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Titel der Masterarbeit / Title of the Master's Thesis

„Wie resilient sind regionale industrielle Dekarbonisierungs-pfade?
Einsichten aus der Baustoffindustrie in Niederösterreich“

„How resilient are regional industrial decarbonisation pathways?
Insights from the building material industry in Lower Austria“

verfasst von / submitted by

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Abstract (English)

The scientific article submitted as a master's thesis deals with the influence of crises on the dynamics and resilience of path development towards decarbonization in the construction materials industry in Lower Austria, with special attention to the COVID-19 pandemic. The research is based on theories of path development, regional innovation systems, and regional resilience. An evolutionary perspective is adopted by tracing the path development and examining the institutional and industry-specific structures at multiple levels across different phases to gain insights into their resilience to crises.

Of particular relevance in the decarbonization of certain economic sectors is the construction sector, due to its high share of global greenhouse gas emissions. The sector faces the challenges of reducing its emissions. In addition to innovations and new developments in low-emission building materials, established conventional building materials as well as regional institutions and actors that facilitate these transformations are crucial for the decarbonization of the sector. Lower Austria was chosen as a case study due to its history of building material production and concentration of companies in the construction industry, with a focus on traditional building materials such as cement and wood.

The research aims to answer questions about the factors driving sustainable industrial path development and the influence of crises on sustainable transitions, particularly whether crises (especially the COVID-19 crisis) can serve as catalysts for sustainable transitions.

Abstract (German)

Der als Master-Abschlussarbeit eingereichte wissenschaftliche Artikel beschäftigt sich mit dem Einfluss von Krisen auf die Dynamik und Resilienz von Pfadentwicklung zur Dekarbonisierung der Baustoffindustrie in Niederösterreich, mit besonderer Beachtung der COVID-19 Pandemie. Die Forschung basiert auf Theorien zur Pfadentwicklung, regionalen Innovationssystemen und regionaler Resilienz. Eingenommen wird eine evolutionäre Perspektive, indem die Pfadentwicklung nachgezeichnet und die institutionellen und branchenbezogenen Strukturen auf mehreren Ebenen über verschiedene Phasen hinweg untersucht werden, um Einblicke in ihre Resilienz gegenüber Krisen zu gewinnen.

Von besonderer Relevanz bei der Dekarbonisierung bestimmter Wirtschaftssektoren ist der Bausektor, aufgrund seines hohen Anteils der emittierten globalen Treibhausgasemissionen. Der Sektor stellt sich den Herausforderungen, seine Emissionen zu reduzieren. Neben Innovationen und neuen Entwicklungen in niedrigemissionsreichen Baustoffen, sind für die Dekarbonisierung des Sektors vor allem aber auch etabliere, konventionelle Baustoffe entscheidend, sowie regionale Institutionen und Akteure, welche diese Transformationen begünstigen. Der Fall Niederösterreich wurde aufgrund seiner Geschichte der Baustoffproduktion und seiner Konzentration von Unternehmen in der Bauindustrie ausgewählt, mit Fokus auf die traditionellen Baustoffe Zement und Holz.

Die Forschung zielt darauf ab, Fragen zu beantworten, welche Faktoren die nachhaltige industrielle Pfadentwicklung antreiben, welchen Einfluss Krisen auf nachhaltige Transitionen haben und ob Krisen (besonders die COVID-19 Krise) als Katalysatoren für nachhaltige Transitionen dienen können.

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Introduction

Core of this thesis is the following academic paper (see pp. 32), which is currently under review. The following framework provides a more in-depth background and supports the development of the attached academic paper in certain subject areas.

The academic paper aims to contribute new insights on the sustainability path development of the building materials industry, and the impact of the COVID-19 crisis on this path. The main assertion of the paper is that the COVID-19 crisis presents an opportunity to support green industrial pathways and decarbonization efforts in Lower Austria. It emphasizes that crises have varying impacts on regions and industries, and it remains uncertain how they affect ongoing green industrial transformations. It utilizes a case study approach focusing on the building materials industries in Lower Austria within a regional context to investigate how crises impact the dynamics and resilience of transitions towards industrial decarbonization.

The construction sector is identified as a key sector for decarbonization due to its significant contribution to global energy consumption and greenhouse gas emissions. Beside the need for innovations, innovations in existing materials such as cement, bricks, and wood, as well as systemic changes at the technological and policy levels is emphasized to facilitate the transition towards environmentally friendly materials and processes. The region of Lower Austria was chosen because it is home to traditional and renowned building material manufacturers that demonstrate economic significance for the region. Especially the cement and wood construction material industries are strongly represented, playing a crucial role in sustainable industrial development.

It is highlighted that close collaboration among various stakeholders on different levels is required to address the challenges of decarbonization. The study also explores institutional influences and changes over time of sustainable industrial pathway development. It also seeks to understand potential transitions towards greater (or lesser) sustainability, considering both environmental and economic dimensions. Both dimensions play a crucial role in determining the resilience of the region and are considered risks to the region.

The objective of the study is to investigate whether the crisis has accelerated the regional transformative capacity towards more sustainable pathway development, in connection

with the prevailing resilience of the construction industry in Lower Austria. The following research questions arise from the research background on industrial sustainable pathway development, combined with the study of resilience: What factors are currently driving sustainable industrial path development, and what is the impact of crises or sudden shocks like the COVID-19 pandemic on sustainability transitions? Can crises serve as catalysts for sustainable transitions, and how resilient are industrial pathways?

To answer these questions, a multi-scale approach was selected to trace the socio-technical sustainable dynamics in Lower Austria's building material industry. Two theoretical frameworks are adopted in the research: the research of pathway development including challenge-oriented innovation systems and the research of resilience. For debating on pathway development, a multiscale approach that incorporates analysis of influencing factors on different spatial and institutional levels is adopted (Toedtling & Trippl 2018; Warnke et al. 2016). For better understanding the impact of the COVID-19 crisis on the pathway development of greening the construction sector, the research on regional economic resilience is addressed (Martin et al. 2016; Martin & Sunley 2020), including the concept of *"bouncing back"*, *"bouncing forward"* and *"bouncing beyond"* is also integrated (Martin et al. 2016). There is limited research that first, makes a regional reference to transformations of pathways and second, on the building material industry and regional innovation systems and their connections to other policy levels (Toedtling & Trippl 2018). The combination of these two approaches aims to identify the factors influencing the path development of a green construction industry and to understand the possible impact of the COVID-19 crisis on sustainable dynamics.

The theoretical discussion is supported by empirical data collected through interviews and surveys with actors in the construction industry in the Lower Austria region. Additionally, current reports and publications were analysed in depth and contextualized within previous studies on regional pathway developments.

This paper is organized into several sections. Section 2 provides a comprehensive overview of the theoretical frameworks that underlie the study, including path development, regional innovation systems, and regional resilience and a definition of our understanding of sustainability. Section 3 focuses on the topic of decarbonization in the building and construction sector. In Section 4, the research design, methods and data used are outlined. Section 5 provides an overview of the case study region of Lower Austria and presents

the results of the analysis of the green path development in the regional building and construction industry. Section 6 examines the potential impact of the COVID-19 crisis on sustainable industrial path development and its resilience. Finally, Section 7 provides a conclusion and summarizes the main findings of the study. Subsequently, the academic paper follows, which is currently under review.

Theoretical Context

This section introduces the broader theoretical field of the article. The background lies in the studies of Evolutionary Economic Geography and Regional Innovation Systems (RIS), which are two closely related research areas that deal with the analysis and explanation of regional economic development and innovations. After an overview of the development of regional economic geography, this paper provides a more detailed insight into the approaches of these streams and pioneering studies and the interdependencies of the approaches. Subsequently, the article will explore further approaches such as Regional Innovation Systems, path development research (see section “Theory of pathway development & transition”), and research on resilience of industrial sectors in times of crisis (see section “Regional resilience in times of crises”), focusing later the construction industry in Lower Austria. In view of the broad interpretive approaches to the concept of sustainability, the third section of this chapter provides a definition of the interplay between ecological and economic sustainability (see section “Derivation of the term sustainability”).

Development of the regional focus in economic geography

In economic geography, there are several renowned scholars who have evolved the concept of neoclassical thinking and integrated the importance of space. From incorporating space and the environment into neoclassical theories to conducting multi-scalar analyses at local and international levels, regional economic geography today demonstrates that economic development depends on much more than just supply and demand. It emphasizes that no region can be adequately treated with a "one-size-fits-all" approach. Therefore, an evolutionary multi-scalar approach is also chosen for this study.

The following will provide a concise overview of the development of the research field of regional economic geography by summarizing some of the most well-known representatives of these research areas and their key statements.

Michael Porter is a renowned economic geographer and professor at Harvard Business School. He developed the concepts of regional competitiveness and clustering (see Porter 1996; 1998). Porter argues that the concentration of companies and industries in certain regions can help increase the competitiveness of a region. He has also argued that governments and institutions can play an important role in creating an environment that supports the development of clusters and the competitiveness of regions.

Alfred Marshall brought another influence into economic geography research: Marshall was a 19th-century British economist and is considered one of the founders of microeconomics (see Marshall 1923). He developed the concept of external economies of scale, which states that companies and industries can benefit from concentration in a particular region because they can benefit from the resources and know-how of other companies and industries in the region.

Another influencing researcher is Philip Cooke: He is a British economic geographer and professor at Cardiff University. He developed the concept of Regional Innovation System (RIS), which states that innovations in a region arise from the interactions between companies, universities, and governments. Cooke argues that a strong RIS can help make a region more competitive and achieve economic growth (see Cooke et al. 1997; Cooke 2008).

Bjørn Asheim is a Norwegian economic geographer and professor at the University of Stavanger. He contributed to the theory of regional innovation systems and emphasizes that innovations often arise in networks and collaborations between different actors and institutions. He highlights those regional differences and characteristic play an important role and that a closer connection between regional development and innovation processes is necessary to strengthen the competitiveness of regions. Asheim also argues that it is important to consider and support the knowledge base and competencies of companies and other actors in a regional context to promote innovation and growth (Asheim & Isaksen 2002).

These researchers have contributed to deepening and expanding our understanding of regional economic development and innovations. Meanwhile, there are newer research approaches that are strongly focused on analysing the interactions between different actors and factors in a region to promote innovation and regional development.

Using a multiscale approach, rooted in economic geography and research on green industrial development paths and resilience, will help to comprehend the transformation towards sustainability in the construction sector in Lower Austria. In the following sections, the concepts of path development and resilience will be analysed in depth and linked to the examination of the path development and challenge-oriented regional innovation systems of the green building industry.

Theory of pathway development and transition

The concept of path development and path dependence is a well-established area of research in economic geography. This approach investigates the patterns of regional economic specialization and attempts to explain the business cycle dynamics of sectors from a multiscale spatial perspective (Brenner 2008). The idea that path development in different regions can vary greatly is no longer novel (Tödtling et al. 2021). Previously, explanations based on neoclassical (demand-driven) and regional innovation system perspectives have been overtaken by multiscale approaches. Path developments are influenced not only by regional factors such as relevant assets, technologies, qualifications, and institutions, but also by global interconnectedness and international framework conditions (Tödtling & Trippl 2018). This means, that regional development is no longer studied within regional boundaries alone, but on a multiscale level, taking into account the international, national, regional, and local networks and organizations, institutions, and markets (Coenen et al. 2012; Coenen & Truffer 2012; Tödtling & Trippl 2018; Trippl et al. 2020).

The study of pathways and transitions towards sustainability in specific regions has become a crucial area of research. Numerous publications examine the diverse development of green innovations and the formation of green industrial pathways in a regional context (Tödtling et al. 2020). Recent approaches to pathway development differ from a narrow,

neoliberal perspective (Regional Innovation Systems (Cooke et al. 1997) & National Innovation Systems (Cirillo et al. 2019; Lundvall 1992; Schot & Steinmüller 2018)) and advocate for a multiscale perspective that incorporates networks and institutions beyond regional and national boundaries (Isaksen and Trippl 2017; Tödtling and Trippl 2018, Warnke et al. 2016). As regions respond differently to global challenges, some are taking more radical steps towards sustainable development, including decarbonization, while others are lagging behind. It is important to recognize that regions have varying capacities for transformative change and challenge-driven innovation. The concept of challenge-oriented regional innovation systems (CoRIS) considers social, public, and institutional innovations at national and international levels, taking a multiscale approach. The CoRIS approach emphasizes the importance of collaboration between actors in a region to overcome specific challenges, rather than focusing solely on sectors or technologies. By aligning regional innovation systems with concrete goals and tasks, resources and collaboration can be optimized to find solutions to specific problems. Overall, the statement of the CoRIS approach is that regional innovation systems should be better aligned with challenges to promote innovation and economic development (Binz & Truffer 2017; Isaksen & Trippl 2017; Tödtling & Trippl 2018; Trippl et al. 2020; Warnke et al. 2016).

Furthermore, the development of pathways and transitions to sustainability are influenced by international framework conditions in the current global interconnected and interdependent context (Tödtling & Trippl 2018; Hassink & Gong 2019). These international framework conditions shape regional and national regulations as well as socio-technical regimes. Organizations such as the International Labor Organization (ILO) and the International Standardization Organization (ISO) set standards that are widely recognized and implemented globally, leading to socio-technical changes. A prime example of such a long-term, sustainable transition is the EU Taxonomy for defining sustainable economic activities, which was formalized as part of the European Green Deal in 2020 (European Commission 2022). These cross-border recognized standards emphasize the importance of a multiscale approach in analysing and understanding regional pathway development.

Regional resilience in times of crises

In addition to a multiscale approach to path development, it is important to understand how crises and shocks impact the development of regions and industries. Crises and shocks can occur on multiple scales (e.g., climate crisis, political disruptions, violent conflicts and wars) and have varying effects on different regions. However, crises can sometimes cause institutions to shift from established paths, leading to new behaviours and processes that foster innovation and open up opportunities for transformation and greater resilience.

One such crisis that has affected the entire world is the COVID-19 pandemic, which began in December 2019. Early publications in 2020 have explored the dimensions of the crisis, its regional differences, and its effects on the socioeconomic level (Davenport et al. 2020). Like other crises, the impact of COVID-19 varies from region to region and affects the socioeconomic level in different ways, reflecting resilience. Despite its controversial and often criticized definition and implementation, resilience has become a key aspect of urban and regional policymaking and has become the subject of broad scholarly debates.

The Organization for Economic Cooperation and Development defines economic resilience as “the capacity of an economy to reduce vulnerabilities, resist shocks and recover quickly” (Caldera Sánchez et al. 2017). One cannot speak of *one* stable, invulnerable resilience. Every crisis has its own characteristics, a varying duration and different impacts on each region and spheres of life. In a region, different sectors can vary greatly in resilience as well as affectedness and overcome crises differently (Hassink & Gong 2019).

The evolution of regional resilience is outlined by Martin and Sunley (2020), who highlight the various ways in which global crises affect and impact regional and local contexts. They mention two key differences in resilience in this context: "*bouncing back*" and "*bouncing forward*" (Bristow 2010; Martin & Sunley 2015). According to the original definition of resilience in engineering by Holling (1996), resilience means "*bouncing back*" and, when applied to regional development research, refers to a region returning to its original equilibrium and prior growth path after a shock. The faster a region returns to equilibrium, the more resilient it is. "*Bouncing forward*" refers to the possibility that a region may not only return to its prior state after a shock but emerge stronger from it with

higher economic performance indicators or greater resilience to future crises (Boschma 2015; Martin et al. 2016). Furthermore, there is a possibility that crises may lead to a "*bouncing-beyond*" the current organization of the economy towards a more green and inclusive future: Adversity can lead to growth and development, resulting in regions and economic activity becoming stronger and more capable through a process known as "*bouncing beyond*." They acquire new skills and abilities in the process (Martin & Sunley 2020, Grillitsch & Asheim 2022).

Crises may force society and economies to adopt new behaviours and processes, resulting in restructuring and opportunities for innovation. This can change the trajectory of a sector and lead to the formation of new networks, organizations, and cooperation at the regional level (Torfing 2016). Innovation in this context includes not only technical advancements but also changes in the way networks, organizations, and cooperation are formed.

What both pathway development and resilience approaches share is their multiscale perspective. Considering the insights from path development research, this study regards the institutional framework conditions that have influenced and continue to influence the development in Lower Austria. Additionally, the study examines the factors that drive path development during the COVID-19 crisis and the effects of the crisis. A resilient region will therefore not only be able to cope with disruptions, but also to master long-term developments and challenges. By combining the approaches of path development and regional resilience, a region can be able to promote long-term successful developments while also being able to respond to unforeseen events.

Derivation of the term sustainability

"Sustainability" is a trend that has established itself in nearly all areas of life. It is a comprehensive term that encompasses, among other things, climate change mitigation and adaption, Protection of biodiversity, water, and other resources, decarbonization, circular economy, and recycling, which are transforming our lifestyles to be more or less "green". However, since there is no universal definition, the term sustainability will be defined for the theoretical and empirical context of this work.

The concept of sustainability is open to interpretation and has different definitions. Its origin can be traced back to forestry, where it was defined by Carl von Carlowitz as the practice of only cutting down trees at a rate that allows for natural regeneration within a specific time frame (Grober 2013). Today, sustainability encompasses both ecological and economic sustainability, as they are closely related. This can be understood from two perspectives: the inside-out and the outside-in perspective (see figure 1).

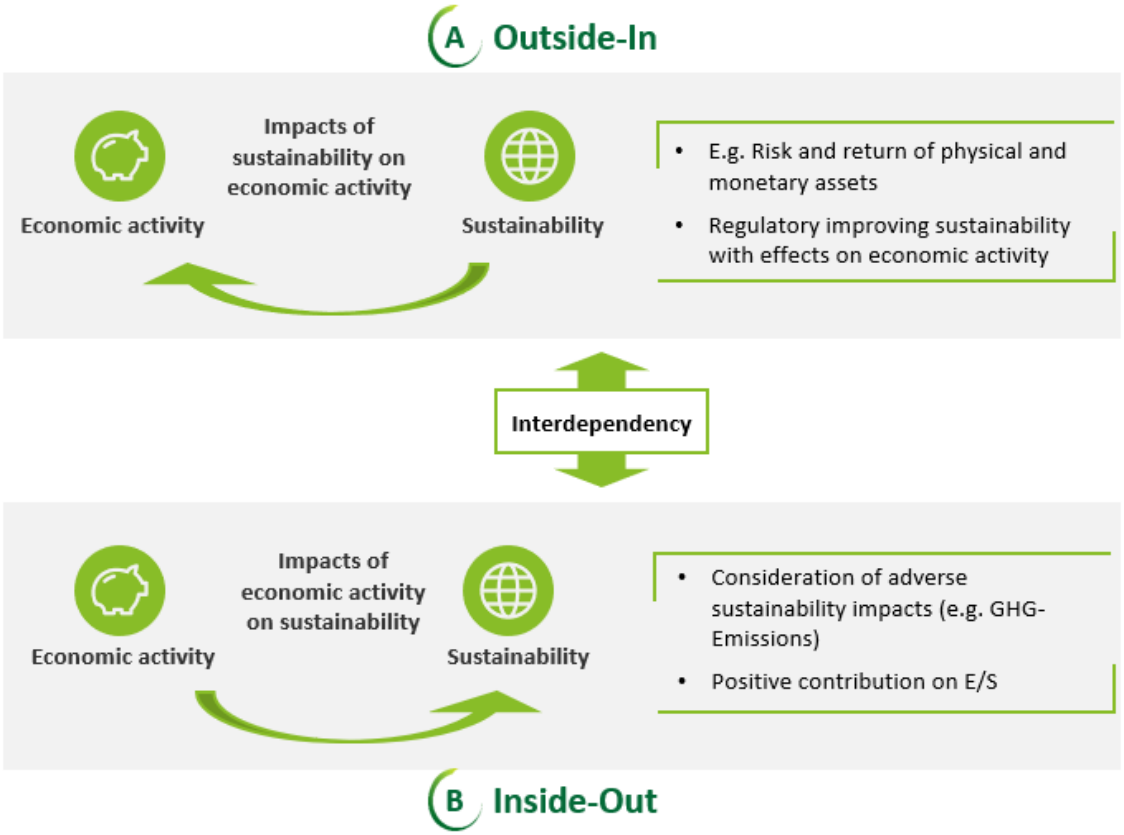

Figure 1: Ecological and economic sustainability (own figure)

The former perspective (inside-out) refers to the impact of an economic activity on sustainability, such as ecological impacts like GHG emissions emitted by economic activity. The latter perspective (outside-in) refers to the impact of sustainability on the company or economic activity, considering physical and transitory risks that may threaten the business and its performance. With increasing climate change risks, companies in all sectors will need to consider ecological sustainability in their operations in order to increase their resilience and economic sustainability (Aagaard et al. 2021).

When talking about sustainable (pathway) development, it encompasses both ecological and economic sustainability. For the purpose of understanding resilience of a region or

sector, it is important to assess how it strives for both ecological and economic sustainability in times of crisis and external shocks.

Methods

The core message of this study is that a multidimensional qualitative research approach was utilized, following Yin's framework (2014), to analyse the impact of the COVID-19 pandemic on the Lower Austrian construction industry. Various sources, including 10 semi-structured interviews with stakeholders from different sectors of the industry, publicly available reports, and an online survey distributed to companies in Lower Austria, were employed to gather data and insights. The interviews covered a wide range of companies, from small and medium-sized timber construction firms to international players in the timber and mass building materials industries, as well as consulting companies.

Qualitative data analysis was conducted using MAXQDA software, aligning codes with the theoretical and conceptual framework. The findings from the interviews were validated through publications and professional articles, and the online surveys provided additional information on developments in digital and green innovations in relation to the COVID-19 crisis.

The results from the surveys, interviews, and literature review are presented in the next chapter. The first section provides an overview of the general development of the construction industry in lower Austria, focusing on regulations, standards, and trends. The second section highlights the changes and effects resulting from the COVID-19 crisis.

Greening the building and construction sector

As mentioned above, the trend of decarbonization is an influential factor in making regional and global developments "greener" and establishing a sustainable way of life and economy. It is important to emphasize that decarbonizing building materials is essential for sustainable development. However, institutional frameworks on different level are also crucial for green path development, including, among others, circular economy, recycling, and changed consumer behavior.

When addressing the decarbonization of economies, the construction sector plays a crucial role in decarbonizing economies due to its significant contribution to global final energy consumption. Given that the construction and usage of buildings in the EU account for a substantial portion of total energy consumption and greenhouse gas emissions (IEA/UNEP 2019; UNEP 2021; IPCC 2014), there is a pressing need for transformation in construction methods, refurbishments, renovations, and the adoption of environmentally friendly energy sources. These changes present a significant opportunity for reducing climate-damaging emissions and achieving substantial emissions reduction in the construction sector.

Additionally, savings potential of emissions in the construction and building sites can be found not only in the scope 1 emissions (direct emissions produced during heating), but also in indirect upstream and downstream emissions (scopes 2 and 3), which occur before the actual use of the building. These emissions include for example the extraction, production, and transport of building materials, waste disposal and many others.

The case study of the construction industry's path development focuses on the building materials cement and wood and examines the impact of different institutions on their development. Despite the introduction of new products, cement and concrete, as well as wood, will continue to play an important role in the construction industry. Hence, it is crucial to enhance existing low-emission construction materials and make them more environmentally friendly and sustainable. Developing solutions and advancements for conventional building materials such as wood and cement can help reduce scope 2 & 3 emissions and minimize their ecological footprint.

Cement, a massive mineral product, and wood, a biogenic product, are traditional building materials with distinct material properties and differing ecological footprints. Both materials have potential for improving resource efficiency and sustainability, though decarbonization is only possible to a certain extent. Wood and cement have very different ecological aspects, they differentiate themselves in lifetime-span, recyclability, cradle-to-cradle and others. Experts argue that neither wood nor concrete can serve the construction industry alone and that a combination of building materials is needed for resource-efficient and smart solutions.

Factors influencing the sustainability and efficiency of building materials are briefly summarized below. These properties are the main arguments and trends in current debates on improving sustainability in the construction sector and have been confirmed in all interviews. There is an ongoing effort to improve and innovate in these areas to meet current regulations and requirements and remain competitive. In addition to general resource efficiency and energy-saving measures in actual use (for which numerous certifications and guidelines have already been adopted) (European Commission 2021; European Commission 2021[2]), there is a trend towards paying attention to upstream and downstream processes, including extraction, manufacturing, deconstruction, and post-life recycling. Based on the interview guide, current research approaches, and analyses, the following characteristics have emerged, which reflect current debates about sustainability and resource efficiency (Pfoh et al. 2016):

1) Ecological Evaluation:

   For a comprehensive evaluation, it is not only important to consider the annual energy consumption of a building (Scope 1 emissions), but also the material and energy consumption and environmental impacts throughout the entire life cycle, including direct and indirect emissions as measured by Scope 1, 2, and 3 carbon emissions. Emissions at the Scope 3 level, which occur during the manufacture and construction of the building, can be several times higher than the emissions consumed during its use. It is also crucial to consider the life cycle of the product.
2) Degradability and Recycling.

   Many building materials can be recycled into secondary raw materials after being deconstructed from primary raw materials, conserving resources. It is essential to consider the degradability and recyclability of buildings in the planning stage. The more homogeneous the building materials are, and the fewer pollutants used, the higher the deconstruction capability.
3) Cradle-to-Cradle:

   This approach aims to consider at the planning stage that the raw materials used in a building can be fully recovered after their useful life and fed back into the cycle as part of a circular economy.

The trend of evaluating building materials and practices throughout their entire life cycle prior to construction includes approaches that emphasize circular economy principles,

such as recycling of building materials and waste, deconstructability, adaptability of building components, using buildings as material storage, carbon capture and storage, development of digital building models, logistics and procurement, and material flow management. At the same time, efforts are being made to enhance conventional building materials with regards to their ecological performance and functionality through technological advancements.

Overall, the construction sector is characterized by weak innovation processes and a lack of knowledge transfer, which tends to delay innovation and results in incremental change that is heavily path dependent (e.g., Gibbs & O'Neill 2015; Fastenrath & Braun 2018[2]; Niskanen & Rohracher 2022).

Ecological assessment of wood and cement in the construction industry

Cement, a commonly used building material, has faced criticism due to its negative environmental impact, including its contribution to global and Austria's greenhouse gas emissions (Fingerloos 2022; Mauschitz 2021; Monteiro et al. 2017). Despite this, the cement industry is under pressure to innovate and make the product more environmentally friendly. However, finding widely applicable alternatives for mass building materials in the short term is challenging (Dehn et al. 2018). However, it should be noted that Austria emits lower levels of CO_2 emissions than any other country, making substitution of building materials challenging in the fields of building construction and civil engineering (Mauschitz 2021).

In terms of ecological evaluation, there are natural materials (e.g., wood or bamboo) that can be used to some extent as a substitute for cement or at least compatible. Wood is a product that has historically been a very traditional building product. It is rather niche in the building industry today but has a lot of future potential due to its sustainability capabilities. Wood has the advantage that it is a renewable raw material, and a sustainable sourcing is possible, if a regional and sustainable forestry is ensured. The environmental protection organization WWF emphasizes that although wood is a renewable resource, sustainable use is crucial as it is still a scarce commodity. Otherwise, uncontrolled logging has far-reaching impacts on people and the environment (WWF 2020).

Both materials can be 100% recyclable if processed correctly: concrete can be recycled and reused as a building material and unglued wood can be fully recycled. Currently, most of the installed wood products are glued, which makes them non-recyclable (Umweltbundesamt 2014). A disadvantage of wood compared to cement is the possible short lifetime of about 30 years in comparison to about 100 years of cement.

In the realm of cradle-to-cradle design, both building materials have significant potential, but so far, their application has been limited. Digital and intelligent solutions, such as Building Information Modeling (BIM), hold promise for a more sustainable future.

Both building materials have unique technical characteristics and both cement and wood can be sourced, produced and distributed regionally in Lower Austria, making them easily accessible. Cement production is localized and further processing into concrete typically occurs within a short distance.

Overall, the construction sector has weak innovation processes and lags behind other sectors (McKinsey & Company 2020, Fastenrath & Braun 2018). Traditional building materials such as the mineral product cement and the biogenic product wood have different properties and ecological impacts. Improving resource efficiency and sustainability for both materials is possible, but full decarbonization is limited. The combination of building materials is the way forward, as neither wood nor concrete alone can serve construction projects.

Innovations in the construction sector are focused on structural and organizational changes, shaping the development of building materials in Lower Austria. To achieve greater sustainability and durability, both product innovations (e.g., existing product improvement, new CO_2-saving products) and structural changes in the organization (e.g. process efficiency through BIM, lean management) are necessary, as well as support from regional policy frameworks.

Results

Case Study Region of Lower Austria

The Lower Austria region was selected for the case study due to its rich history of building material production and its concentration of international and regional companies in the construction industry. Many construction companies in Lower Austria are facing the challenge of transitioning to a low-emission and environmentally friendly economy. From one-person timber builders to internationally active timber constructors with hundreds of employees, to leading corporations in the mass raw material-based construction industry, current global trends in decarbonization, recycling, and cradle to cradle are influencing their business objectives and operations to varying degrees.

Lower Austria is one of nine federal states in Austria with a population of almost 1.7 million people (8.9 million in Austria as a whole). Over the last 20 years, Lower Austria has seen a significant increase in its gross value added and has become a major business location in Europe, thanks to its proximity to Vienna, and direct connections to metropolitan areas such as Munich, Bratislava, Budapest, and Prague, as well as high-growth markets in Central and Eastern Europe. The gross regional product was above the Austrian average in 2017-2019, with a growth rate of 1.7% in 2019 and a relative share of 15.5% of the total gross domestic product (Amt der NÖ Landesregierung, Abteilung Wirtschaft, Tourismus und Technologie 2020). However, in the crisis year 2021, losses of 2.7% and 2.9% are forecast for both GDP and GRP (Statistik Austria 2021).

Lower Austria is characterized by the diversity of its business landscape, which operates in various industries. 99.8% of companies are one-person businesses and SMEs (Amt der NÖ Landesregierung, Abteilung Wirtschaft, Tourismus und Technologie 2020). The construction industry plays a significant role in the national economy: *"With around 6,800 companies, 45,000 employees, and a gross value added of around 3.1 billion euros, the construction sector is one of the key industries in the domestic economic landscape,"* according to Lower Austria's Economic and Digitalization Regional Councillor, Jochen Danninger (Umwelt Journal 2021).

The region of Lower Austria is home to numerous international corporations and SMEs that are involved in the construction sector at various levels. The region is also home to

several important manufacturers and suppliers of construction materials, including multinational companies such as Porr, Wienerberger, Würth, and Lafarge. These companies have a high economic impact on the region and are known for their innovative power. Wienerberger AG, for example, was the third largest construction company in Austria in 2020 with net sales of 3.35 billion euros (Statista 2022).

Regional cluster initiative ECOPLUS

Lower Austria has supported sustainability transitions in the building and construction industry since the 1990s through regional cluster initiatives. The key initiative is "EcoPlus", which was launched in 2001 by the Chamber of Commerce of Lower Austria. The agency facilitates networking and exchange between companies, research institutions, and educational institutions, and promotes international competitiveness of Lower Austrian companies through the promotion of cooperation projects and interconnection with international networks and clusters. The initiative is fully financed by the European Regional Development Fund (ERDF) and the province of Lower Austria and currently has 563 cluster partnerships, with over 2,213 companies regularly participating in projects and sector-specific exchanges (EcoPlus 2022).

The initiative started with the wood cluster in 2001, followed by the eco-construction cluster in 2004, and finally the construction, energy, environment cluster (Bau.Energie.Umwelt Cluster) in 2007 to represent both branches of the construction industry. Although the regional innovation system provides sufficient support and some technological innovations have been adopted, there is still room for improvement (I1; EcoPlus 2022).

The following section draws the development of transitions towards more sustainability in construction industry over the last 50 years. There a several institutions which have been adopted, therefore it is necessary to gain an overview on different levels such as local, regional and international institutions.

Path development of construction industry in lower Austria

The next sections provide an overview of the sustainable path development of the construction materials industry, including a summary of the main drivers of sustainable transition. During the analytical steps taken to address the research question, it quickly became evident that regulations play a crucial role in the pathway development of the construction industry. Therefore, the following sections extensively delve into regulations and certification systems that support the transformation. This is followed by presenting the results from the surveys conducted with stakeholders in Lower Austria and their perception of how the construction industry in Lower Austria has changed during the COVID-19 pandemic.

Oil crisis induced dynamics of pathway and new regulations, driving sustainable development (1970)

The oil crisis of 1973 had a significant impact on the European and Austrian economy, prompting a revaluation of practices in various industries, including construction. The construction sector in Scandinavia stood out for its pioneering role in implementing strict emissions regulations, which influenced other European countries to varying degrees (Almssad 2018; Stenberg 2018).

Representatives in Lower Austria recognize the oil crisis as a pivotal moment that led to discussions about resource conservation and a sustainable shift in various sectors of the economy (I1; I3). Efforts to reduce emissions in the building sector have shown progress, but the increasing number of households necessitates further measures and innovations to save emissions (Klimafonds 2016).

Regulatory and certifications driving sustainable pathway development

With the aim of measuring buildings according to their ecological aspects, various certification systems have been introduced at the international, national, and regional level, focusing on energy efficiency, environmental protection, and the reuse of building(-materials) after their lifetime. There are various certification systems worldwide that offer different profiles or variations. The goal of a greener building and construction sector has been emphasized at different policy levels in many countries and at the supranational

level in the Global North over the past decade. The most notable and youngest example is probably the European Green Deal, which highlights energy-efficient buildings as a critical intervention in mitigating climate change (European Commission 2021).

Cross-border certification systems first emerged in the 1990s, while the first national certification systems were established about a decade later. The certificates are not always established by the state, but also often originate from the ambitions of non-governmental organizations. Many regulations and certificates promote energy-efficient measures and are critical turning points in Austria and the EU, shaping the development of the construction industry.

Players in the construction industry were motivated and guided by legal requirements to construct sustainable buildings. Over the past few decades, there have been several top-down approaches at international, national, and regional levels aimed at promoting sustainable transformation in the construction industry. Country-specific standards and building regulations, as well as harmonized technical norms that are adapted to legal and social requirements, can lead to innovative solutions and steer development in a specific direction. Meanwhile, socio-economic support programs and certification systems can also provide incentives to use certain products and processes, leading to multiple chain reactions.

International level

A key driving force is the European Green Deal and the EU Taxonomy published in 2020 (see section 5.5). The EU Taxonomy sets a uniform definition of sustainable economic activities and is (for now) mandatory for reporting by listed and large companies. It aims to increase sustainability in areas such as climate change, circular economy, pollution reduction, and biodiversity protection, impacting the construction industry. Compliance with the EU Taxonomy is crucial, shaping the industry's direction and development towards environmentally friendly practices. The EU Taxonomy and other regulations provide significant leverage for financial services institutions by directing the flow of funds towards sustainable activities. By implementing these regulations, financial resources are increasingly directed towards projects that meet sustainability criteria. This enables financial institutions to play an active role in promoting environmental and social goals by

supporting investments in sustainable companies and projects (European Commission 2021[1,2,3,4]).

Besides the EU Taxonomy, international certification systems such as DGNB (in Austria represented by ÖGNI), BREEAM, and the LEED are also well-established in Austria. The EU awards energy-efficient buildings under the title EU Green Building.

In Lower Austria, innovative projects like C2PAT (see section 5.5.) demonstrate how cross-sector cooperation can contribute to sustainable development by reducing emissions and utilizing CO_2 as a valuable resource.

The EU Taxonomy is viewed by many actors in the Lower Austrian economy as an opportunity and a driving force for the transition to sustainable development, despite some criticism of its criteria for implementation in the real economy. In addition to meet the criteria, a major challenge for companies is to evaluate the data for compliance with the EU Taxonomy. Low data availability and lack of digitization are hindrances to this industry (I2; DGNB 2021).

National level

At the national level, Austria offers various building assessment systems and subsidies to promote sustainability in the construction industry, including the popular klima:aktiv rating system and the IBO eco-passport (IBO 2023). The National Sustainability Strategy, introduced in 2002, focuses on resource conservation, energy efficiency, and building quality location (Energie NOE 2022).

Regional level

When focusing on the case study region of Lower Austria, it becomes evident that key support structures for green building were established in 2001, with the launch of the regional economic development agency named EcoPlus by the Lower Austrian Chamber of Commerce (EcoPlus 2022). Regional initiatives, such as the establishment of EcoPlus and housing subsidies for owner-occupied homes in Lower Austria, further support green building practices (Energie NOE 2022).

The evaluation of regulations by stakeholders in Lower Austria is mixed. 87% of companies surveyed saw government regulations as supportive of green innovation, recognizing the role of regulations in driving and guiding innovation. However, some stakeholders also see regulations as impeding innovation progress and restricting it (Lemke & Fastenrath 2022; I9; McKinsey & Company 2020).

Non-regulatory factors influencing path development of Lower Austrians construction industry

Non-regulatory factors, including societal awareness, digitization, and consumer demand, also play significant roles in the path development of the construction industry. Generally, global corporations are known to have high innovation ambitions and the necessary human and financial resources to drive innovation. Small companies, particularly in the timber construction industry, drive innovation through individual projects and collaboration with both private households and internationals players in the construction industry using other building materials. They are constantly developing new market solutions with customized solutions (I2; I6; I7). Digital technologies like drone flights and Building Information Modeling (BIM) contribute to resource conservation and efficiency (I1; I2; I5).

Another important factor driving sustainable development is consumer demand, which is influenced by factors such as increasing environmental awareness and government subsidies for sustainable products. Lower Austrian construction industry players have noted that social dynamics, such as increased environmental awareness and protest, are favourable towards green innovation activities (Lemke & Fastenrath 2022).

However, the construction industry entrepreneurs argue that consumer demand for ecological and environmentally friendly products is limited by cost, as consumers are not willing to pay more for sustainable products (I4; I6). Some experts have observed that demand for certain sustainable products is only present when they are subsidized and can be purchased at a more attractive price, and that demand and purchase of these products decrease and are replaced by conventional, less expensive products when subsidies end: "*The exciting part in the building industry or handcraft industry in Austria is that the ecology stops relatively quickly at the price. If a product costs 5% more, but is ecological, this means at the moment that the ecological product is 90% likely not to be taken"* (I4).

Overall, the sustainable development of the construction industry is driven by a combination of regulatory frameworks, certification systems, innovation potentials, and changes in consumer demand. The international, national, and regional levels each play important roles in shaping the industry's direction and promoting sustainable practices.

Impact of the COVID-19 crisis on the construction sector in Lower Austria

The impact of the COVID-19 crisis and the temporary worldwide lockdowns has been felt across different sectors of the construction industry: In order to assess current trends and changes influencing the (sustainable) path development and resilience, the following summarizes perceptions, trends, and changes that have become noticeable at companies and have impacted daily business.

Increasing prices, postponed projects and changing demand

In 2020, the COVID-19 pandemic and the measures taken to control its spread caused one of the worst economic crises in 75 years both in Austria and globally. Different regions and sectors of the economy were affected differently, leading to diverse reactions to the same crisis. The COVID-19 crisis has had a significant impact on the construction industry, leading to changes in trends and perceptions in Lower Austria. The industry experienced a temporary shutdown during the first lockdown but quickly resumed operations. However, there was a decline in sales, followed by a rapid recovery (WKO 2022; Wöhl & Ziegler 2021). The construction industry faced challenges such as increasing prices of building materials due to various factors like production disruptions, transportation capacity issues, and high demand.

However, the relatively positive situation in the construction industry will be hindered in part by substantial increases in building materials costs in the first half of 2021. For instance, prices of reinforcement steel, cement, insulation materials, and construction timber have risen steeply. The reasons for the price hikes are diverse and include COVID-19-related production disruptions, lack of transportation capacity, particularly in shipping ("container crisis"), hoarding by market players to prevent future price increases, and price increases on the producers' side due to high demand (Wöhl & Ziegler 2021).

Despite the minimal monetary losses in the construction industry, a few mechanisms have undergone significant changes due to COVID-19. One prominent feature is the alteration in consumer demand behaviour, especially among private customers, and the rapid increase in construction material prices. This can be attributed to both regional and national demand spikes, as well as international impacts.

On a regional level, the increased demand for construction materials and real estate is attributed to changes in living conditions during the lockdowns. Consumers are seeking homes with outdoor spaces, leading to higher demand for real estate and land in the outskirts of Vienna. This change in demand affects both the new construction and renovation industries, causing an increase in demand for building materials in both the DIY sector and the direct contract sector, where construction companies are commissioned to renovate existing properties (I1; I5). This trend is also linked to the increased amount of time spent in home office. The home is used differently in a home office setting than in an office routine and spatial conditions need to be adjusted.

Experts, the media, and economic actors attribute the sharp rise in prices to various factors, such as higher domestic demand due to the national premium for sustainable investments, increased cross-border demand for sustainable investments, and lower supply caused by the temporary closure of plants. "*I would say it's not just one reason, it's many reasons and it varies by material"* (I6).

The temporary loss of production capacity during the lockdown, coupled with increased demand in Lower Austria and the entire country, has resulted in supply bottlenecks and rising prices that have persisted for several months to years. Some companies have been forced to increase their prices multiple times in a single fiscal year for the first time in their history. "*Traditionally one increases at the beginning of the year: conventional price increases, the one or other product, depending upon purchase situations. But that one must increase during the year massively three times and without compromises (or with few exceptions) around nearly hundred per cent, that never happened before"* (I4). For end customers, this has resulted in some postponing the construction of their homes due to the 20-30% increase in project costs. Some construction companies, who previously advertised price guarantees, are now offering customers incentives of several thousand euros to cancel their projects to avoid bankruptcy (I4).

In addition, factors on the world market also have an influence on the price development of Austrian building materials: "*Today, if you need a container to ship anything from China or anywhere else, instead of $3,000 you now have to pay $20,000. And there are 10 others waiting for the container. And there are a lot of supply chains attached to it. Shortages always lead to price increases"* (I4).

In contrast to other sectors of the economy, the bottlenecks in the construction industry can't be primarily attributed to the lockdown and border closures. International supply dependencies are less relevant, especially for locally sourced materials like concrete, brick and wood.

The increase in price and bottleneck were also noticeable for wood products. Explanations for the price increase include higher demand from the USA and other regions such as Asia, particularly China, as well as declining availability due to climatic changes and pest infestations. The support for the construction industry from the U.S. Federal Reserve and declining availability of wood on the Canadian market due to pest infestation are also cited as reasons for the price increase. (I5; Denkler 2021; Intracen 2022)

It is important to note that the ability of companies to handle and overcome supply bottlenecks depends on their size and structure. Large international companies have the advantage of being able to access resources from other locations and thereby mitigate bottlenecks to some extent. In contrast, small companies, such as regional wood construction companies, have limited flexibility and resources to manage this stress factor (I7).

The shortage of (qualified) workers

However, the border closures have significantly impacted the availability of the workforce. Companies in Austria faced short-term struggles due to the shortage of labour as construction sites had to be completely shut down. The shortage of skilled workers in the construction industry had been a concern in previous years, but the crisis has highlighted this weakness in the industry (I2; I3; I6; I5; I8). *"I think the biggest inhibiting factor is actually the labour shortage. That is indeed a huge problem, and it extends from the lowest level, from the construction site, but actually also into the area of consulting, planning, architects, consultants, etc. We don't have them; they don't really exist in Austria." (I8); "But that is not something that is pandemic-driven, that has happened before and that*

will continue to happen, that will strengthen rather than soften. (I5)". The shortage of skilled workers became more pronounced as a result of border closures, causing temporary closures of construction sites.

The issue of vacant job positions and low interest in new training opportunities was indeed highlighted by the COVID-19 crisis, but this problem existed even before the crisis. To address this issue, companies and politicians are exploring ways to create incentives for trainees in the construction industry and increase the number of training contracts (I5).

The survey of stakeholders has revealed that companies rate the availability of qualified labour as well as the availability of technologies, knowledge, skills as very important factors favouring green innovation activities (Lemke & Fastenrath 2022).

Home office as a driver of changed demand and acceleration of businesses' digitalisation processes

Other behaviours that have changed because of the pandemic and that experts believe will persist in the medium to long term include changes in internal operations. The COVID-19 pandemic has demonstrated the viability of remote work for many businesses, resulting in cost savings for both employers and employees. The increased use of digital communication tools has also significantly altered travel behaviour, which is likely to continue even after the pandemic subsides. These changes are expected to make the construction industry more sustainable in the future, with less travel and commuting (I1; I2; I5). This development also shows a connection with the changed demand for renovation needs and DIY actions as described above. Furthermore, McKinsey published a study in which is claimed that the Corona pandemic will accelerate change in the construction industry worldwide: *"Digitalization, new manufacturing processes and materials, and increased mergers of companies will fundamentally change the construction industry"* (McKinsey & Company 2020).

Discussion

The study of regional path development and how crises affect it is an exciting and far-reaching field. Given that the COVID-19 pandemic has had a profound impact on social and economic life, this study aims to examine the effect of the crisis on the development of green industrial paths. As described in chapter of theoretical context, regional development can react in three ways during a crisis: bouncing back, bouncing forward, or bouncing beyond (Martin & Sunley 2020). To account for the different levels of influence, this study includes factors and institutions from various scales in its analysis (Isaksen and Trippl 2017; Tödtling and Trippl 2018; Warnke et al. 2016). The multi-scalar nature of the crisis, with its effects being felt at various levels, highlights the importance of taking a multi-scale approach in analysing its impact on pathway development.

Overall, it can be stated that three institutional frameworks influence pathway development and correlate with each other: Society, Business, and Policies (especially regulatory and certification) (see figure 2).

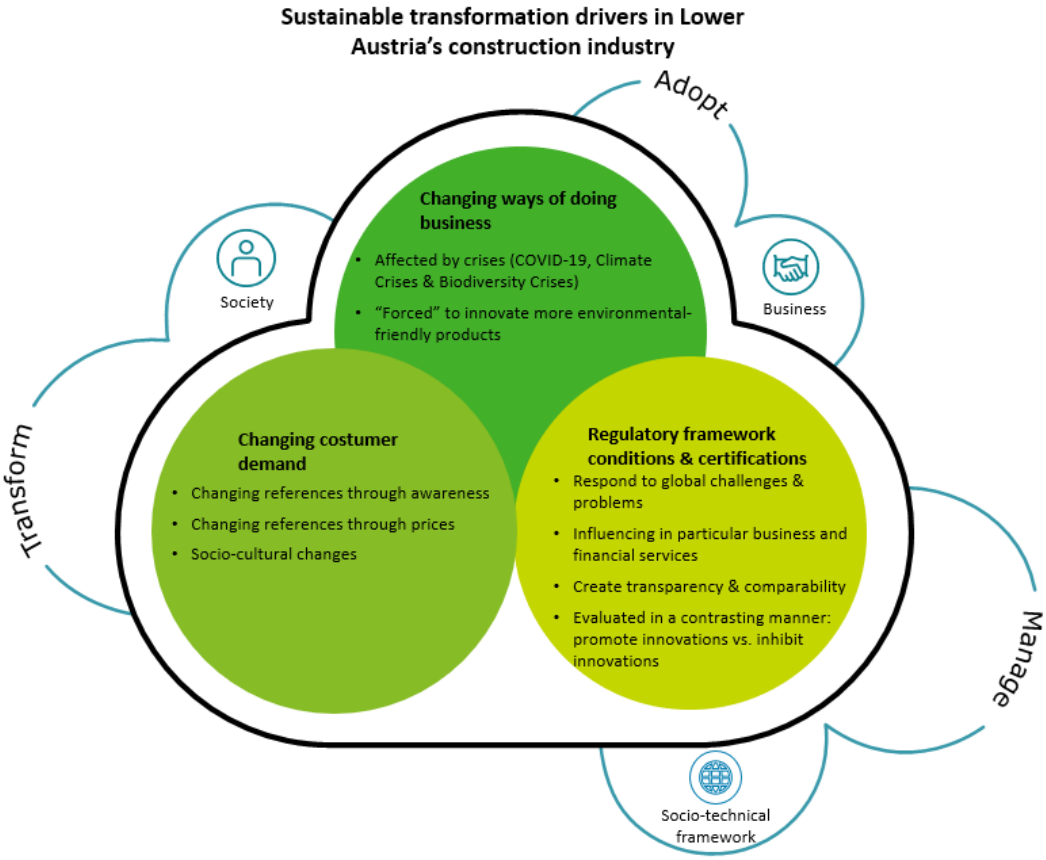

Figure 2: Influencing actors and institutions on the overall pathway development (own figure)

So how is green path development affected by crises? And how resilient are (green) paths?

Through literature research and discussions with experts in the Lower Austrian construction sector, it has become clear that sustainability (among other things, as defined by the technical criteria of ecology, such as emissions and life cycle, degradability and recycling, as well as cradle-to-cradle) is strongly influenced by regulations at the international and national level. In particular, the EU Action Plan motivated by the climate crisis, and the publication of the EU Taxonomy, have triggered a transformation in all economic activities, including the construction sector.

The requirements and regulations, as well as prohibitions, are evaluated differently in the construction industry. On one hand, they inhibit innovation by restricting creativity through building regulations, but on the other hand, they also drive innovation by forcing old business practices to be re-evaluated. Overall, the development of the construction industry in recent years has been shaped primarily by these ambitions, which were triggered by various crises and shocks, such as the oil crisis and the climate crisis.

What was repeatedly emphasized by experts is not only the influence of top-down requirements (regulations and guidelines), but also that of bottom-up changes in consumer behaviour and preferences, which highlights the importance of a multiscale analysis (Isaksen and Trippl 2017; Tödtling and Trippl 2018; Warnke et al. 2016). The awareness of private consumers about sustainability has been largely shaped by the climate crisis in recent years, leading to increased reflection, questioning, and focus on sustainability among consumers, as stated by the stakeholders. In the survey, 91% of the respondents stated that social dynamics, such as increased environmental awareness and protests, are important external factors for green innovation ambitions.

However, the idea of sustainability is often hindered by cost, with consumers losing interest in more expensive, sustainable products if the price exceeds that of conventional building products. The demand for sustainable products only increases when government subsidies are available. Without such subsidies, the interest in sustainability quickly decreases.

But what influence has the recent COVID-19 crisis had on path development? Has it even acted as a catalyst for sustainable innovation?

The ongoing COVID-19 crisis has impacted all aspects of life, including the construction industry. The analysis indicates that the crisis has not significantly contributed to the advancement of sustainable development and innovation in the sector. Instead, the crisis has exposed the existing weaknesses of the construction industry, which have been gradually deteriorating for years. In conclusion, the results show that the crisis has uncovered structural problems, and, in some areas, new awareness could be gained. The COVID-19 pandemic is expected to have a significant impact on the construction industry. The pandemic is accelerating changes such as digitalization, new manufacturing processes and materials, and increased mergers of companies, which will fundamentally transform the industry. Experts in Lower Austria also see potential opportunities for acceleration in certain trends.

Furthermore, the ongoing COVID-19 crisis could potentially lead to a "bouncing-beyond" scenario (Martin & Sunley 2020). Prefabrication and digitalisation have been gaining attention in recent times and the need for these innovations has been emphasized by the pandemic, potentially leading to strengthened and accelerated ambitions in this direction. The COVID-19 pandemic has brought to light several vulnerabilities within the industry and served as a wake-up call, highlighting the pressing need to address the industry's digitalization and workforce challenges. Building Information Modeling (BIM) has emerged as a promising solution, offering benefits such as enhanced efficiency, for example due to the use of drone flights, promotion of sustainable practices, and reduction of errors in future projects. Although there was no significant increase in funding or resources allocated to digitalization in business' operations during the pandemic, the increased visibility of weaknesses and inefficiencies in the construction industry may elevate the importance of the BIM trend in the future.

In addition, the pandemic has brought about changes in work styles, highlighting the strengths and weaknesses of established methods. Home office has shown its benefits and limitations, and the necessity for remote appointments has become apparent, potentially leading to long-term changes in travel behaviour, with its pros (reduced traffic and stress) and cons (limited social and networking opportunities).

However, players and companies in the construction industry did not report an increase in innovation ambitions or capacities for green innovations during the crisis period, and as a result, there was no noticeable acceleration in the regional path development. Rather, these investments in sustainable innovations were already in place before the pandemic, and in some cases, funding for sustainable innovations was even cut due to the crisis.

Linked to path development is also the issue of resilience (Martin et al. 2016; Martin & Sunley 2020). Several factors contribute to the resilience of the construction industry in Lower Austria. The construction sector in the region is particularly resilient and was less impacted by some effects of the pandemic. This is mainly due to the local procurement of building materials such as wood and cement, reducing dependence on other regions, companies, and suppliers.

Despite the stability of project and order volumes in comparison to other industries, and even reaching new heights, the construction industry faced substantial price increases. This was due to a change in the demand behaviour of private individuals, who are now investing more in housing; regulatory measures such as investment bonuses and subsidies; and global factors, including increased demand from China and America, leading to a construction boom with significant price increases and supply chain disruptions, such as production stoppages and border closures.

Almost simultaneously with the developments on the world markets, regional subsidies were initiated, which aimed to promote sustainable project projects. To mitigate economic losses during the pandemic and promote sustainable investments, the government launched special stimulus measures including the investment premium. However, it's important to critically examine the impact of such measures on the market. While the investment premium was meant to promote sustainable development, it's possible that the increased demand for sustainable investment opportunities may have driven up the prices of sustainable building materials like timber to the point where non-sustainable alternatives are being used again.

In the theory of resilience there are still hardly any references to possible negative developments, which therefore fall further back than "bouncing back". This could also be linked to the concept of exnovation, where poorly implemented policies and institutional frameworks could eliminate advancements and result in a form of exnovation.

Conclusions

This paper examines the impact of the COVID-19 crisis on the decarbonization of the building material industry in Lower Austria. It analyses the factors driving sustainable industrial path development and resilience in the industry. The research utilizes theoretical frameworks and a multi-scale approach to assess the influence of different spatial and institutional factors. The study aims to provide insights into the sustainability path development of the building materials industry and the effects of the COVID-19 crisis on this trajectory.

The crisis has affected the construction industry in various ways, including increased prices due to shortages and rising demand for certain types of properties. Companies have had to adapt to new work models, and remote work is expected to continue even after the pandemic. Economic policy measures have been implemented to regulate the market in the short term, but underlying weaknesses in the construction industry, such as a shortage of skilled workers and low digitalization, hinder sustainable developments. The rise in wood prices may also lead to postponed projects and the use of less sustainable building materials.

The study emphasizes the importance of regulatory requirements at the international level, public awareness, and changing demand as drivers of sustainable path development. EU-wide regulations and certificates (such as EU Green Deal, EU Taxonomy, European Sustainability Reporting Standards (ESRS) for Financial Institutions and others), play a significant role. Efforts are being made in the cement industry to reduce CO_2 emissions and achieve sustainability goals. Collaboration between different industries and the development of innovative projects contribute to sustainability.

The research highlights the need for a multi-scale perspective and challenge-oriented approaches to pathway development, as influencing factors extend beyond regional boundaries. The construction sector in Lower Austria benefits from regional sourcing of materials, resulting in higher resilience. Political measures should be coordinated with regional conditions to effectively support resilience. Future research should also consider the contribution of small and medium-sized enterprises to decarbonization processes and explore the impact of regulatory frameworks on industrial pathways.

Likewise, it becomes clear that regulatory frameworks have a significant impact on the development of industrial pathways. More research is needed in this area, as concluded

as well by scientists Bamgbade et al. (2019) in their academic paper “Analysis of some factors driving ecological sustainability in construction firms”

Influencing factors go beyond regional boundaries, which underlines that beyond traditional RIS approaches, multiscale perspective and challenge-oriented research approaches to pathway development are necessary to map regional developments (Isaksen and Tripp 2017; Warnke et al. 2016, see Tödtling et al. 2021). In summary, regional responses to crises are influenced by the nature, origin, and duration of the crisis. Multiscale approaches, such as the CORIS approach, are recommended for analysing sustainability-oriented industrial change and regional innovation systems involving various actors.

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Article: How resilient are regional industrial decarbonisation pathways? Insights from the building material industry in Lower Austria

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Industrial decarbonisation; regional innovation systems; green industrial pathways; multi-scalarity; change agency; COVID-19

Abstract

It is often assumed that crises are important catalysts for structural change. In this vein, 'build back better' programs are sought to tackle acute crisis and, at the same time, catalysing paths towards a less carbon-intense production and consumption. However, little is known about how crises affect ongoing decarbonisation efforts in different industry sectors and how this might differ in a variety of regional contexts. By tracing and analysing the development and uptake of less carbon-intensive products in the building material industry in the Lower Austrian region, this paper explores key processes and agency that may accelerate or decelerate the dynamics of regional decarbonisation pathways. The building sector has been identified as one of the largest global contributors to greenhouse gas emissions and resource consumption. Cement production alone has a similarly critical importance in terms of CO_2 emissions as the aviation and container shipping industries. That is why a faster uptake of low-carbon building materials such as green cement and bricks, and other renewable raw materials such as wood is a key goal of decarbonisation strategies in the building materials industry. Departing from an evolutionary regional innovation system perspective, this paper traces decarbonisation pathways in the regional building material industry by considering multi-level institutional and agency structures in different phases in order to gain insights into their resilience to crises.

1. Introduction

Winston Churchill once stated: Never let a good crisis go to waste. In this light, the numerous pandemic recovery programs are aimed to stabilise regional economies while, at the same time, supporting green industrial path creation and decarbonisation efforts (e.g., Griffith et al. 2021, UNEP 2020). It becomes clear that the impact of crises develops unevenly across regions and industries. While sudden shocks can open up opportunities for new industrial decarbonisation pathways, it is widely unclear how crises affect already initiated and ongoing green industrial transformations. In other words, how resilient are industrial decarbonisation pathways in times of crisis? Bailey at al. claimed early during the pandemic that "this situation threatens to roll back progress made in advancing Sustainable Development Goals (SDGs)" (Bailey et al. 2020, 1164). To better understand the

impact of COVID-19 crisis on industrial decarbonisation efforts, this paper takes an evolutionary economic regional perspective by developing insights into the decarbonisation pathway dynamics of the building material industry in Lower Austria.

The building and construction sector has been identified as a key sector for decarbonising economic activities, as it is responsible for more than 30 percent of the global final energy consumption (IEA/UNEP 2019; IPCC 2014; UNEP 2021). Apart from the resources and energy used during the construction processes and the energy usage in buildings, the production of building materials is identified as significant driver of greenhouse gas emissions. Cement and brick production alone accounts for more than 2.8 gigatons of CO_2, which are about 8 percent of the globally emitted emissions (see Monteiro et al. 2017). Due to global urbanisation trends and large infrastructure projects, the global demand for cement is estimated to increase between 12 to 23 percent by 2050 (IEA 2018). For this reason, there are calls for accelerating the decarbonisation of the building and construction sector through low-carbon products, environmental technologies, circular approaches and digitalisation. Innovations are particularly needed that can reduce or replace key building materials such as cement, bricks and steel. While these products will be indispensable in the near future, there is hope for a faster uptake of green cement, technologies and other renewable products such as wood or bamboo that can increasingly replace resource-intensive products.

Despite the increasing attention given to the geography of sustainability transition around different aspects of the building sector (e.g., Gibbs & O'Neill 2015; Fastenrath & Braun 2018; Friedman & Rosen 2022; O'Neill & Gibbs 2020; Niskanen & Rohracher 2022), there is little research that, first, establishes a distinct regional link to industrial transformation pathways; second, systematically examines the innovation systems in which the building materials industry is embedded; and third, elaborates the role of multi-scalarity in the co-evolution of technological and institutional innovations. It becomes increasingly clear that the "combination of technology and policy solutions" (IEA 2018) is important for the uptake of new products and production processes that create pathways to reducing emissions. Systemic socio-technical changes are needed for enabling sustainability transitions in the building and construction sector, which is a sector that can be characterised

as a slow innovator due to complex value and production chains and powerful incumbents such as producers of mass products or large property developers (Fastenrath & Braun 2018[2]). Strengthening existing and promoting new industrial pathways to low-emission and environmentally friendly materials and processes is a challenge that needs to be solved in a collaborative way involving stakeholders from the public and private sectors, research and civil society. In order to better understand the hurdles and obstacles to such a challenge-oriented change and subsequently be able to make policy recommendations, it is necessary to take a closer look at institutional influences and change agency over time.

This paper sheds light on the question if the crisis has mobilised further regional transformative capacity understood as the ability to renew or restructure socio-technical structures towards less resource-intensive ways of production. The starting point of the analytical perspective is an evolutionary phase approach that helps to track the key support structures and change agencies driving regional industrial decarbonisation pathways at different points in time. Over the last few years, literature in Economic Geography on path(way) creation and development have helped to better conceptualise and analyse processes of change agency and regional industrial change from an evolutionary perspective (e.g., Binz & Truffer 2017; Hassink et al. 2019; Njøs et al. 2020; Sotarauta & Grillitsch 2022).

Drawing on previous work that developed phase models when analysing sustainability-oriented pathways in specific industries or technologies (Baumgartinger-Seiringer et al. 2021; Binz et al. 2016; Fastenrath & Braun 2018[1,3]), the paper traces key socio-technical decarbonisation dynamics in Lower Austria's building material industry considering a multi-scale approach that includes the analysis of influencing factors at different spatial and institutional levels.

The regional context of Lower Austria was chosen as a case study region due to its longer history in the building material industry and related regional support structures. Since the 1990s, regional cluster initiatives have supported low-carbon transitions in the building

and construction industry. In addition to regional policy and agency mechanisms, this paper explores regulations, subsidies and grants at national and international levels (e.g., EU Green Deal). The analysis focuses on the interactions between policy and support structures and the regional innovation system. The empirical analysis is based on a triangulation of primary data obtained through ten expert interviews with a variety of actors in the building and construction industry, as well as documents and secondary data from a regional business survey that focused on the impact of the COVID-19 crisis.

This paper is structured as follows: Section 2 provides a brief overview of the underlying theoretical-conceptual approaches: green path development, regional innovation systems, and regional resilience. The context of decarbonisation in the building and construction sector is provided in section 3. Section 4 gives an overview of the research design, methods and data. Section 5 introduces the case study region of Lower Austria and then presents the results of the analysis of the green path development in the regional building and construction industry and the potential impact of the COVID-19. Section 6 provides the discussion of the results before section 7 provides conclusions of this study.

2. Regional industrial decarbonisation pathways, regional innovation systems and multi-scalarity

The development of industrial pathways and transitions towards more sustainable ways of production and consumption has become a key research topic in recent years. Within this debates, industrial decarbonisation efforts in times of climate change and biodiversity crisis have merged centre stage. The literature in Economic Geography on (green) industrial path development and (challenge-oriented) regional innovation systems has made significant contributions to a better understanding of the way sustainability-oriented changes take place in different industries and spaces (Coenen et al. 2012; Coenen & Truffer 2012; Grillitsch & Hansen 2019; Jacobsen et al. 2022; Tödtling & Trippl 2018; Trippl et al. 2020). Particularly, the co-evolution and interactions of technological, economical, and institutional-political processes has been addressed and highlighted in this context (e.g., Benner 2022; Fastenrath & Braun 2018[3]; Chlebna et al. 2023). Against this background, and to better understand economic development in times of uncertainty and

crisis, a new understanding of innovation, innovation systems, and innovation policy was outlined that goes beyond a purely economic and competitive logic (Coenen et al. 2015; Coenen & Morgan 2020; Schot & Steinmüller 2018; Uyarra et al., 2019).

We argue that regional industrial decarbonization pathways require a more nuanced investigation. While some regions have already been undertaking decarbonisation efforts for many years, others are just about to instigate sustainability-efforts. A concept that better supports the systematic analysis of industrial decarbonisation efforts from a regional perspective is the CoRIS (Challenge-oriented Regional Innovation Systems) concept (Tödtling et al. 2022). It builds on the traditional approaches of regional innovation systems (Cooke et al. 1997; Lundvall 1992) but introduces a new underlying logic of the types of innovation (including social, public, institutional innovations) goals of regional innovation systems (beyond economic goals), and stakeholders (from triple to quadruple helix). It also highlights the need for more multiscalar perspectives including networks and institutions across national and international boundaries (Binz & Truffer 2017; Isaksen & Trippl 2017; Tödtling & Trippl 2018; Trippl et al. 2018; Warnke et al. 2016).

The analysis of multi-scalarity is important as it becomes clear that industrial path developments are not solely embedded and influenced by regional structures, conditions and assets (such as natural resources, technologies, qualifications). In times of global interconnectedness and interdependencies, these path developments are often driven by international framework conditions (Tödtling & Trippl 2018; Hassink et al. 2019). International and national framework conditions are significantly shaping regional socio-technical systems. Prominent examples are the International Labor Organization (ILO) and the International Standardization Organization (ISO). The standards set by these organizations are implemented worldwide and lead to socio-technical changes. More recent examples in the decarbonisation context are the European Green Deal 2020 (European Commission 2022) and the new EU Taxonomy both steering and defining new industrial pathways. These public sector standards, which are recognized across borders, prove that a multiscale analysis is required for considering and understanding regional and local pathway development.

2.1 Unpacking the resilience of regional industrial decarbonisation pathways

Apart from the lacking perspectives on multi-scalarity it is the lack of understanding how crises affect ongoing industrial sustainability transitions. The impact of shocks such as the COVID-19 crisis, financial crisis or sudden natural hazards on regional economic structures are gaining more and more attention over the last ten years (e.g., Bailey et al. 2020). Although resilience is a contested concept, often criticized for its fuzzy conceptualization and operationalization, it has become a key element of urban and regional policymaking and scholarly debates have even become broader.

The broadest but often used definition of economic resilience is given by the OECD: Economic resilience is "the capacity of an economy to reduce vulnerabilities, resist shocks and recover quickly" (OECD, 2016). Related to this basic understanding of resilience, most of the literature on regional economic resilience has been focused on how quick economies or specific industry sectors can 'bounce back' and return to pre-crisis conditions (Bristow 2010; Hassink 2010; Martin and Sunley 2015). This understanding follows the original understanding of resilience of (ecological) systems returning to an equilibrium state (see Holling 1996). Following this logic, a region is more resilient, the faster it gets back to the equilibrium and continues its growth path. However, clear is that an industrial sector as a whole does not have to follow a particular path. Different trends and areas of a sector can also be accelerated or slowed down by a crisis. In a region, different sectors can vary greatly in resilience as well as affectedness and overcome crises differently (Hassink & Gong 2019).

Other scholars have introduced the perspective of resilience as a 'bouncing forward' and adaptability of regional structures to overcome times of crisis (Boschma 2015). More recently, Trippl et al. (2023) argued that both perspectives fail to conceptualise shocks as a window of opportunity for challenge- or mission oriented regional economic transformations. This new understanding of resilience points to the ability of regions to also "(…) transit to a new sustainable path characterized by a more productive and equitable use of its physical, human and environmental resources" (Martin & Sunley 2020, p. 7). In the vein of this new understanding of resilience, the OECD recommends to governments (at a national level) to strengthen mission-oriented innovation systems and related policies to building up economic resilience. Directionality setting and purposive technological

transformation are seen as important driving forces for resilience and decarbonisation efforts today (OECD 2021).

These views resonate with the current notions of transformative resilience (Giovannini et al. 2020; Trippl et al. 2023), understood as a systemic response to a crisis, it could be argued that the COVID-19 pandemic can help accelerate ongoing sustainability transitions by breaking path dependencies and building capacity for more radical changes in different industries. Bailey et al. argued that "while coordinated policy actions at the supra-national and national levels are essential to cope with health, economic and environmental challenges, region-specific policies also need to be implemented to take into consideration regional heterogeneity and the uneven spatial effects of Covid-19" (Bailey at al. 2020, 1168).

Building on these new conceptual perspectives of regional resilience, this paper aims at exploring the impacts of shocks on ongoing regional industrial decarbonisation pathways (see figure 3). Shocks (e.g., climate crisis, political disturbances, violent conflicts and wars) often occur across scales and have very different effects on regions. The key question linked to that is: how can already ongoing decarbonisation processes withstand and thrive in times of crisis? So far, it is unclear which regional structures are more conducive to positively catalysing a crisis to promote transformative industrial change. How do shocks such as the global financial crises or the COVID-19 crises influence the course of decarbonisation pathways?

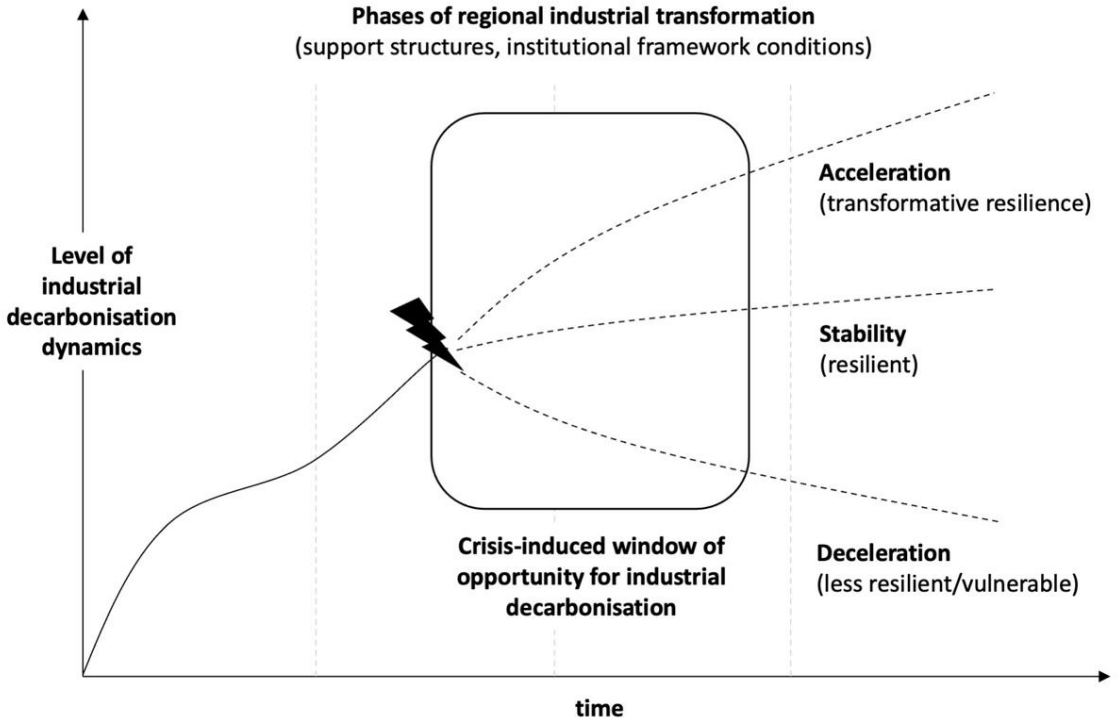

Figure 3: Possible turning points of an industrial decarbonisation pathway during crisis (own figure)

In this paper, we also take a closer look at multi-scalar relations. By tracing trajectories in the building sector in Lower Austria with a focus on building material industries, we explore the regional and international support structures and institutional capacities that might have led to decarbonisation efforts. This requires a broader understanding of innovation taking into account not only important technological innovations (renewal of products and production processes) but also institutional and organizational innovations (Torfing 2016).

Coupled with the observations from path development research, we therefore consider which institutional framework conditions influence and have influenced the development in Lower Austria's building material industry. Furthermore, we address the issue of which influencing factors determine path development during different phases over the last decades and more recently during the COVID-19 crisis and which effects are associated with the crisis.

3. Decarbonising the building and construction sector

One sector that is gaining increasing attention when it comes to decarbonisation of industries is the resource-intensive building and construction sector. The European Commission makes clear that 40% of total energy consumption and 36% of total greenhouse gas emissions in the EU comes from construction and usage of buildings (EU 2022). Building design concepts seeking to lower carbon emissions in new and older buildings through energy-efficiency, such as low-/plus-energy buildings, passive houses or net-zero buildings, are increasingly discussed and practiced. While these concepts are known for decades, in some parts of the world they remain niche phenomenon in many regions. This has certainly to do with the knowledge gaps and the economic capacities for many challenges regions. On the other hand, innovation activities and knowledge transfer in the construction sector are consistently described as slow because the sector tends to delay innovation, as change is often incremental and tends to be very path dependent (e.g., Gibbs & O'Neill 2014, 2015; Fastenrath & Braun 2018; Niskanen & Rohracher 2022).

In order to significantly change the sector in terms of energy efficiency on a global scale, new energy-efficient and environmentally friendly materials (such as green concrete, bricks and steel) as well as novel construction methods and new reuse and recycling processes are currently being discussed (EU 2022). How to drive these needed socio-technical changes remains a big question. Industry actors (e.g., material producer, building companies, property investors) tend to prefer concerted self-regulation, which, however, often ends in small changes (e.g., Affolderbach & Schulz 2018; Fastenrath & Braun 2018[2]). That is why there are often calls for stricter regulations and directives. Over the last thirty years, energy-efficient building has been promoted at various political levels in many countries of the Global North and at the supranational level (Gibbs & O'Neill 2015; Fastenrath & Braun 2018). The most recent and prominent example is the European Green Deal which highlights energy-efficient building as a key climate change mitigation intervention (EC 2021). Standards for new buildings have already reached a high level in the EU, so the Commission emphasises the importance of decarbonising efforts for existing buildings through renovation (especially for large public buildings such as schools, hospitals, and offices).

Another related new trend is to better consider the life cycle of buildings from the beginning of the design phase. Circular economy approaches have become new trends paying attention to the recycling of building materials and construction waste, the deconstructability and adaptability of building elements and modules, the concept of buildings as material stores, carbon storage (carbon capture and storage), the development of digital building models, logistics and procurement, or material flow management. However, circular elements in the building industry are still niche developments. New practices and actors are rare, and regulatory aspects of recycling and the circular economy have also hardly found their way into laws and directives. One key aspect particular attention is paid to new building materials that are less carbon-intensive and can be reused or cycled.

Cement production is responsible for about 8% of global GHG emissions (Monteiro et al. 2017) and for 3% of GHG emissions in Austria (Fingerloos 2022; Mauschitz 2021). Cement and bricks are long established building materials and will most likely continue to play a big role over the next few decades. There is the hope that through the political and societal debates, industry actors are being forced to innovate radically to make products more environmentally friendly. One material that is discussed in the both contexts, alternative materials and circular economy, are natural materials (e.g., wood or bamboo) as substitutes. Wood as a building material certainly holds potential to reduce the negative environmental impact building projects and important aspect in decarbonising the sector. In fact, in the long term, wooden buildings can even be used as CO_2 storage through bioeconomic construction methods. The mineral product cement and the biogenic product wood are traditional building materials, which have very different material properties and differ in their ecological footprint[1].

In this paper we will explore how the uptake of greener building materials is embedded in the wider green building debate in Lower Austria and how it developed over time, and which impact the COVID-19 crisis might have on current and future development. The focus will be on structural and organizational support structures of the innovation system.

[1] *see ILÖ 2015: CO_2 accounting of building products; Stephan, 2018: Nachhaltigkeit im Bauwesen: ökologische Analyse von Baustoffen und Bauteilen*

While the entry point is the regional innovation system, the paper provides a more nuanced view on policy and regulation frameworks at different spatial levels.

4. Methods

To gain a detailed and nuanced perspective on the key actors and processes for industrial decarbonisation processes in the Lower Austrian building material industries with a focus on cement and wood-based materials, a qualitative research approach was applied for this case study (Yin 2014). A wide range of data sources were used and triangulated: ten semi-structured interviews which were conducted between August and October 2021 with regional experts and stakeholders in the context of the building material and construction industry; publicly available policy and economic development documents; and secondary data based on an online business survey that specifically looked at the impact of the COVID-19 crisis on businesses in Lower Austria. The ten interview partners included small and medium-sized companies (including internationally operating wholesaler for building material supplies and wood construction company), regional customer service provider, regional economic development agency, as well as interest groups (cement and brick industry).

The interviews provided comprehensive insights into the pathways of the regional building material industry, greening initiatives and the impact of the COVID-19 pandemic. The main questions were focused around how and when greener approaches in the sector were introduced and, second, how the regional businesses were affected by the crises, what measures were taken in response to the crises, whether greening activities and strategies were implemented, and if so, whether the crisis accelerated or slowed them down. The transcribed interviews were coded and sub-coded using MAXQDA, a software for qualitative data analysis (Saldaña 2021). Secondary data such as reports and data from the business survey helped to triangulate interview findings. The data of the regional business survey conducted online in October 2021, reinforced the findings from the interviews on the impact of COVID-19 on the region more generally and on green innovations and pathways more specifically (Lemke & Fastenrath 2022).

The next section presents the results from the analysis of semi-structured interviews, the business survey and document analysis. After an introduction to the context of the case study region and the role of the building materials industry, the path of decarbonisation efforts is traced in different phases, focusing on institutional support structures, regulations, and the introduction of standards. In the lates phase, the analysis focuses on the effects resulting from the COVID-19 crisis.

5. Exploring decarbonisation pathways in Lower Austria's building material industry

5.1 Setting the scene – The Lower Austrian Region

Lower Austria is one of the 9 federal states in Austria and has almost 1.7 million inhabitants (Austria has in total 8.9 million inhabitants). In the last 20 years, Lower Austria has had a significant increase in its gross value added and became an important business location in the heart of Europe benefiting from its proximity to Vienna and the Eastern European markets and capital cities such as Bratislava, Budapest and Prague. The region is an interesting case for the study of sustainability transitions and resilience in the building material industry, as companies of regional and international importance are located here. Multinational companies such as Porr, Wienerberger, Würth or Lafarge have both a high economic importance for the region and a high level of innovation competence through their own R&D departments. Wienerberger AG is of the world biggest brick producers and third largest construction company in Austria (Statista 2022). Lower Austria's construction industry is significant for the whole country. It achieves value of 5.70 billion euro (11.1 % of the total value added in Lower Austria), generates income of 3.27 billion euro and secures around 74,000 salaried jobs (KMU Forschung Austria 2021).

Despite the increasing importance and economic growth rates, Lower Austria, like many other European regions, is facing the challenge of decarbonisation their resource-intense industries. National and international regulations, such as the EU Taxonomy (European Commission 2021[2]) will push to significantly reduce CO_2-emissions along the entire value chain. Building materials will be further classified in terms of their sustainability

performance such as energy-intensity during production (often referred to as grey energy), energy-efficiency in use, recyclability and longevity. Digitization measures, such as the digital twin of the building, will increase efficiency and make it possible to retrieve information on all materials used at any time (McKinsey & Company 2020). Even if industry does not have to start from scratch in the search for solutions and the regional innovation system offers comparably sufficient support, there is still a long way to go.

How decarbonization efforts in Lower Austria's building material sector were introduced and developed over the last decades will be analysed in the following sub-sections. Drawing on a variety of sources described above, the focus of the analysis follows in different phases. What influences and which actors and assets have played a role in developing a greener pathway in the regional building sector is analysed.

5.2 Crises induced niche-development (1970-1990s)

There is wide agreement amongst interview partners that the starting point for thinking about resource-efficiency and wider sustainability efforts in the building and construction sector can be traced back to the oil crises in 1973. Similar to the current energy crisis due to the war in Ukraine, the economic shock at the time affected wide parts of Europe's economy. It became clear that new greener pathways in the building sector are needed based around the questions how buildings could become more energy efficient, and the users therefore more independent of high energy consumption and prices (e.g., I1). As in many other European countries higher building standards and regulation were put in place. The Scandinavian countries are considered pioneers in the 1970s and 1980s due to stricter regulations in construction sector and developing new building methods such as low-energy buildings and passive houses (Stenberg 2018). In the 1990s also Austria introduced stricter regulation with the result that emissions could be reduced by 40% since then (Klimafonds 2016). The 1990s must be seen an important experimental phase when green building ideas were implemented and tested and in different European local and regional contexts. At the same time, renown and applied international building rating schemes such as BREEAM (GB) and LEED (US) were introduced (see figure 4).

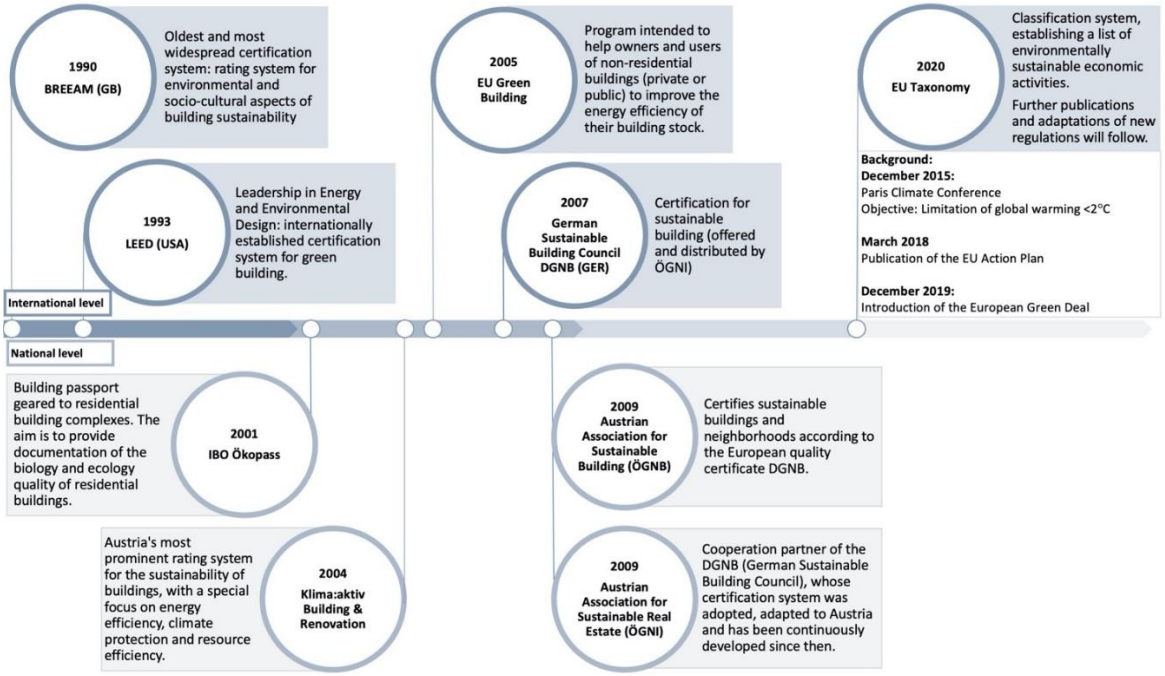

Figure 4: Austrian and international building regulations and building rating schemed that have influenced regional pathways (own figure)

5.3 Niche-formation phase I - Building regional institutional support structures (2000s)

The 2000s were probably the most important phase for greener path development when further legislation and several Austrian-based green building certification schemes were launched (see figure 4). In 2002, the Austrian Federal Government published the National Sustainability Strategy ("NSTRAT 2002"), which included targets for resource conservation, energy efficiency and quality of the building sector.

At the supra-national level, green building became a hot topic in 2005 when the European Commission's launched their Green Building program. The voluntary programme enabled assistance for owners and users of non-residential buildings (private or public) in improving the energy efficiency of the building stock.

When zooming into the case study region of Lower Austria it becomes clear that still important support structures in the context of green building were started then. In 2001, the regional economic development agency named Ecoplus was launched by the Chamber of Commerce of Lower Austria (Ecoplus 2022). The agency supports regional businesses

through funding schemes and networking platforms which bring together companies, research- and educational institutions and promotes the exchange between them through five cluster initiatives (construction, energy and environment; plastics; mechatronics; food; e-mobility). The cluster 'construction, energy and environment' is the oldest and is focused on green building solutions and counts today more than 200 partner organisations and companies. It goes back to a wood cluster initiative in 2001 that then merged into a larger eco-construction cluster in 2004. The current structure of the cluster was already formed in 2007 when stakeholders in the context of the building material industry (mineral-based materials) were included so that all key parts of the regional production and value chain were represented. But not only the cluster partners are relevant, also the cooperation with non-cluster members. Today, over 2.213 cooperating companies regularly participate in projects and sector-specific exchanges (Ecoplus 2021; I10).

5.4 Niche-formation phase II – institutional mainstreaming at supra-national level (2010s)

In the 2010s, the building sector finally became a key political target at different levels. There have been various top-down policy and planning approaches at supranational, national and regional level in recent two decades to promote sustainable transformation in the construction industry. Particularly initiatives at the EU level must be seen as a key intervention in European policy making around building standards and sustainability transitions. The EU stated at the time that the building sector is crucial for achieving the EU's energy and environmental goals and improve the quality of citizens' life and alleviate energy poverty while bringing additional benefits, such as health and better indoor comfort levels, green jobs, to the economy and the society. With the *Energy Performance of Buildings Directive 2010/31/EU* and the *Energy Efficiency Directive 2012/27/EU* were first powerful legislative frameworks to boost energy performance of buildings in the entire EU. This discussion was certainly fuelled by the 2014 IPCC report in which the building sector was featured as a key sector to be transitioned (IPCC 2014) and the Paris agreement from 2015. As interview partners explained, many stakeholders in the construction industry were motivated and guided by those discussions and the legal requirements to construct more sustainable buildings (I1; I2; I4; I8).

Apart from those policy-driven developments, also industry-led approaches were accelerating through various certification systems focusing on energy efficiency[2]. In Austria, several building assessment systems such as *klima:aktiv* and the IBO eco-passport are popular certification system. Used are also international certification systems such as DGNB (in Austria represented by ÖGNI), BREEAM and LEED. The EU awards energy-efficient buildings under the title EU Green Building. Despite the appeal of the labels and the impact they created over the last decades, they must be scrutinized, as there are often loopholes for greenwashing.

The mix of policy regulations and industry-developed certificates was an important turning point in Austria and many other countries. They have certainly been formative for greener paths in the construction industry. While major steps have been taken, especially in the construction sector, only slow changes have been observed in the building materials industry with its important products such as concrete, cement, bricks, and steel.

5.5 Mainstreaming – Incentives, EU Taxonomy and changing consumption patterns (2020s)

To further promote change in the building materials industry, the Austrian government offers various subsidies. One example is the so-called Forest Fund, which supports the uptake of timber construction. Here, a CO_2 bonus is intended to support the replacement of other, CO_2-intensive building materials. At least 80% of the wood used must have been harvested and processed within a maximum radius of 500 km around the building's location (Energie NOE 2022).

Apart from national subsidies, there are also regional programs that are intended to promote certain demand behaviours and create incentives to increase demand for certain sustainable products. One of the regional subsidy programs in Lower Austria is the housing

[2] see for example Fastenrath & Braun 2018[2] on the uptake of the greener office building in Australia and the link to the certification scheme of the Australian Green Building Council (GBCA).

subsidy for new owner-occupied homes. This program stipulates, for example, that ecological building materials must meet the following specific values and standards in terms of the following properties: renewable raw materials, minimal transport costs, lower energy consumption in the manufacturing process, processing at the construction site, retention time in the building, and the cost of demolition and disposal. The state of Lower Austria also offers subsidies for renovations and additional subsidies for new buildings, with special support for energy-efficient and environmentally friendly construction methods (Energie NOE 2022).

Regulation and subsidy measures are seen differently by Lower Austrian stakeholders in the building and construction sector. Most see opportunities and potential, because prohibitions and regulations also force/guide new innovation approaches. These rules, regulations, and temporary national and regional subsidies for certain products meant that there was always innovation at the product level (e.g., installation of sustainable windows with organic products and non-chemical foams) to meet all demands (I4; I10). Others, however, also see these regulations as the reason why innovation is progressing slowly and is being restricted (I9; see also a study by McKinsey & Company 2020).

Furthermore, some experts observed that certain sustainable building products were only in demand when they were subsidized. Costumers are often not willing to pay more for sustainable products (I4; I6). Interview partners agree that subsidies and regulation generally raise awareness not just among the producers and business but also among the consumers. More generally, the debates about climate change (particularly advocated through Fridays for Future Movement) were mentioned by several interview partners. However, the demand for ecological and environmentally friendly products stops at a certain price. An interview partner described this discrepancy as follows:

“The exciting part in the building industry or handcraft industry in Austria is that the ecology stops relatively quickly at the price. If a product costs 5% more, but is ecological, this means at the moment that the ecological product is 90% likely not to be taken” (I4).

EU Taxonomy – sustainability financing

To further drive decarbonisation in the building sector, the EU introduced a Taxonomy approach as part of the European Green Deal in 2020. This initiative goes back to the "Action Plan: Financing Sustainable Growth" (EU Action Plan) of the EU Commission which was published in March 2018. It triggered various initiatives for sustainable financing and thus forms the basis for the EU Taxonomy (European Commission 2021[2]; European Commission 2021). To date, the EU Taxonomy is mandatory for non-financial reporting by listed and large companies. Nevertheless, in the medium and long term, all activities will largely be guided by these guidelines, as the lending and investment policies of financial institutions are also aligned with them. Therefore, the Green Deal and the Taxonomy are already leaving their mark on the construction industry by shaping the current industry path development towards greener outcomes (European Commission 2021[3]). The Taxonomy has several objectives to increase sustainability. It focuses on climate change adaptation and mitigation, but also on aspects around sustainable use and protection of water and marine resources, the transition to a circular economy, pollution avoidance and reduction, and the protection and restoration of biodiversity and ecosystems.

A goal for the construction sector (including demolition) is to reduce the volume of waste and through avoiding or recycling materials and waste about at least 70%. In addition, construction materials and components must not contain pollutants and the greening of roofs should contribute significantly to the protection of biodiversity (European Commission 2021[4]).

The EU Taxonomy is seen by many actors of the Lower Austrian economy as a chance and driving force for the transition to sustainable development, even if the criteria for implementation in the real economy are critically questioned in some places. A major challenge is the lack of digitization needed to implement and promote sustainability (I2; DGNB 2021).

There is wide agreement that the EU Taxonomy will push industries to reorient and innovate their production towards less carbon-intensive innovate. One promising project in Lower Austria is C2PAT (Carbon2productAustria), a circular economy approach based on cross-sector cooperation between the cement manufacturer Lafarge, the oil company

OMV, the electricity producer and trader VERBUND and the plastics manufacturer Borealis for the capture and use of CO_2 on a large industrial scale. A key goal is to develop circular cross-sectoral carbon value chains to reduce the high emissions emitted in the cement production (Lafarge 2020).

5.6 COVID-19 – catalyst or decelerator of industrial decarbonisation efforts?

Undoubtedly, the COVID-19 pandemic led to a significant global economic crisis. While some sectors such as the tourism and hospitality sectors were heavily affected for a longer time period, the building and construction industry could recover relatively quickly. In Lower Austria the sector experienced a decline of 8.1 percent (2020) and 3.5 (2021), the first negative results after years of growth in the sector (WKO 2022). Even though the construction industry has suffered comparatively little in terms of monetary losses, a few notedly changes in the construction sector due to COVID-19 can be observed.

5.6.1 Home office as a driver of changed demand and acceleration of businesses' digitalisation processes

Real estate statistics and interview data point to clear changes in demand structures in terms of private living environments. Similar to other regions, with the pandemic consumers preferred homes in the countryside, or apartments with balconies or terraces (I1). Demand for real estate in Lower Austria, especially in those areas close to Vienna, has risen sharply with the pandemic. At the same time, renovation activities, and, with that the demand for building materials, has risen both in the do-it-yourself sector and in the contract sector by commissioning construction companies to refurbish and renovate existing property (I1; I5). The work from home orders during lockdowns and home office rules is certainly a key explanation for this development. Lockdowns and home office also had an impact on many companies in the sector. As interview partners explained, the crisis was used to accelerate digitalisation efforts in many businesses. Many meetings were held via digital meetings, which changed commuting and business travel behaviour and will most likely be continued in most instances (I1; I2; I4; I5; I6).

More generally, in the building sector, the urgency and opportunities of digitization projects such as Building Information Modelling (BIM) has become more apparent. The trend toward digitization is a key driver for more efficient and resource-saving activities. BIM a digital trend, which shows a promising potential for resource saving, recyclability and reuse (I1; I2; I5). Digitalisation could help tackling sustainability issues through circular aspects in the building process but also help in times of labour shortages. For example, drone flights over quarries will replace more and more human workers in the coming years and increase efficiency (I1). McKinsey published a study in which is claimed that the Corona pandemic will accelerate change in the construction industry worldwide: "Digitalization, new manufacturing processes and materials, and increased mergers of companies will fundamentally change the construction industry (McKinsey and Company 2020).

5.6.2 Uncovering structural challenges – the shortage of (qualified) workers

One critical factor for the building and construction sector during COVID-19 was the shortage of workers. Particularly the border closures at the beginning of the crisis were a hurdle in recruiting workforce. As a result, some construction sites had to be closed temporarily. The structural problem of shortage of skilled workers in the construction industry was clearly uncovered during the crisis as most interviews partners explained (I2, I3, I6, I5, I8). A typical interview quote in this regard:

“I think the biggest inhibiting factor is actually the labour shortage. That is indeed a huge problem and it extends from the lowest level, from the construction site, but actually also into the area of consulting, planning, architects, consultants, etc. We don't have them; they don't really exist in Austria.” (I8).

While the lack of qualified labour is a general structural problem in the building and construction sector for years, it is often mentioned as a hurdle for further sustainability transition processes. This could also be found in the business survey which was conducted with 50 Lower Austrian businesses. Companies rate the availability of qualified labour as well as the availability of technologies, knowledge and skills as very important factor for driving green transformative activities (Lemke & Fastenrath 2022).

5.6.3 Disrupted supply chains, high demand and exploding prices for building materials

The temporary loss of production and transport capacities during the COVID-19 related lockdowns, coupled with increased demand for building materials, 'hoarding' and high shipping cost has led to supply bottlenecks and quickly rising prices. The challenges trickled down to the regional level as one of the key material suppliers of the Lower Austrian region explained. Many suppliers were forced to raise prices several times in a fiscal year for the first time in their history. The interview partner explained how unusual the situation has been.

"Traditionally we increase (prices) once at the beginning of the year: conventional price increases depending upon purchase situations. But for some products we had to increase (prices) massively for three times during this year, some around nearly hundred per cent, that never happened before. (…) Some construction companies, which have advertised price guarantees before the pandemic, were then offering the customers 5000€ to withdraw from the project (during the pandemic). The companies would otherwise go bankrupt" (I4).

Many companies in Lower Austria had to deal with increased prices, particularly smaller businesses without financial reserves. Almost 80% of the 50 companies that participated in the business survey reported that COVID-19 has resulted in price increases for materials. The companies surveyed that are part of Lower Austria's green building cluster coped comparatively better with the crisis year 2020. While some companies recorded negative sales development, for the majority sales developed positively or remained at least stable (see Lemke & Fastenrath 2022). The cement and wood sectors both source products regionally and are therefore generally more resilient against international supply chain constraints. Thus, discussions about supply chain transformations and re-regionalization of sourcing are less relevant here.

The increase of the price and the bottleneck were particularly noticeable for wood products: Various factors are responsible for the price increases. One key factor is certainly the high demand for wood in the USA and China. The higher demand is strongly linked

to the support for the construction and home building industry through COVID-19 recovery packages and low interest rates on construction loans from the U.S. government. As the availability of timber from Canada has declined sharply over the past five years due to climatic change linked increased pest infestations, such as the mountain pine beetle (I5, Denkler 2021; Intracen 2022), more European timber is being traded globally. In Lower Austria particularly smaller home building companies were less flexible in terms of material sources which then put pressures on the company's liability for projects as a representative of a regional wood construction companies explained (I7).

6. Discussion

This paper has revealed a number of valuable insights in the context of the evolution and resilience of regional industrial decarbonisation pathways. It shows the importance of looking more closely at different phases and co-evolution of paths (Benner 2022; Fastenrath & Braun 2018[3]) to better understand their resilience and opportunities for greener industrial pathways today. Particularly the co-evolution between material and technology development and policy-making at different levels have been identified as crucial.

It became clear that the driving and hindering factors and related actors altered from phase to phase and that external and multi-scalar processes played an important role. This strongly resonates with the discussion and calls for more multiscale perspectives in regional research (Binz & Truffer 2017; Isaksen & Trippl 2017; Tödtling & Trippl 2018; Trippl et al. 2018). While the role of regional support structures (through cluster initiatives driving green building innovations locally) are certainly important, industrial decarbonisation efforts are strongly linked to national and international institutions, in this case stricter building regulations.

Decarbonisation efforts in the Lower Austrian building materials industry go back at least 50 years. While first innovative initiatives were pushed from the bottom-up at earlier stages by regional experts and companies, the last two decades are characterised by strong influential top-down induced policy initiatives. The starting point can be traced back to the 1970s when sustainability efforts were triggered by the oil crises in 1973. This crisis

can be interpreted as a first transformative resilience building event, as first challenge-oriented initiatives were formed as a response.

The first phase (1970s to 1990s) can be seen as a *crisis induced niche-developed*. The oil crisis at that time was an important trigger for a rethinking of the energy efficiency of buildings and niche developments. First European countries (e.g., in Scandinavia and Switzerland) introduced stricter building regulations and supported research for building design innovations (low-energy, passive houses) and related building materials. Austria made adjustments to building regulations in the 1990s, which then led to sustainability-oriented changes in the regional building material industry.

The second phase (2000s) can be seen as *niche-formation I*. Apart from new federal building legislation, Austrian-based green building certification were launched and created new market motivations. At the same time, Lower Austria's economic development agency paved the way for important support structures by initiating five cluster initiatives. One of those clusters was dedicated to the green building industry. Incrementally the cluster could gain more and more regional member companies and organisations. Additionally, supra-national green building initiatives were started by the European Commission. Taking these findings together, one could argue that the early days of decarbonisation pathways in the building sectors was influenced by multi-level niche formation and protection.

The third identified phase (2010s) is the continuation of the *niche-formation phase*, but is characterised by an even stronger institutional support (e.g., EU building directives) and industry-led initiatives. The combination of policy and industry support have been formative for decarbonisation efforts in the building material industry in Lower Austria.

The current phase (2020s) can be interpreted as a *mainstreaming* phase. In particular, the EU Action Plan and the publication of the EU Taxonomy but also the activist initiatives around 'Friday for Future' are seen as currently important driving forces for industrial decarbonisation efforts. This decade will show weather the combination of regional and international institutional framework conditions can push and lead to significant industrial decarbonisation processes.

Players in the building and constructing industry have traditionally taken a more critical view of increasing regulation and the top-down principle, arguing that these limit their innovative power and are too expensive (Fastenrath & Braun 2018[2]). The empirical insights of this study show that the success and degree of industrial decarbonisation depends on a number of factors. What was repeatedly emphasized by experts is not only top-down requirements (regulations and guidelines at different spatial levels), but also local bottom-up activities due to changes in demand behaviour and preferences of consumers. In the business survey in Lower Austria that informed this study, 91% of the respondents stated that social dynamics (increasing environmental awareness, protest, etc.) are important external factors for green innovation ambitions (Lemke & Fastenrath 2022). In recent years, the awareness of private consumers has been formed primarily by the issues of the climate crisis, so that today, according to the stakeholders, consumers at least reflect more, question more and pay more attention to climate change and other grand societal challenges.

While the role of the COVID-19 crises on decarbonisation efforts is not entirely clear yet, the results indicate that the crisis was not an immediate accelerator for further decarbonisation efforts and environmental innovation in the building material industry. Investments in innovation in the sector were already planned before the pandemic and are not the result of the crisis. In a few cases, expenditures for environmental innovations were even withdrawn by the crisis. Large regional incumbent companies decide about the speed and transformative depth of innovation, they remain the key regional driving force for change. Incumbent companies play an ambivalent role – they are important innovators in Lower Austria driving the development of alternative building products, but at the same time they can be seen as transition detractors as discussed in other studies on sustainability transitions in the building sector (Fastenrath & Braun 2018[3]). This 'regime resistance' (Geels 2014) must be seen as a more significant challenge for driving decarbonisation efforts than crises such as COVID-19.

Nevertheless, also other challenges could be identified through this study. Pointing to significantly increased prices for goods such as wood as an alternative natural and low-carbon material, interview partners argued that it might have even slowed down the up-

take of wood construction. Some building companies had to cancel projects cat short notice because the cost of wood construction had enormously increased due to increased national and international markets. There is the risk that costumers go back to more conventional building materials. Interview experts suggested that the demand for these more expensive, sustainable products only increases when government subsidies are available. More generally, the construction sector has come through the crisis relatively unscathed (compared to sectors such as tourism and hospitality). Special government stimulus measures were launched to absorb economic losses during the crisis and promote sustainable investments in particular. At the same time, there is also a risk that international events and the subsidization of sustainable products can lead to a reciprocal development: Sustainable products are in such high demand that prices rise and, in addition to this development, a worldwide state of shock drives prices up even higher. The danger then is that these expensive sustainable products will again be substituted by conventional, less sustainable products and the opposite effect will occur. Against this background, an in-depth analysis of regional and national financial instruments is absolutely necessary.

While COVID-19 crisis did not accelerate decarbonisation processes in the industry directly, it has revealed some common weaknesses and challenges in the industries that have been developing for many years and could eventually become opportunities for sustainability initiatives. The relatively low degree of digitalization and shortage in skilled labour in the construction industry will pose major challenges for the construction industry in the future. Here, however, the hope arises that the shock of COVID-19 crisis has led to an increased awareness about the fact that there is an urgent need to catch up in these areas. Particularly, the important role of Building Information Model (BIM) has been discussed as an important driver for increase efficiency. Digital twins of building are sought to help building circular economy element sin the building and construction industry. The COVID-19 crisis indirectly shaped decarbonisation efforts by home office regulations. Industry representatives argued that it was realised that digital meetings will change travel behaviour of workers in the long term.

7. Conclusion

In times of urgent overlapping economic and socio-ecological crises there is increasing interest in regional economic resilience. While economic stability and competitiveness during and after crises remains the main focus of research and policy making, more attention is recently being paid to efforts to decarbonise regional industrial production. Decarbonise production to tackle climate change has become one of the most important grand societal challenges. While there is a growing amount of literature on the creation and development of green paths (Binz & Truffer 2017; Chlebna et al. 2023; Grillitsch & Hansen 2019; Hassink et al. 2019; Trippl et al. 2020), and green regional industrial restructuring (Jakobsen et al. 2022), little attention has been drawn to the resilience of green regional industrial pathways. So far it is unclear is how stable ongoing regional industrial decarbonisation efforts during crises are. This leads to the key questions: are there regional contexts and sectors that can better protect green industrial niches in times of crisis, or even use the crisis to accelerate ambitions toward what has recently been described as transformative resilience (Trippl et al. 2023)?

To better understand the stability and longevity of sustainability-oriented regional industrial transformations, this paper brings together the discussion about green industrial pathways, innovation systems and economic resilience. By analysing the regional decarbonisation efforts and the related innovation context in the Lower Austrian building materials industry as a case study, this paper focuses on two aspects: first, the regional structural conditions and support structure and their embeddedness in a multi-level institutional framework that have shaped transformations in the Lower Austrian building materials industry over time, and second, the potential impact of the COVID-19 crisis on ongoing regional decarbonization processes.

The results of the analysis on the regional building material sector have shown that pathway dynamics are complex and dynamic. The main findings are, first, that the driving and opposing forces for change varied at different stages; second, not only technological innovations and efficiency improvements were important; third, the provision of relevant subsidies and political support at different levels have been crucial; fourth, the impacts of

crisis can be ambivalent. On the one hand, the COVID 19 crisis accelerated the digitization processes in the industry, which could lead to higher resource efficiency; on the other hand, the costs for alternative products such as timber construction rose so sharply that the dynamics in this niche segment have weakened significantly.

Future research should further address the impact of crises on decarbonisation pathways in different industries by distinguish between the nature of the crises. Long-term crises such as climate change seem to have a different impact on path development than shorter-term shocks, even if the innovations and changes brought about by the climate crisis seem less radical than the changes brought about by the COVID-19 crisis. The second aspect for future research on the resilience of decarbonisation processes is the role of smaller and medium sized companies. While this study found that larger incumbents are the main innovation force in the region, the innovativeness of small companies should not be underestimated. Particularly companies in the timber construction industry are driving innovation through individual projects and interaction with both private customers and stakeholders in the construction industry.

To better understand the framework conditions and related processes of regional industrial decarbonisation further conceptual and empirical research should move beyond a traditional RIS approach. The CORIS approach helps to put challenge-oriented innovation centre stage and consider external support structures and new stakeholders beyond the triple helix (Tödtling et al. 2022; Trippl et al. 2023). More studies should use the CORIS approach to analysis sustainability-oriented industrial changes.

The findings of this paper also have implications for policymaking. Policy action at multiple levels is critical to creating a framework in which challenge-driven innovation can thrive, even in times of crisis. However, context-specific regional action is needed to better address the uneven geography of challenges and industrial decarbonisation resilience. Likewise, it becomes clear that regulatory frameworks have a significant impact on the development of industrial pathways. More research is needed in this area (see for example Bamgbade et al. (2019).

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Plagiatserklärung

Ich, Nora Isabel Voßbeck, versichere, dass ich die Masterarbeit mit dem Thema *„How resilient are regional industrial decarbonisation pathways? Insights from the building material industry in Lower Austria“* selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe. Die Stellen der Arbeit, die ich anderen Werken dem Wortlaut oder dem Sinn nach entnommen habe, wurden in jedem Fall unter Angabe der Quellen der Entlehnung kenntlich gemacht. Das Gleiche gilt auch für Tabellen, Skizzen, Zeichnungen, bildliche Darstellungen usw. Die Masterarbeit habe ich nicht, auch nicht auszugsweise, für eine andere abgeschlossene Prüfung angefertigt.

Wien, 10. Juli 2023