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THE IMPACT OF DECARBONIZATION ON PHYSICAL CAPITAL ASSET UTILIZATION IN LATVIA

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The Impact of Decarbonization on Physical Capital Asset Utilization in Latvia

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Abstract

A stranded asset refers to economic assets that lose their ability to contribute value within their own sector and in other sectors due to the decarbonization of production processes required to meet global climate targets. This process involves either idling or abandoning a portion of physical capital, which can harm the sector in which it is employed and propagate negative effects throughout the entire economy. This study examines the exposure of sectors in Latvia to the risk of physical capital stranding resulting from decarbonizing the economy. Using Input-Output Tables and capital stock data, we quantify the effects of stranded assets and find that the mining and quarrying sector has the highest external asset stranding multipliers. The sectors in Latvia most vulnerable to the impacts of global fossil stranding include land transportation and pipeline transport (H49), electricity, gas, steam, and air conditioning (D35), and agriculture (A01).

Keywords: capital utilization, stranded assets, Input-Output Model, Ghosh multipliers

JEL codes: C67, E22, L72

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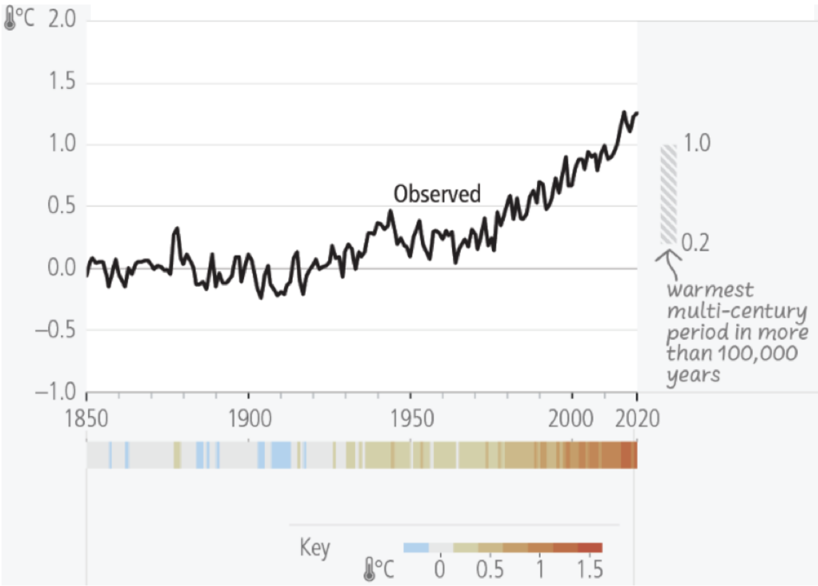
1 Introduction

Since the Industrial Revolution, humanity's economic choices have caused climate change to accelerate in recent decades. Global temperatures have risen by about 1.1 degrees Celsius since the pre-industrial era according to the latest report of the Intergovernmental Panel of Climate Change (see Figure 1)[1], and this warming is causing a variety of changes, including more extreme weather events, such as hurricanes, floods, droughts, and wildfires; rising sea levels, which are inundating coastal communities and displacing people; melting glaciers and ice sheets, which are contributing to the sea level rise and reducing freshwater supplies; changes in plant and animal life, as species struggle to adapt to the changing climate. [2]

Figure 1: Global surface temperatures



Source: Synthesis Report of the IPCC Sixth Assessment Report

The recognition of climate change is now widespread, embraced by both the general public and governments. A notable sign of this global shift in perspective is the unanimous adoption of the Paris Agreement at COP 21 on 12 December 2015 and its subsequent ratification on 4 November 2016. This accord signifies a momentous turning point, not only in the annals of human history but also in the narrative of our planet. Its primary objective is to curtail global warming to less than 2 degrees Celsius above pre-industrial levels, uniting all nations to reshape policy practices and collectively combat climate change.[3]

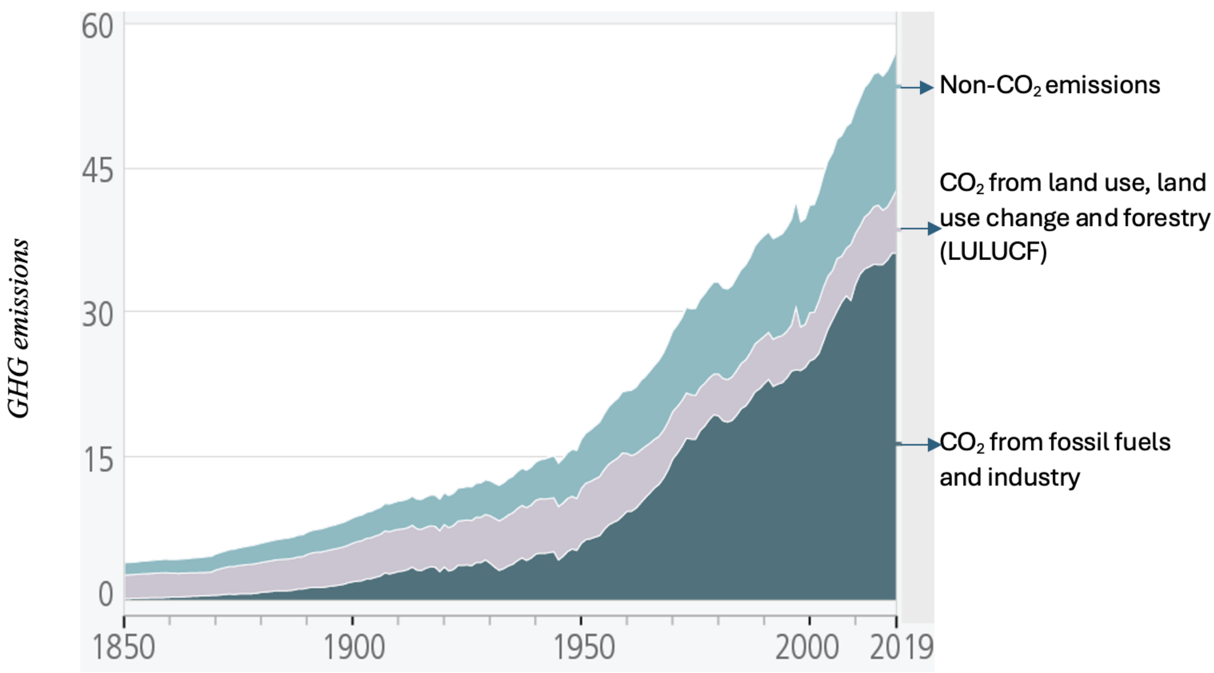
[1] Global surface temperature has increased by 1.1 degrees Celsius by 2011–2020 compared to 1850–1900.

[2] https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_LongerReport.pdf

[3] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

Implementing climate policies at the national level is a substantial and challenging task that demands significant ambition and dedication. The goal of achieving a world that is climate-neutral by 2050 requires substantial reductions in greenhouse gas (GHG) emissions, which inevitably entail significant costs. Figure 2 demonstrates the main sources of GHG emissions in the world. Transition costs encompass various aspects, including direct expenses associated with policy measures like carbon pricing mechanisms, initiatives to enhance energy efficiency, and mandates for investments in renewable energy. However, a substantial portion of these costs emerges from a concept known as *asset strandedness*, which unfolds over the medium to long term. *Stranded assets* occur when existing economic assets become incapable of generating added value within their respective sectors, leading to adverse interactions between different sectors of the economy. Stranded assets encompass more than just financial costs; they also encompass the risk of stranding for human capital, durable goods, infrastructure, buildings and equipment as countries switch to low-carbon economy. Edwards et al. (2022) estimates the value of stranded fossil power plants to be \$1.4 trillion. Roncoroni et al. (2021) calculates that climate policies could strand 3% of the banks' and investment banks' total value at risk.

Figure 2: Sources of GHG emissions



Source: Synthesis Report of the IPCC Sixth Assessment Report

The decarbonization process, a crucial step in reducing GHG emissions, often involves the idling or abandonment of a portion of physical capital. This action, while necessary for environmental reasons, can have adverse effects on the specific sectors where this capital is utilized and, subsequently, affect the broader economy. To effectively address this challenge, it is essential to adopt a systematic approach that involves identifying, analyzing, comprehending, and mitigating the associated risks. These risks are commonly referred to as stranded asset risks, reflecting the potential loss of value in assets or potential loss of utilization of assets that are no longer viable in a decarbonized economy. In this particular context, we aim to measure and quantify the impact of stranded assets, using economic multipliers as a valuable tool. By doing so, we can gain a more comprehensive understanding of how these risks permeate through various sectors and the wider economy, aiding in informed decision-making and the development of strategies to navigate the transition to a low-carbon future.

The recent studies in the literature provide a sound basis for analyzing stranded assets and the risks associated with them. Caldecott et al. (2014) offer an extensive overview of scenario analysis frameworks applicable to stranded assets, drawing from the experiences of numerous financial institutions. Building upon this foundation, Caldecott et al. (2016) develop a practical framework for assessing the risks associated with stranded assets. Subsequently, Caldecott (2017) refines the conceptual and technical aspects of this emerging field. Their scenario analysis aims to address uncertainties and risks stemming from environmental factors related to stranded assets. It enables users to customize and incorporate scenarios into valuation models and stress testing to meet their specific needs. Following this pioneering work, Buhr (2017) challenges the conventional environmental, social, and governance (ESG) categorization, proposing a reclassification of risks into operational or management risks, climate risks, and natural capital risks. While stranded assets can result from all three categories, the most significant and irreversible strandedness is expected to arise from climate and natural capital risks. Bos and Gupta (2019) conduct a literature review of stranded assets by considering the context of "latecomers to development". They identify seven dimensions in the literature, including spatial, technological, economic, ecological, political, legal/policy, and social aspects. They emphasize the importance for latecomers to make informed decisions regarding resource development to avoid carbon lock-in and assess the potential for creating stranded assets, especially when transitioning to low-carbon economy. Fischer and Baron (2015), Silver (2017), Kruitwagen et al. (2017) and Harnett (2017) delve into the investment and corporate dimensions of stranded asset risks. They underline the need for tailored approaches to risk assessment, information disclosure, and learning. Thomä and Chenet (2017) adopted a market failure-based perspective, while Covington (2017) highlights the imperative of accelerating emissions reduction. Binsted et al. (2020) explores the susceptibility of developing countries with low emissions to stranded asset risks, providing additional insights into this multifaceted issue.

Sen and von Schickfus (2020) analyze the impact of German climate policy proposal which aims at reducing the use of coal in electricity production. Findings of the paper show that investors internalize the risk of stranded assets; however, they anticipate a financial compensation for them. The concept of stranded assets predominantly originates from the fossil fuel industry, with most research papers concentrating on the implications of asset strandedness within this sector. Nevertheless, alternative perspectives are also noteworthy. Rautner et al. (2016) offer a similar assessment of the risk of stranded assets in agriculture, forestry, and other land-use sectors.

Cahen-Fourot et al. (2021) and Godin and Hadji-Lazaro (2022), given our aim of reaching a decent quantification, provide an invaluable venue of analysis. These studies, the former of which analyzes economic sectors and the latter countries, combine the almost traditional power of the input-output analysis with that of network theory, making the computation of intuitive as well as practical impact coefficients, i.e. multipliers, possible. As their novel methodological framework allows for clearly revealing how an initial triggering effect (in a sector or country) cascades down through others, we maintain the same framework in our analysis of the stranded asset risks in Latvia's economy.[4]

Our analysis of the potential impacts of stranded assets in Latvia is based on Cahen-Fourot et al. (2021) approach. This method takes into account the capital intensities of different sectors in the economy, as well as the flows of value added between them. By combining these two factors, we are able to quantify the numerical impacts of stranded assets. To our knowledge, this approach has not yet been applied to Latvia's data, no other method has been used to assess the potential impact of stranded assets in the country.

In the next section we provide a brief story of Latvia's experience with climate risks. Section 3 introduces the method and Section 4 presents our computational results with a discussion before concluding the study in Section 5.

2 A Brief Account of Latvia's Experience with Climate Risks

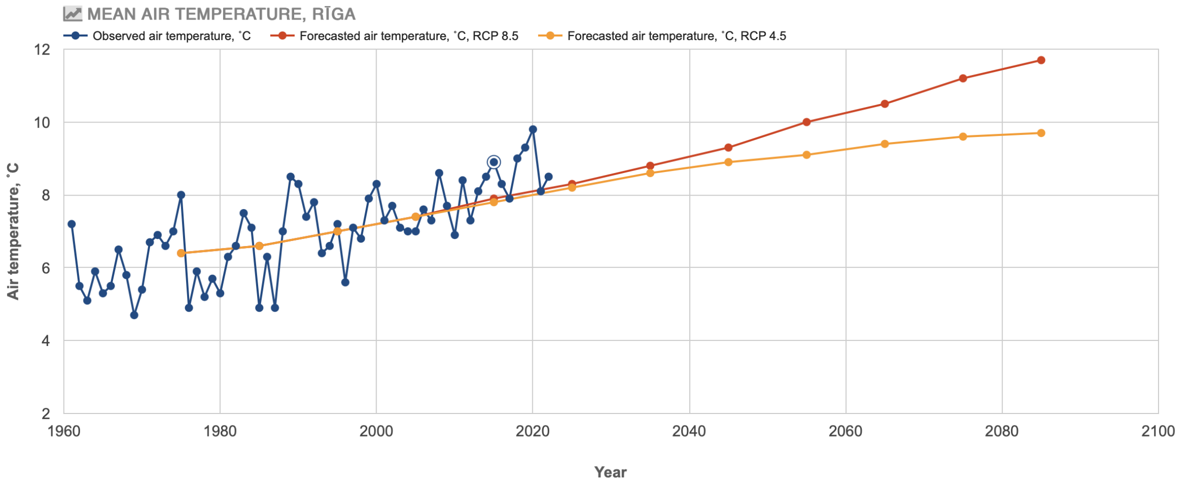
Latvia has been experiencing climate risks in various forms, such as extreme weather events, water scarcity, and coastal erosion. The country has witnessed increased frequency and intensity of heatwaves, heavy rainfall, and snowstorms, which have led to disruptions in transportation, agriculture, and energy supply.

The latest analysis of the Latvian Environment, Geology and Meteorology Center's

[4]Before proceeding, we need to note how salutary the recent expansion of the related scientific contributions focusing on asset strandedness is for the economics profession. By re-orienting their attention to stranded assets, economists are forging the problem of analyzing the challenges posed by decarbonization in their field of scientific expertise, so enhancing their grasp and resolution of the issues. The approach of Cahen-Fourot et al. (2021), for instance, provides the scientific and technical community with invaluable insights. Indeed, most of this value originates from the decent use of a well-known framework like input-output analysis in conjunction with sectoral capital intensities and a sector's sensitivity to risks of strandedness.

current and projected climate change scenarios reveals clear indications of significant shifts in the climate. The most noteworthy transformations are associated with extreme climate variables, such as mean temperature as shown in Figure 3, suggesting that Latvia will increasingly encounter unusual and extreme weather conditions within its territory.[5]

Figure 3: Mean temperature in Riga



Sources: Latvian Environment, Geology and Meteorology Center. Climate Change Scenarios in Latvia.

The government of Latvia has recognized the severity of climate risks and has taken measures to address them, including the development of adaptation plans, the implementation of climate-friendly policies, and the promotion of public awareness and engagement. The country has also joined international efforts, including the Paris Agreement and the European Union's climate targets, to combat climate change.

According to the report Strategy of Latvia for the Achievement of Climate Neutrality by 2050, the energy sector is responsible for the highest amount of GHG emissions and contributed to 34% of the total emissions in 2017.[6] This sector includes emissions from combustion processes across all sectors of the economy. Within the energy sector, the largest contributor to emissions is public generation of electricity and thermal energy, accounting for 40% of emissions. The commercial, institutional, household, agriculture, forestry, and fisheries sectors contribute 39% of emissions, while the manufacturing industry and construction, military transport, and diffuse emissions from oil and natural gas make up the remaining portion. The transportation sector is responsible for 29% of Latvia's total GHG emissions, making it the second largest source. Compared to 1990, emissions from the transport sector have increased by 9.4%. Road transport is responsible for the majority of emissions in this sector, accounting for 93.88% of total transport emissions in 2017. Among the different types of vehicles, passenger cars are the

[5]https://www4.meteo.lv/klimatariks/files/summary.pdf

[6]https://unfccc.int/sites/default/files/resource/LTS1_Latvia.pdf

largest emitter, followed by freight vehicles and buses. Railway is responsible for 5.5% of the transport sector's emissions, while maritime transport and aviation account for only 0.48% and 0.14%, respectively. The agricultural sector is responsible for 24.6% of Latvia's total GHG emissions, making it the third largest source. The cultivation of agricultural land (60.8%) and farming (31.2%) are the main contributors to emissions in this sector. However, since 1990, GHG emissions from agriculture have decreased by 50.5% due to restructuring of the national economy, lower production rates in rural farms, and the division of large-scale farms into smaller ones. Fluctuations in the number of farm animals and the use of mineral nitrogen fertilizers also have a significant impact on emissions. However, in recent years, there has been an increase in emissions from agriculture due to an increase in the use of mineral fertilizers containing nitrogen for the cultivation of agricultural land.

Latvia has taken several actions to address climate change and reduce GHG emissions. The country has set targets to increase the share of renewable energy in its energy mix, aiming to reach a target of 50% by 2030. According to the baseline scenario provided in Latvia's National Energy and Climate Plan 2021–2030[7], the proportion of GHG emissions from non-ETS[8] activities is predicted to decrease to 75% of total GHG emissions by 2030. The total GHG emissions from non-ETS activities are expected to fall by 7% between 2005 and 2030. In 2030, the majority of emissions are projected to come from transport (32%), agriculture (39%), and non-ETS energy (including industry, services, households, agriculture, forestry, 22%).

The baseline scenario for the energy sector's GHG emissions projections involves continuing the implementation of existing policies, such as renewable energy sources (RES), and energy efficiency measures until 2030. Measures like replacing fossil fuels with biomass in district heating and renovating buildings for energy efficiency are expected to reduce GHG emissions in households and the services sector. However, there are no measures planned for wider use of RES in electricity generation. Latvia has also implemented energy efficiency measures in buildings and industry, such as improving insulation and promoting the use of energy-efficient appliances.

In the transport sector, road transport accounts for around 90% of total emissions, but replacing cars with more efficient and environmentally friendly vehicles and using alternative and RES fuels are expected to reduce GHG emissions by 793 kt CO2 eq in 2030 compared to 2017. The energy sector's ETS emissions are expected to decrease by 595 kt CO2 eq (22.7%) in 2030 compared to 2005, while non-ETS emissions are expected

[7] https://energy.ec.europa.eu/system/files/2020-02/lv_final_necp_main_lv_0.pdf

[8] The ETS covers industries, such as power generation, manufacturing, and aviation, while non-ETS sectors include agriculture, waste management, buildings, and transport. ETS participants have to purchase permits to cover their emissions, while non-ETS sectors do not have the same obligation. However, both ETS and non-ETS sectors are subject to emissions reduction targets under the EU's Effort Sharing Regulation.

to decrease by 1167 kt CO2 eq (21.5%).

In addition, Latvia has introduced policies to encourage the use of low-emission vehicles, including tax incentives for electric vehicles and the development of charging infrastructure. The government has also invested in research and development of climate-friendly technologies and supported projects to reduce emissions in agriculture and forestry.

3 Data and Methodology

To derive the *asset standing multipliers* of all productive sectors in Latvia, we use 2014 (latest available) Input-Output(IO) Table and Sectoral Capital Stock data. These multipliers capture the monetary value of physical capital stocks that would become stranded in a sector due to a unitary drop in primary inputs utilized by another (or the same) sector, considering both direct and indirect effects. We identify the sectors most likely to have large stranding effects and the sectors most exposed to the risk of capital asset stranding.

In an IO Table the inter-industry matrix Z shows how much of each industry's output is used as inputs by other industries. Additionally, there are column vectors representing the final consumption demand (f) and row vectors representing the value added items (v) of each industry, such as compensation of employees, consumption of fixed capital, and gross operating surplus. Each industry appears twice in the Z matrix, once as a producer of goods and services (rows), and once as a user of intermediate inputs (columns).

The main principle of IO tables is that the total supply of goods and services produced by all industries (x^T) is equal to the total use of goods and services by all industries (x), which can be expressed as $x^T = i^T Z + v$ and $x = Zi + f$, respectively. Here, i is a column vector of ones with the same dimension as Z.

Figure 4: Example of IO Table

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Country A</th><th colspan="2">Country B</th><th rowspan="2">Final demand (f)</th><th rowspan="2">Total demand (x)</th></tr>
<tr><th>Sector 1</th><th>Sector 2</th><th>Sector 1</th><th>Sector 2</th></tr>
<tr><th rowspan="2">Country A</th><th>Sector 1</th><td>A.1 used in A.1 prod.</td><td>A.1 used in A.2 prod.</td><td>A.1 used in B.1 prod.</td><td>A.1 used in B.2 prod.</td><td>Consumption of A.1</td><td rowspan="4">Intermediate production + final demand</td></tr>
<tr><th>Sector 2</th><td>A.2 used in A.1 prod.</td><td>A.2 used in A.2 prod.</td><td>A.2 used in B.1 prod.</td><td>A.2 used in B.2 prod.</td><td>Consumption of A.2</td></tr>
<tr><th rowspan="2">Country B</th><th>Sector 1</th><td>B.1 used in A.1 prod.</td><td>B.1 used in A.2 prod.</td><td>B.1 used in B.1 prod.</td><td>B.1 used in B.2 prod.</td><td>Consumption of B.1</td></tr>
<tr><th>Sector 2</th><td>B.2 used in A.1 prod.</td><td>B.2 used in A.2 prod.</td><td>B.2 used in B.1 prod.</td><td>B.2 used in B.2 prod.</td><td>Consumption of B.2</td></tr>
<tr><th colspan="2">Value added (v)</th><td>V.A. in A.1</td><td>V.A. in A.2</td><td>V.A. in B.1</td><td>V.A. in B.2</td></tr>
<tr><th colspan="2">Total supply (xT)</th><td colspan="4">Intermediate consumption + value added</td></tr>
</table>

The primary impact of transitioning to a low-carbon economy will be on the methods used to produce goods and services. In this regard, the demand-driven Leontief model is inadequate for analyzing the rapid substitution away from fossil-based input factors. Instead, the focus should be on the supply side and production processes. As a result, the IO system developed by Ghosh (1958) is used. Ghosh (1958)'s approach is supply-driven and defines a matrix, B, that shows how output of one sector is allocated to all other industries. Each element of this matrix, b_{ij}, represents the share of industry i's output that is used by industry j. The Ghosh matrix, G, is defined as $(I - B)^{-1}$. Each element of G^T, g_{ij}, describes how a unitary change in primary inputs flowing into sector j affects the output of sector i. In other words, an increase of one monetary unit of primary inputs used in production in sector j will increase the output of sector i by an amount equal to $g_{i,j}$, which includes both direct and indirect effects.

We then integrate the Ghosh matrix with the sector-specific physical capital stocks, denoted by k. We use the Socio-Economic Accounts under the World Input-Output Database (WIOD). The capital stock data corresponds to fixed assets as defined in the guidelines of System of National Accounts 2008 (SNA08).[9] The capital intensity of sector i is determined by calculating the ratio of the capital stock (k_i) to the domestic output (x^d) of that sector. This ratio is denoted as κ_i and represents the capital intensity measure for the analysis. The capital stock (k_i) refers to the total value of the fixed assets (both tangible and intangible) employed in sector i for production purposes. It includes assets, such as buildings, machinery, equipment, and other long-term productive resources. The output (x^d) represents the total value of goods or services produced by the sector. By calculating the ratio $\kappa_i = k_i/x^d$, we obtain the capital intensity measure for sector i. This measure provides insights into the efficiency and utilization of capital within the sector, helping to assess the relationship between capital stock and domestic output.

To obtain the matrix of asset stranding multipliers, denoted by S, we multiply the Ghosh matrix with the diagonalized vector of capital intensities: $S = \hat{\kappa}G^T$.[10] Each element, $s_{i,j}$, in the resulting matrix S represents the amount by which the utilization of capital in sector i will change in response to a unitary change in primary inputs used by sector j. In our context, the values in S indicate how much capital stock in sector i could be stranded due to a unitary reduction in primary inputs used by sector j in the production of goods and services.

[9]Fixed assets, as defined in the System of National Accounts 2008 (SNA08), refer to tangible or intangible assets that are used repeatedly or continuously in production processes for a period of more than one year. These assets are intended to be used within the production process to generate goods or services.

[10]$\hat{\kappa}$ represents the diagonalized vector of capital intensity measures, denoted as κ_i. The capital intensity measure κ_i quantifies the ratio of capital to output in each respective sector. The diagonalized vector $\hat{\kappa}$ refers to the arrangement of the capital intensity measures in a diagonal matrix form.

Figure 5: Example of stranding multipliers matrix

		Country A		Country B		Stranding exposure
		Sector 1	Sector 2	Sector 1	Sector 2	
Country A	Sector 1	S(A.1,A.1)	S(A.1,A.2)	S(A.1,B.1)	S(A.1,B.2)	Stranding exposure of A.1
	Sector 2	S(A.2,A.1)	S(A.2,A.2)	S(A.2,B.1)	S(A.2,B.2)	Stranding exposure of A.2
Country B	Sector 1	S(B.1,A.1)	S(B.1,A.2)	S(B.1,B.1)	S(B.1,B.2)	Stranding exposure of B.1
	Sector 2	S(B.2,A.1)	S(B.2,A.2)	S(B.2,B.1)	S(B.2,B.2)	Stranding exposure of B.2
Stranding multiplier		Total stranding from A.1	Total stranding from A.2	Total stranding from B.1	Total stranding from B.2	

The total amount of stranded physical assets resulting from a unitary decrease in primary inputs in sector j can be obtained by summing up the columns of matrix S, which gives the total asset stranding multiplier for that sector: $s_j^{TOT} = i^T S$. The value of s_j^{TOT} is expected to be greatly influenced by the sector-specific capital intensities, and consequently, the degree of internal asset stranding. To determine the effect of a unitary decrease in primary inputs of a sector on the utilization of capital stock in all other sectors, we introduce a measure for the external asset stranding multiplier: $s_j^{EXT} = s_j^{TOT} - s_j^{diag}$. The exposure of a sector to the risk of asset stranding can be measured by summing up the rows of matrix S, which gives the exposure index: $s_i^{EXP} = Si$. The external exposure to the risk of asset stranding, s^{EESR}, can be calculated by subtracting the diagonal elements of the matrix S from the exposure index of a sector: $s^{EESR} = s_i^{EXP} - s_j^{diag}$. This measures the extent to which a sector's capital utilization is affected by a unitary decrease in the primary inputs of all other sectors, except for its own impact on itself.

This study is built upon a set of fundamental assumptions and constraints that are integral in shaping the model we utilize. These foundational assumptions represent the analytical framework that is constructed. While some firms/sectors may be affected to varying degrees by changes in the production levels of the sectors they rely on as intermediate inputs, this analysis operates under the assumption of a single production function across all sectors of the economy. Additionally, our scenario considers the situation where intermediate inputs are non-substitutable, margins are constant, and productivity remains constant, all in accordance with the Leontief production function. It is important to acknowledge that the constraints posed by the available data and the scale of the economy under examination must be considered when interpreting findings of the paper.

4 Results and Discussion

4.1 Results

We proceed to implement the aforementioned methodology by initially considering a global perspective, where the world is regarded as a single entity composed of various sectors. Subsequently, we turn our attention towards analyzing country-level interactions to discern the countries that are most susceptible to the risk of asset stranding. Ultimately, we direct our focus towards the Latvian case to assess its potential exposure to the aforementioned risk.

4.2 Global Fossil Stranding

In this section, we examine the detailed network between various productive sectors on a global scale, wherein we regard the world as a singular entity. Our primary objective is to quantify the extent of vulnerability of the capital stock to the possibility of remaining idle in the wake of a slight perturbation in the global fossil mining sector.[11]

Table 1 reports the results for: (i) total stranding multipliers; (ii) external stranding multipliers; (iii) exposure to stranding risk, (iv) external exposure to stranding risk. The first two columns of multipliers provide insights into sectors that have the potential to generate the most stranded assets in the economic system in the event of a marginal decline in their primary inputs. Conversely, the third column displays the sectors that would be most impacted by capital stranding in case of a uniform reduction in inputs across all sectors. Finally, the last column highlights the sectors that are most vulnerable to capital stranding due to a uniform reduction in inputs across all sectors except for their own.

The first column in the table ranks the mining and quarrying (B) sector as sixth, with an total stranding multiplier of 4.88. This means that a unitary decrease in primary input of $1 in the global fossil sector poses a risk of $4.88 of stranded capital in the entire economic system. However, most of the stranding risk originates from within the sector itself. When we exclude internal stranding, the mining and quarrying (B) sector is identified as having the highest potential for creating a stranding effect on the rest of the economy, with an external stranding multiplier of 2.53.

The top four sectors with the highest external asset stranding multipliers are mining and quarrying (B), water supply and waste management (E), manufacturing of coke and petroleum products (C19), and financial services (K). The last two columns in the data show the total and external exposure of each sector to a scenario where a marginal shock occurs in all sectors. Real estate (L68) and public administration (O84) are the most

[11] We replicate the findings of Cahen-Fourot et al. (2021).

Table 1: Stranding multipliers

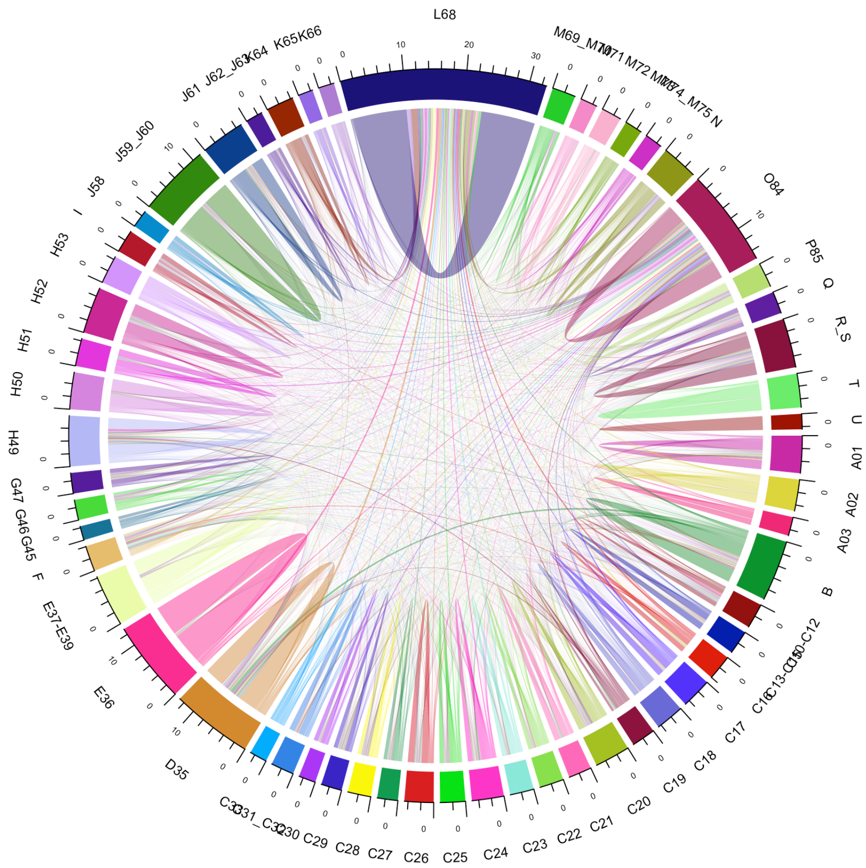
	Total stranding	External stranding	Total exposure	External exposure
1	L68 (9.986)	**B (2.526)**	L68 (22.736)	L68 (13.193)
2	E36 (7.000)	E37-E39 (2.473)	O84 (12.031)	O84 (8.862)
3	J59-J60 (5.751)	C19 (2.447)	D35 (7.359)	D35 (3.915)
4	D35 (5.537)	K64 (2.381)	E36 (5.966)	H49 (2.780)
5	E37-E39 (5.051)	N (2.285)	J59-J60 (5.644)	F (2.594)
6	**B (4.880)**	H53 (2.207)	R-S (4.809)	R-S (2.582)
7	H52 (4.013)	M69-M70 (2.142)	B (4.771)	B (2.418)
8	O84 (3.402)	D35 (2.093)	H49 (4.687)	C10-C12 (1.944)
9	N (3.390)	C18 (2.091)	J61 (3.650)	Q (1.854)
10	A02 (3.382)	M73 (2.013)	A01 (3.346)	A01 (1.732)
11	J61 (3.297)	A02 (1.925)	H52 (3.333)	C20 (1.643)
12	H49 (3.287)	H52 (1.922)	E37-E39 (3.172)	J61 (1.601)
13	H53 (3.265)	C17 (1.916)	F (3.001)	C24 (1.457)
14	H50 (3.125)	C20 (1.864)	H50 (2.709)	C29 (1.336)
15	C18 (3.116)	M74-M75 (1.828)	C20 (2.686)	C26 (1.315)

vulnerable sectors due to their high capital intensity and heavy reliance on intermediate inputs. [12]

The chord diagram shown in Figure 6 illustrates the global network and the influence of sectors on each other. The size of each sectoral segment indicates the magnitude of total stranding multipliers. Most sectors have both inward and outward links (external stranding multipliers). However, administrative and support service activities (N) and professional, scientific and technical activities (M) only have outward impact, while health (Q) and education (P) have inward links. The sectors with the highest level of risk in terms of exposure are real estate (L68) and public administration (O84). The stranding effects caused by the mining sector (B) are mainly focused on the electricity and gas sector (D35).

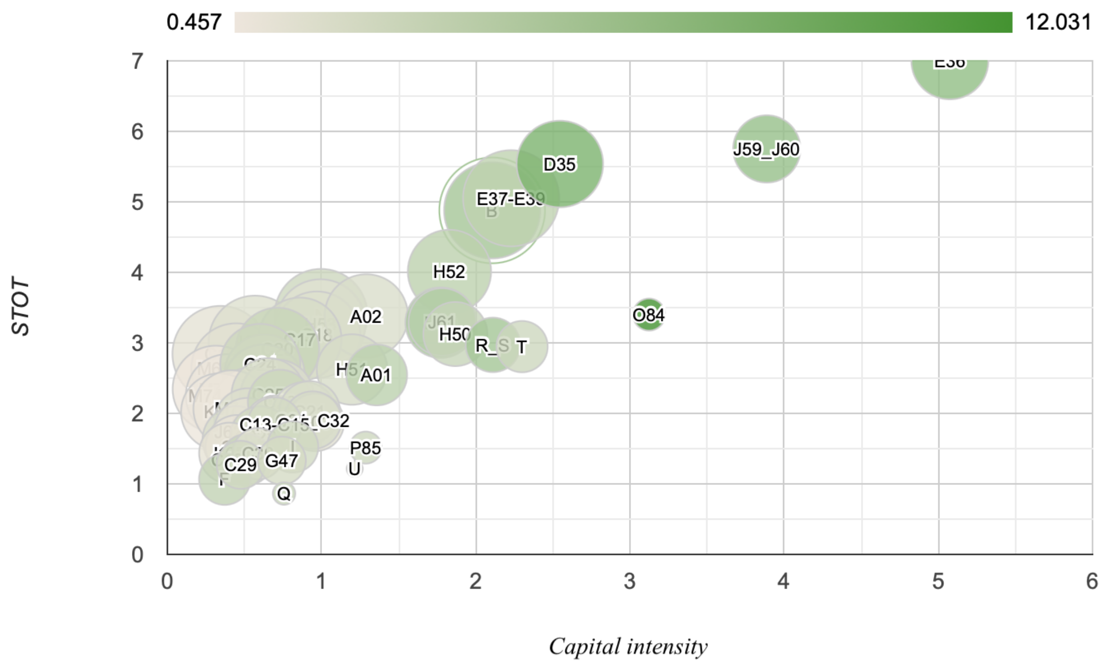
[12]The real estate industry heavily depends on fossil fuel energy from the power and refining sectors to provide heating and electricity to buildings. Additionally, it relies on construction services, which are highly reliant on inputs derived from fossil fuels. Similarly, the public sector is a major owner of buildings and infrastructures. Also, this sector encompasses military and defense operations, which consume a substantial amount of fossil fuel energy.

Figure 6: Chord diagram



Finally, Figure 7 provides the relation between all three capital stranding measures and capital intensity of the sectors in 2014. One should be careful when interpreting the total stranding multipliers. More capital intensive sectors have higher total stranding multipliers. The bubble sizes refer to the external stranding multiplier which reduces the relevance of capital intensive activities. A larger bubble indicates a larger impact of external stranding on the sector. For example, the J59-60 (broadcasting activities) sector has a high total stranding multiplier but a low external stranding multiplier, implying that a decline in primary input in J59 has a significant inward impact on the other hand it has a very limited impact on the rest of the economy. Meanwhile, B (mining and quarrying) category or D35 (electricity, gas, steam and air conditioning) has a lower capital intensity but the same level of total stranding multiplier as J. The color of the bubbles indicates the multiplier representing the exposure of each sector to fossil stranding. A higher value indicates a greater vulnerability to stranding.

Figure 7: Capital intensity and capital stranding measures



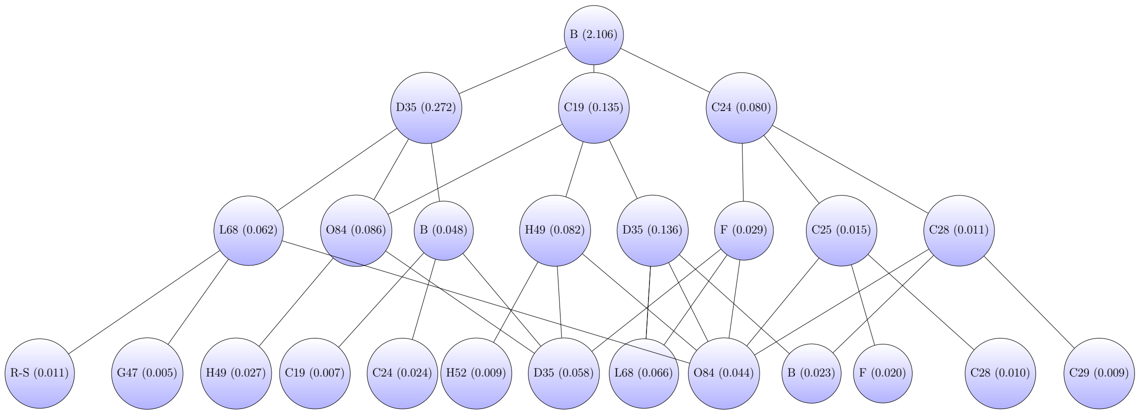
Notes: Author's calculations. Global production (2014). STOT represents the total amount of stranded physical assets due to global fossil stranding and is expressed as a multiplier. Capital intensity is defined as the ratio of capital to output in a given sector. The color of the bubbles indicates the multiplier representing the exposure of each sector to fossil stranding. The size of the bubble represents the magnitude of the multiplier associated with the external stranding of the sector. Please note that the multipliers, colors, and sizes of the bubbles are used for comparative purposes and do not represent specific physical units of measurement.

Moreover, the external stranding multiplier is high, implying a high degree of impact on the rest of the economy. Due to the high stranding potential and stranding risk exposure of the entire range of productive sectors, in the next section we delve more into the impact of a primary input decline in sector B on the economy.

4.2.1 Cascades of Physical Asset Stranding due to Global Fossil Stranding

The objective of this section is to analyze the potential stranding of physical assets caused by the shift away from fossil fuels and to investigate how the stranding process initiated in the fossil fuel sector can propagate throughout the economy. To achieve this goal, we aim to identify the most significant stranding links arising from the loss of primary inputs that support the production of a particular sector (sector B). We choose the top three sectors based on these links and position them on the first layer of the cascade network. Then, we repeat this process for the sectors in the first layer, identifying the top three sectors that have the strongest stranding links originating in the layer. The strength of the stranding links diminishes as they cascade downwards and get progressively further from the initial shock. We continue this process for each layer, excluding the sectors that have already appeared in the upper layers, until no new sectors emerge.

Figure 8: Stranding cascades from global mining

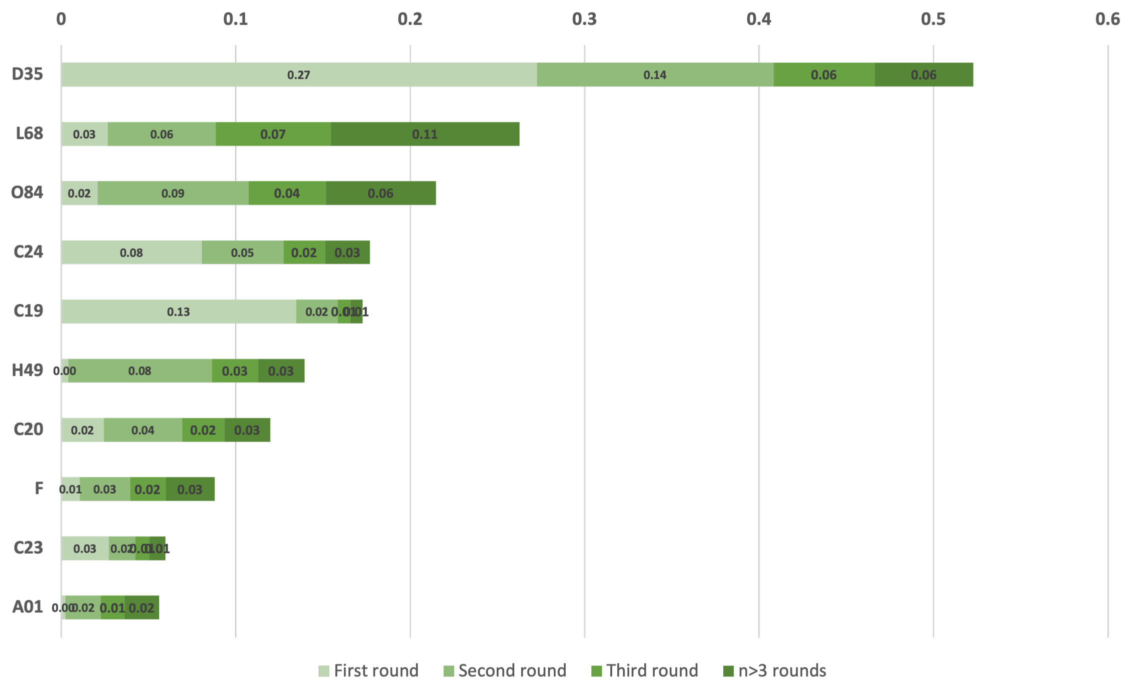


The most prominent stranding link arising from a unitary loss of primary inputs that support the production of sector B is directed towards D35 (electricity, gas, steam and air conditioning supply), while C19 (manufacture of coke and refined petroleum products) and C24 (manufacture of basic metals) are also significantly impacted by immediate stranding triggered by B. In the second layer, the stranding links continue to affect L68 (real estate activities) and O84 (public Administration) from D35, as these sectors heavily rely on electricity in their production processes. Similarly, the cascading effect from C19 affects H49 (land transport) and O84 (public administration), while C24 leads to stranding in C25 (manufacture of fabricated metal products), F (construction), and C28 (manufacture of machinery and equipment). Service sectors such as J (information and communication), K (finance and insurance), M (professional services), and N (administrative services), are absent from the networks, indicating that their physical capital assets may not be severely impacted by the decarbonization process. However, sectors D35 (electricity, gas, steam and air conditioning supply), L68 (real estate), and O84 (public administration) are at risk of stranding.

It is important to highlight that the experiment conducted in this study is static in nature, offering insights into the immediate effects of fossil stranding on the production sectors. When interpreting the results, it is crucial to bear in mind this characteristic of the analysis. Additionally, the analysis does not account for the potential substitution effects involving other types of inputs and energy sources.

In the following analysis, we delineate the primary, secondary, tertiary, and subsequent impacts for the leading 10 sectors. Figure 9 shows that the power sector (D35) has the highest exposure to global fossil stranding, which is followed by real estate (L68) and public administration (O84). These findings can be elucidated by their capital intensity levels and their reliance on fossil fuel-intensive intermediate inputs.

Figure 9: First-, second-, and third-round effects



Notes: Author's calculations. The values provided represent the multipliers, which are used to quantify the amplification of global fossil stranding effects within the economic system. These multipliers serve as ratios that illustrate the relationship between a change in the primary inputs that support the production of sector B and the resulting overall impact on the production of other sectors.

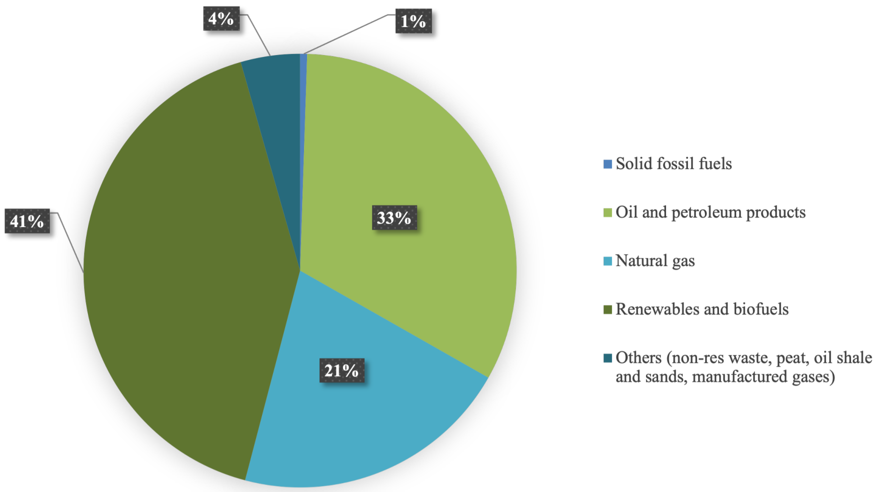
4.3 Physical Asset Stranding in Latvia due to Global Fossil Stranding

In this section, our attention turns to examining how the global fossil stranding affects Latvia's sectoral production. Before analyzing the cascading effects across sectors resulting from a global fossil fuel restriction, we delve into Latvia's energy consumption and import statistics.

Based on Eurostat's energy statistics, renewables and biofuels constituted the largest share (41%) in the energy mix in 2020, followed by fossil fuels, including oil and petroleum products (33%), and natural gas (21%) as shown in Figure 10. Notably, there have been some changes in the energy mix since 2014. One significant observation is the halving of solid fossil fuels, largely replaced by renewable energy sources. This shift aligns with Latvia's decarbonization plan, indicating a progressive transition towards cleaner energy sources.[13]

[13] According to Eurostat, Latvia was among the leaders in the European Union during 2022 and 2023

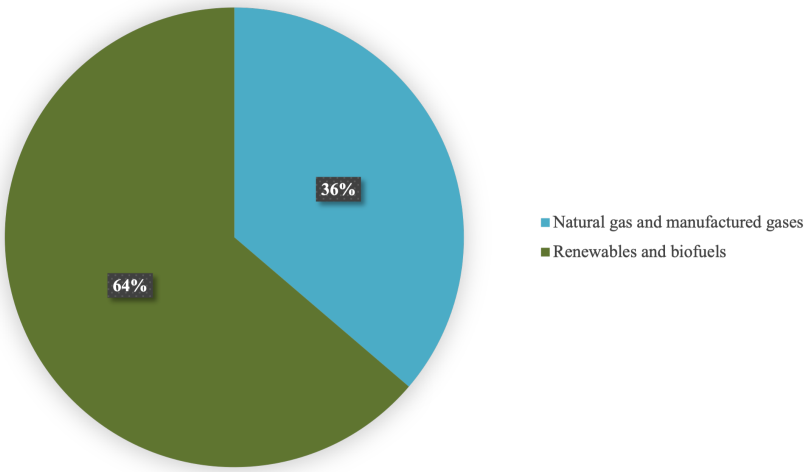
Figure 10: Energy mix, 2020, %



Sources: Eurostat, EU Energy Statistical Pocketbook and Datasheets.

Subsequently, our focus shifts to the electricity production composition of Latvia. Presently, the predominant share of electricity production is derived from renewable energy sources with 64% (see Figure 11). Back in 2014, both natural gas and renewable energy equally contributed to Latvia's electricity production. As a result, the stranding risk of assets in the fossil fuel sector is expected to have a profound impact on the country's production sectors.

Figure 11: Electricity mix, 2020, %



Sources: Eurostat, EU Energy Statistical Pocketbook and Datasheets.

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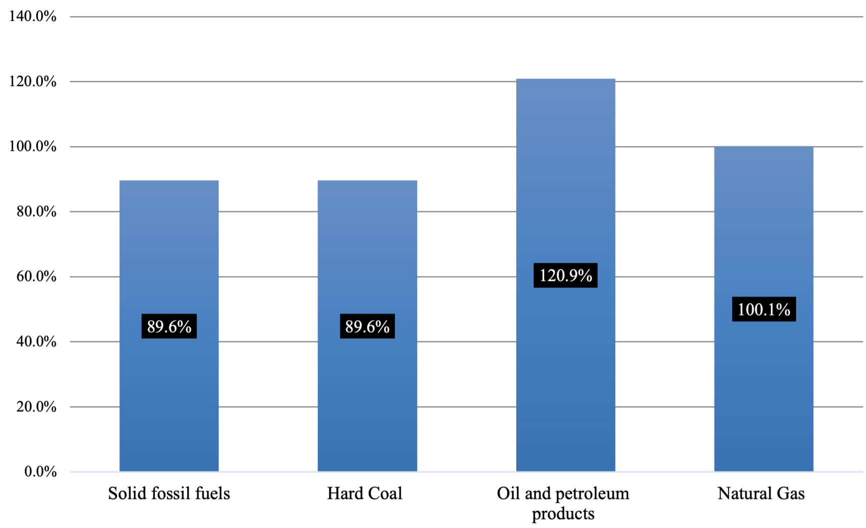
in the reduction of natural gas consumption. Various factors contributed to this decline, including milder weather conditions, energy conservation initiatives following a natural gas shortage due to the Russia-Ukraine war, efforts in previous years to transition to alternative energy sources, and fluctuations in gas prices.

While Latvia demonstrates commendable progress in integrating renewable energy sources, its energy and electricity mix still heavily relies on fossil fuels. This reliance is notable due to Latvia's lack of domestic fossil fuel resources, leading to a significant dependence on energy imports from abroad. In 2020, Latvia's energy import reliance, including electricity, stood at approximately 48%. Over the period from 2008 to 2020, the average import dependency was around 53%. Figure 12 illustrates the composition of import dependency of energy resources in 2020.

Figure 12: Import dependency energy resources, 2020, %



Sources: Eurostat, EU Energy Statistical Pocketbook and Datasheets. Above 100% refers to storage of the energy source.

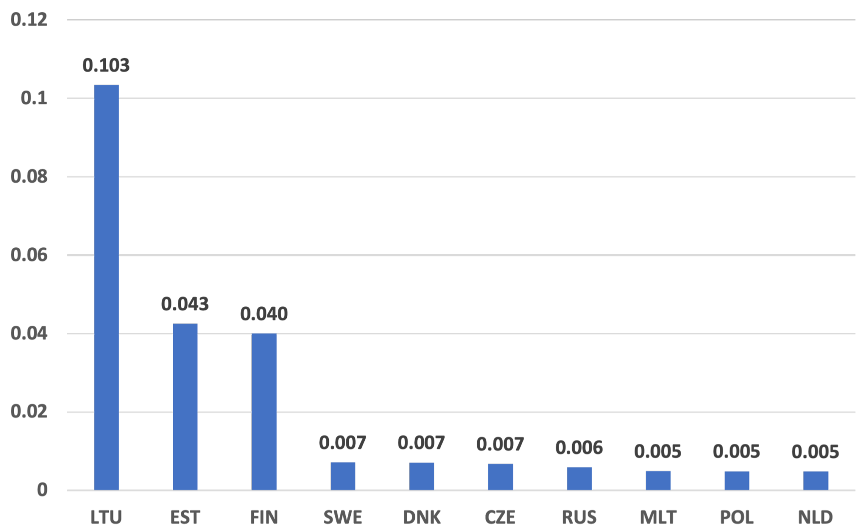
In Latvia, households stand as the primary consumers of final energy, accounting for 29.4%. They are followed by the transportation sector at 27.5% and the industrial sector at 22.9%.[14] Natural gas serves as the primary resource for generating electricity and heat energy in the country. The electricity supply predominantly comes from imports, primarily sourced from Poland, Sweden, and Finland. Latvia lacks a petroleum refinery industry within its borders. As a result, Lithuania, Finland, Belarus, and Russia stand as the primary suppliers of gasoline and diesel to Latvia. Besides energy imports, Latvia primarily imports mineral products, machinery, mechanical appliances, and electrical equipment. It is important to note that these imports are sensitive to becoming stranded assets. As of 2022, Latvia's major trading partners include Lithuania, Estonia, Germany, Poland, and Russia.

By combining the aforementioned details about Latvia's energy sector and its energy dependency, we next delve into the impact of global fossil stranding on Latvian production sectors in the context of stranding physical capital.

[14]Sources: Eurostat, EU Energy Statistical Pocketbook and Datasheets.

Due to its high external stranding impact, initially, we quantify the comprehensive external exposure of the global fossil sector to the Latvian economy. The external exposure of Latvia due to global fossil stranding is calculated as 0.265. This indicates that a $1 decrease in primary input within the global fossil sector correlates with a $0.27 decline in the overall Latvian economy. In this analysis, our primary focus is on the mining industries of the analyzed countries, specifically delving into their impact on Latvia's overall economy. It is essential to note that this impact is not solely direct; it encompasses cascading effects as well. Figure 13 displays the top 10 countries that have an impact on Latvian production due to fossil stranding. Among these countries, Lithuania's fossil sector has the highest impact with 0.103, followed by Estonia with 0.043, Finland with 0.04, and Russia with 0.006. Given Latvia's energy trade connections, it is evident that these nations significantly impact Latvia. This influence is particularly pronounced owing to the mining industry's intimate ties with refined oil and natural gas.

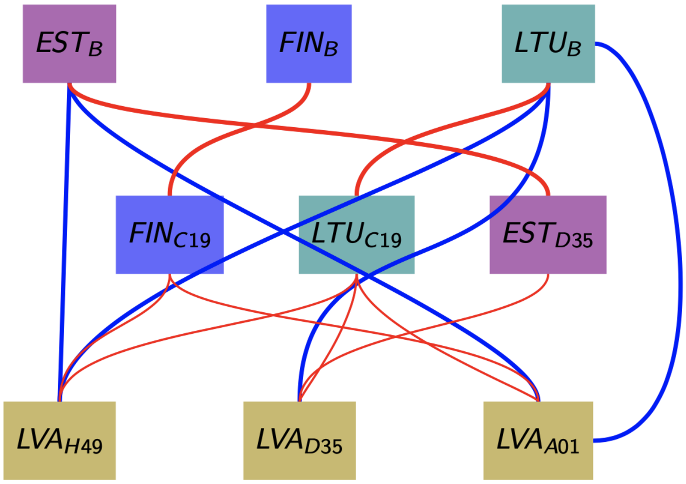
Figure 13: Top 10 countries affecting Latvia's production



Next, we turn our attention to Latvia's sectors. To assess the impact of global stranding on industries, we begin by aggregating all the mining sectors within our dataset to identify the most affected sectors in Latvia. It is important to interpret these findings cautiously as they encompass both the direct and cascading effects of global fossil stranding. The most exposed sectors to global fossil stranding in Latvia are found to be H49 (land transportation), D35 (electricity, gas, steam and air conditioning), A01 (crop and animal production, hunting, and related service activities). It is not surprising to find that the transportation and electricity sectors are among the most exposed sectors due to their heavy reliance on fossil fuels. The prominent position of the agriculture sector on the highest exposure list can be attributed to both its reliance on fossil fuels and the high capital intensity of Latvia's agricultural industry, which is a significant influencing factor.

Finally, we analyze the exposure network of these three sectors. Figure 14 demonstrates the exposure network for Latvia. At the bottom of the chart, the most exposed sectors are placed according to their external exposure multipliers considering their exposure from the global fossil stranding. Next, we look for the strongest incoming one-step and two-step fossil stranding to explore where their exposure originates and how it reaches to them through the production network.[15]

Figure 14: Exposure network for Latvia



Our previous analysis reveals that the land transportation sector (H49) in Latvia appears to be directly (one-step) impacted by the mining sectors of Lithuania, Finland, and Estonia. Since Latvia is an importer of refined petroleum from these countries, we have identified that the coke and refined petroleum products sectors (C19) of Finland and Lithuania have strong second-step effects on the land transportation sector (H49) of Latvia. In addition, we have found that the mining sector of Lithuania has a direct impact on the electricity, gas, steam, and air conditioning sector (D35) of Latvia. Moreover, the electricity, gas, steam, and air conditioning sector of Estonia has second-step effects through its own power sector (D35) to the Latvian power sector. Finland and Lithuania have a second-step effect on Latvia's power industry through their coke and refined petroleum sectors. Finally, it is noteworthy that the mining sectors of Estonia and Lithuania exert a one-step impact on the agriculture sector (A01) of Latvia. In the subsequent step, our observation reveals that the exposure network originates from the manufacture of coke and refined petroleum products in Estonia and Lithuania, as well as from the chemicals and chemical products (C20) sectors in Lithuania.[16]

[15]The number of steps chosen is flexible, yet it is anticipated that the majority of significant stranding cascades will likely occur in the initial couple of steps.

[16]Latvia imports fertilizers, specifically mineral or chemical ones; nitrogenous fertilizers, including

Overall, our findings highlight the complex relationship of various sectors and countries on Latvia's economy and underscore the need for targeted policy interventions to mitigate the adverse effects of fossil stranding.

5 Conclusion

In this paper, we aim to quantify the monetary value of productive capital stock in a sector that may become unutilized due to a reduction in primary inputs from another sector. Our focus is two-fold: first, we examine which sectors should be prioritized for decarbonization globally, and second, we provide a more precise roadmap for Latvia. Our analysis reveals that globally, the mining sector has the strongest external stranding effects. In Latvia, we identify land transportation and transport via pipelines (H49), electricity, gas, steam, and air conditioning (D35), and agriculture (A01) as the sectors most at risk of being stranded due to global fossil stranding. The primary source of this stranding stems from Lithuania, Estonia, the Czech Republic, and Finland. Establishing a comprehensive collaboration scheme to monitor and re-measure these risks is critical. Finally, internalizing these risks in their models will enable policymakers to make robust decisions and develop resilient low-carbon transition pathways.

mixtures of urea and ammonium nitrate in aqueous or ammoniacal solution, from Lithuania.

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Appendix

Table 2: NACE level 2 sectors

Sector Code	Description
A01	Crop and animal production, hunting and related service activities
A02	Forestry and logging
A03	Fishing and aquaculture
B	Mining and quarrying
C10-C12	Manufacture of food products, beverages and tobacco products
C13-C15	Manufacture of textiles, wearing apparel and leather products
C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
C17	Manufacture of paper and paper products
C18	Printing and reproduction of recorded media
C19	Manufacture of coke and refined petroleum products
C20	Manufacture of chemicals and chemical products
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C22	Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products
C24	Manufacture of basic metals
C25	Manufacture of fabricated metal products, except machinery and equipment
C26	Manufacture of computer, electronic and optical products
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles, trailers and semi-trailers
C30	Manufacture of other transport equipment
C31-C32	Manufacture of furniture; other manufacturing
C33	Repair and installation of machinery and equipment
D35	Electricity, gas, steam and air conditioning supply
E36	Water collection, treatment and supply
E37-E39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services
F	Construction
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles
G46	Wholesale trade, except of motor vehicles and motorcycles
G47	Retail trade, except of motor vehicles and motorcycles
H49	Land transport and transport via pipelines
H50	Water transport
H51	Air transport
H52	Warehousing and support activities for transportation
H53	Postal and courier activities
I	Accommodation and food service activities
J58	Publishing activities
J59-J60	Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities
J61	Telecommunications
J62-J63	Computer programming, consultancy and related activities; information service activities
K64	Financial service activities, except insurance and pension funding
K65	Insurance, reinsurance and pension funding, except compulsory social security
K66	Activities auxiliary to financial services and insurance activities
L68	Real estate activities
M69-M70	Legal and accounting activities; activities of head offices; management consultancy activities
M71	Architectural and engineering activities; technical testing and analysis
M72	Scientific research and development
M73	Advertising and market research
M74-M75	Other professional, scientific and technical activities; veterinary activities
N	Administrative and support service activities
O84	Public administration and defence; compulsory social security
P85	Education
Q	Human health and social work activities
R-S	Other service activities
T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
U	Activities of extraterritorial organizations and bodies