogen is around €12 per kilogram. On the other hand, if we produce only 50 tons, it is €19 per kilogram"* (ALPACEM2).

Despite subsidies, hydrogen remains a costly option, posing challenges to its economic viability. *"With subsidies, we can reach a production cost of approximately €10 per kilogram, which is still higher than the €5 to €6 threshold equalling diesel trucks. (...) In case we would use hydrogen gas (H2) to substitute current fuels and multiply hydrogen production cost with annual demand of 25,000 tons, we get a number which is not economically viable"* (ALPACEM2). For it to become economically viable, *"the price should be €1 to €2"* (ALPACEM2).

On top of that, FCEV trucks are much more expensive than the regular trucks they are using now. *"The hydrogen trucks cost €700,000, and the diesel one costs €150,000"* (ALPACEM2). FCEVs have much larger ranges and are suitable for long freights. Typical for the cement industry, Alpacem sells cement in a small radius of 150 kilometres, meaning that after returning to the cement plant, their trucks make around 300 kilometres in one trip. With two deliveries per day, it amounts to 600 kilometres, on average. From this point of view, using expensive FCEVs in Alpacem is unnecessary as *"FCEVs have range up to 1,000 kilometres with one trip"* (ALPACEM2). However, they would have the potential benefit from hydrogen-powered rail transport. *"The part of the railway we use, from Jesenice to Nova Gorica, is impossible to electrify due to its profile, so the only alternative solution could be hydrogen"* (ALPACEM2).

At Alpacem, they believe that hydrogen technology is very promising, but it is most definitely not well-developed and researched enough to save the world. *"The efficiency of electrolysers will go up, for sure. Hydrogen is part of the solution, but it is not an ultimate solution for our sector"* (ALPACEM2).

4.5 Collaborative efforts and strategic initiatives in hydrogen adoption

The development of hydrogen technology as an efficient fuel option and its integration into cement production will require substantial collaboration between industries and stakeholders. *"Green transition is a complex, multidisciplinary problem. It cannot be solved by one person, by one country, by one industry. It is really about working together, sharing the knowledge"* (ALPACEM2).

At Alpacem, they know that energy transition is not a race or a competition. They know everyone is responsible for making the world a better place. *"We try to understand the state of the art of the industry, and we look at other players in the industry to develop our own strategic objectives"* (ALPACEM3). The cement industry is fairly collaborative, and they can share their experience and speak to other experts in the industry as *"the plants are quite unique"* (ALPACEM3).

Alpacem has been part of the North Adriatic Hydrogen Valley (NAHV) since 1 September 2023. In the scope of the partnership, it placed a hydrogen refuelling station at its premises. *"This refuelling station was, at the time, a very important project for us, to show that we are serious and are already working on hydrogen adoption"* (ALPACEM2). The refuelling station is working, but they are not supplying hydrogen because there is no demand in the area yet. *"Currently, the refuelling station is not operating due to no demand – but it sets an example and showcases what we want to do going further. (...) If, for example, a mayor of some municipality would come to us, saying they are buying a hydrogen-powered bus, we would be willing to collaborate"* (ALPACEM2). Alpacem is also partnering with Scania on a pilot project to test Scania's hydrogen internal combustion engine trucks. While the project has not officially begun, discussions are underway. The launch is expected around 2026 when Scania plans to have the vehicles ready for testing.

4.6 Advancing energy transition in cement production

As the cement industry transitions toward greener technologies, it is expected to undergo significant restructuring, which cannot happen overnight. The high capital expenditures and high energy consumption required for adopting new technologies will likely drive industry consolidation, as only the most efficient plants will be able to invest in these innovative technologies.

Alpacem has the advantage of being one of the strongest plants in the region as it also has a strategic position. *"We are present in the Alpe-Adria region, and our strategy is to keep only the locations which will be able to invest into new technologies and produce more efficiently"* (ALPACEM1). Alpacem's position gives them the advantage of being well-connected to the electrical network as they are near two power plants on the Soča River. They also have *"35 megawatts of excess heat that is now released to the air that can be used also for the production of electricity"* (ALPACEM3). This circumstance gives them leverage: *"If in the future we will be able to store energy somehow, then we will be partially able to use hydrogen for that"* (ALPACEM3). On top of that, they are very optimistic regarding Italy's initiative to build a hydrogen pipeline connected to North Africa, offering a potential path toward making hydrogen more affordable and accessible for them due to its proximity to the Italian border.

The transition cannot be done only with collaboration and support between industry stakeholders, but it has to be backed up and supported by policies. *Current governments' involvement and incentives on hydrogen projects are not big enough in practice and should become much stronger. (...) Policymakers should prepare the environment for us to be able to implement hydrogen solutions. We as engineers can solve the problems and come up with solutions, but we need extra support as there is no viable business case around it yet"* (ALPACEM2). Compared to other European countries like Croatia, Germany, or Norway, Slovenia is poorly supported by the government and policies regarding carbon potential and energy transition. *"Some other countries already have some knowledge that was collected over the past decades. We need years of studies and a lot of money to explore this potential; however, the government is currently not giving enough financial initiatives to properly support this process"* (ALPACEM3).

Table 3. A summary of key empirical findings

Topics	Key findings
Decarbonising the cement industry	• Significant global CO_2 emitter • Emission-intensive clinker production • Carbon-neutral cement production by 2035 • Photovoltaic cells and waste heat recovery
Opportunities and challenges of hydrogen in cement production	• Currently not economically viable • Demand exceeds current feasibility • Too costly for hydrogen vehicle adoption
Joint efforts and strategic initiatives in hydrogen adoption	• Need for collaborative efforts • Alpacem's projects promote widespread adoption • Need for government support and initiatives
Shaping the future of energy transition	• High capital expenditures • Future industry consolidation • Alpacem's beneficial access to excess heat and electricity • Required policy support

Source: Own work (2024).

5 Conclusion

The transition to hydrogen in energy-intensive industries like cement production is both promising and challenging. As global efforts to cut carbon emissions intensify, hydrogen is becoming a key solution, particularly for industries that are difficult to decarbonise (Vengatesan et al., 2024). However, widespread adoption is impeded by technical, economic, and infrastructural barriers, which are highlighted in the case of Slovenian cement producer Alpacem. Their hydrogen needs far exceed the available supply, with projections indicating a substantial gap between required and available hydrogen production. Additionally, the economic viability of hydrogen remains a major issue, with production costs for cement producers significantly above the target range needed to make hydrogen a feasible alternative. The high cost of hydrogen-powered vehicles is another limiting factor, as they are currently priced much higher than conventional trucks. Despite these challenges, Alpacem is actively pursuing collaborative efforts, such as its involvement in the North Adriatic Hydrogen Valley (NAHV) and establishing a hydrogen refuelling station.

In the heavy-duty trucking sector, which contributes 17 percent of global CO_2 emissions, hydrogen offers a solution through Fuel Cell Electric Vehicles (FCEVs). FCEVs have the advantage of shorter refuelling times and higher payload capacities compared to BEVs, making them ideal for long-distance and high-load transport. However, the economic challenges are significant. The current cost of hydrogen fuel remains high, with substantial reductions needed to make it competitive by 2030. Additionally, the operational costs of BEVs are around a quarter lower per mile, further complicating the economic case for FCEVs. For now, these vehicles are best suited for specific applications, such as continuous operations or areas with limited access to electric infrastructure.

In heavy industry, particularly in sectors like steel and chemicals, hydrogen is key to decarbonisation. For instance, using hydrogen as a reducing agent in steelmaking could reduce global CO_2 emissions in the industry by up to 30 percent. In the chemical industry, hydrogen is used to produce ammonia, which is vital in various industrial processes. However, infrastructure challenges, such as hydrogen storage and transportation, remain, alongside the need for cohesive global policies to support hydrogen adoption.

The success of hydrogen as a foundation of the energy transition will depend on the alignment of industry efforts, technological advancements, and robust policy support. Only through such coordinated efforts can hydrogen realise its full potential as a clean, sustainable energy source for the future.

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Published by
Časnik Finance d. o. o.

Editors:
Polona Domadenik Muren, Matjaž Koman, Tjaša Redek

Reviewers:
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Printed by
Plusbiro d.o.o.

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First printing

Ljubljana, November 2024

Circulation: 400 copies

In accordance with the amendment to the Value Added Tax Act (ZDDV-L Act, published in the Official Gazette of the Republic of Slovenia No. 72/19), the book belongs to products for which a special reduced VAT rate of 5% from 1 January 2020 is charged.

Published by
ČASNIK FINANCE, D. O. O.

Finance

Proofreader:
Meta Česnik

ISBN 978-961-6541-65-7