Internal working document summarizing the results of the desk research

Deliverable 1.2.

Project: Implications of deep decarbonization of the high emission industries on labour market and employees (DEEPLAB)

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Contents

Introduction

This document introduces the motivation for conducting the research, the sources we used, and the model. It also outlines the detailed methodology for the project's further activities. Before the model can be implemented, we identify relevant sectors and scenarios for the analysis. This document is an internal document of the project DEEPLAB.

The DEEPLAB project responds to the economic and labour market consequences of climate change, especially by mapping the consequences for the workforce in the hard-to-abate industries and their supply chains in Slovakia.

The project aims to widen knowledge by distinguishing the future demand for different qualification levels of employees in hard-to-abate and emerging sectors tackled by decarbonization. Thus, it offers a detailed view of the future labour market developments in the Slovak industry under different pathways of deep decarbonization. The project aims to contribute to the debate on economic transition and its consequences on labour by developing the multi-regional structural model IMPACTECH of deep decarbonization.

The project has two main research questions:

- What are the consequences of decarbonization on the labour market under different technology implementation scenarios?
- What is the impact of the stakeholders' involvement in the quantitative modelling, and what policies can be derived from the modelled scenarios?

The aims of this internal report are (1) to identify sectors which will decarbonize and at the same time have significant impact on employment, (2) identify relevant technologies for the decarbonization and the decarbonisation pathways, (3) suggest scenarios for the modelling, (4) suggest the data categories which we will try to gather with the stakeholders in the interviews, and (5) suggest the outline of the semi-structured interviews with the stakeholders and (6) suggest the scenario for co-creative workshops.

The work on the model stems from a similar study conducted for Europe and for Czechia (Černý et al., 2021, Černý et al 2022), but it is revised based on the new research findings in technology implementation advancement and accounts for the specifics of the Slovak economy. The model will use the most recent data.

The Paris Agreement aims to limit the global average surface temperature rise to below 2°C, preferably to 1.5°C, above pre-industrial levels. The decarbonisation of the economy thus remains in 2024 the urgent and relevant goal of the policies and businesses, framed in the European Union by the European Green Deal, which induces the deep decarbonisation policies based on technological innovations in different sectors to reach a climate-neutral economy (European Commission, 2019).

Decarbonising the industry and energy sector is necessary to slow climate change. It requires decreasing CO2 emissions from production and consumption to the lowest possible level. The strategies to decrease emissions are unclear, and scenarios for studying the optimal ways are necessary to develop for different areas of human activity. Moreover, most of the decarbonisation policies focus on investments and technical measures to reduce emissions, while less attention is paid to the societal and labour market impacts (Lecocq et al., 2022a).

The transition can be summarised in five key steps (Černý et al., 2022):

1. Efficient use of energy and resources, including circular economy principles.
2. Transformation of the energy sector to a high share of renewable sources.
3. Electrification of industrial production, assuming decarbonization of the power sector.
4. Use renewable fuels and sustainable raw materials—such as biomass, green hydrogen, or e-fuels—for processes that cannot be fully electrified.
5. Deployment of carbon capture and storage (CCS) for emissions that cannot be eliminated otherwise.

The first two steps rely on well-established technologies with relatively well-understood economic and structural impacts, though their implementation remains capital-intensive and requires significant infrastructure transformation. From step three onward, the necessary technologies are often still in early stages of commercial viability, making their broader effects on industrial sectors uncertain.

This study primarily focuses on implementing technologies from steps (2) to (4) in the deep decarbonization pathway. Carbon removal and storage technologies (step 5) are also included in some modelled decarbonization strategies.

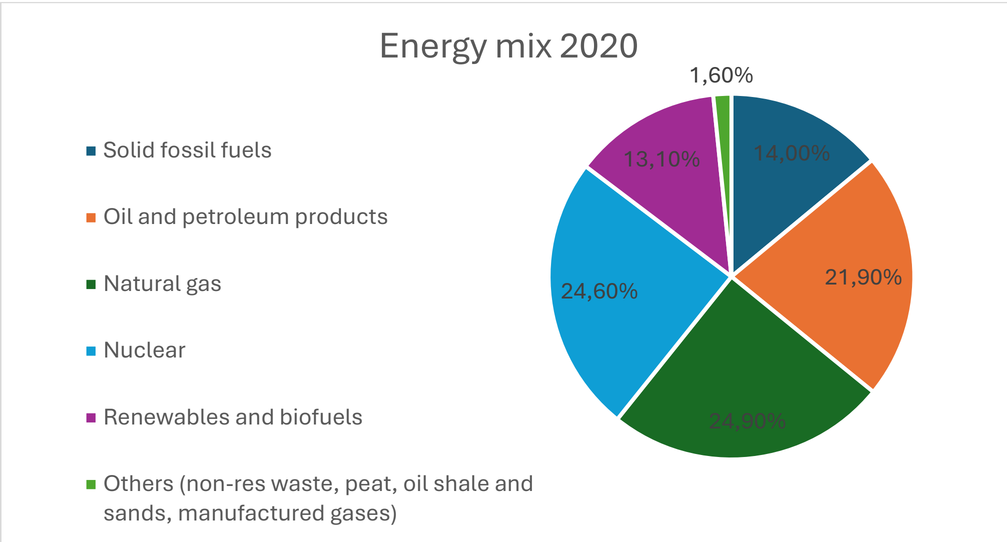
In the text, we first introduce the state of the art of the decarbonisation targets in Slovakia and the primary emission sources. Then, we identify sectors to be further analysed based on their levels of emissions and employment. In the following section, we identify relevant technologies for decarbonization and the decarbonization pathways in the selected sectors based on the desk research. In the next section, we introduce the method of modelling and the method of data collection from the stakeholders, as well as a scenario for co-creative workshops.

1. State of the art of the decarbonisation of the Slovak economy

Slovakia has significantly decarbonised during the past three decades. Apart from the closure of significant emitters, the inflow of foreign manufacturing companies in the 2000s led to the modernisation of outdated factories or the building of new energy-efficient plants. Even though Slovakia's economy's carbon intensity is significantly above the EU average, it has fallen faster than the EU average. (Erbach, 2021).

Slovakia´s energy mix is mainly based on nuclear power, gas, and oil. This is primarily due to the heating sector and transportation. Solid fuels constitute 14% of the total and are used in the heating industry and by households. Renewables constitute 13% of the energy mix, and their share is expected to increase.

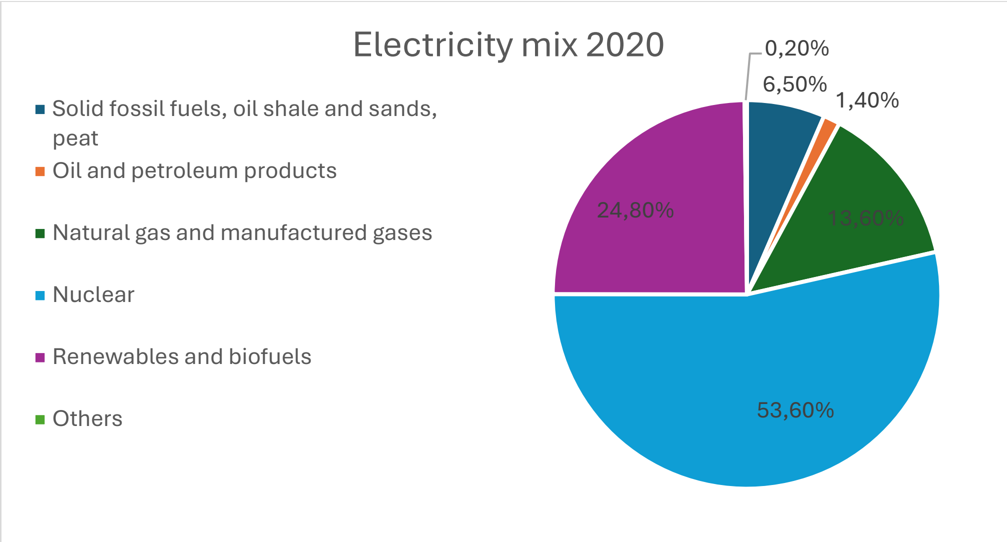
Figure 1Energy mix in the Slovak Republic in 2020.



Source: own compilation based on the EIA (2023)

On the other hand, Slovakia has a very high share of low-carbon electricity at 85% in 2023, which will increase with the opening of the fourth block of the Mochovce nuclear power plant. (IEA, 2024a). Nuclear energy accounted for 53,6% in 2023 in electricity generation, followed by hydropower with 16.4% (IEA, 2025). After decommissioning the coal power plant in Nováky, fossil fuels will only play a minor role in the electricity generation mix, at 5.7% in 2023. Nuclear power generation is regarded as the main lever for further decarbonisation, and small modular reactors are expected to play a role in the future (IEA, 2024).

Figure 2: Electricity mix in Slovakia in 2020



Source: own compilation based on the EIA (2023)

Decarbonisation targets

Slovakia's most crucial decarbonization scenario is set in the National Energy and Climate Plan (NECP), which outlines the country's strategy for achieving its energy and climate objectives from 2021 to 2030. The plan aims to reduce greenhouse gas emissions in non-ETS sectors by 20% compared to 2005 levels (IEA, 2022). It also targets a 19.2% share of renewable energy sources in gross final energy consumption by 2030, with renewables comprising 14% of the energy mix in the transport sector. Additionally, Slovakia plans to achieve a 12% reduction in final energy consumption compared to 2020. The NECP emphasises the importance of energy efficiency, renewable energy development, and regional cooperation to enhance energy security and sustainability. Notably, Slovakia's electricity grid interconnection level is projected to reach 52% by 2030, surpassing the EU's 15% target.

Along with policy targets set in NECP, there are other predictions or projections that estimate the ideal targets for Slovakia to reach full decarbonization by 2050. Similarly, some targets are also set to 2030. Since in our model, we project the use of technologies leading to full decarbonization by 2050, we look at relevant studies predicting or projecting parameters for full decarbonization of Slovak economy.

Decarbonisation of the Slovak economy has been recently studied by Dokupilová and Repíková (2025), who, based on the Pathways Explorer model, suggested the most efficient ways to decarbonise the Slovak economy. Slovakia's decarbonisation strategy should focus on enhancing energy efficiency, expanding renewable energy, and integrating advanced technologies like carbon capture to reduce emissions. (Dokupilová & Repíková, 2025). The key target is to reduce 38% in energy consumption by 2050, increasing renewable energy use to 51%, and upgrading heating systems with biomass, geothermal, and heat pumps. Investments in smart grids and energy storage will ensure a reliable renewable energy transition. Additionally, adopting circular economy principles in high-emission sectors will minimise waste and resource use, reinforcing Slovakia's commitment to a low-carbon future (ibid).

The most difficult will be the decarbonization of industry, the transport sector and agriculture (inc. food consumption**)** (Dokupilová & Repíková, 2025). In Slovakia, hard-to-abate industries are steel production, cement production, and chemicals production. The industrial production produces 39% of GHG emissions; thus, the sector´s electrification and the implementation of new technologies such as carbon capture and storage are assumed to be inevitable if the emissions from industrial production are expected to be reduced (Dokupilová & Repíková, 2025).

Transportation is another sector with difficulties in reducing emissions in Slovakia; therefore, the NECP sets as a goal a decreasing pace of emissions increase, so that in 2030 it will increase by 29% compared to the 2005 level. The share of renewables in the transport sector should reach 14% (MH SR, 2023). To achieve a zero-emission economy by 2050, the modal split of transportation is suggested to change significantly, especially in car use, which is expected to decrease from 71,4% to 40,2%. The share of buses will increase from 8,6% to 19.4%, of bike rides from 3,4% to 11.8%, and of rail from 5,7% to 10,3% (Dokupilová & Repíková, 2025, p. 46).

Another study on Slovakia looked at priorities to decrease emissions and the societal costs, studying the marginal abatement cost curve (UHP, 2022). The study considered available technologies in terms of electrification and carbon-capture and storage (CCS) to reach 55% reduction by 2030 compared to 1990 and to reach full decarbonisation by 2050. By 2030, Slovakia is able to reach 55% decrease at the costs of 2,7 billion EUR spread across private and public spending. To reach higher reductions, steel production electrification is inevitable according to study and implementation of CCS technologies, which are however still CAPEX-intensive.

For the purpose of our model, we created a table summarizing our findings from different literature resources. For the modelling, important are expected increases in RES share in electricity production and expected shares of transportation on emissions reduction. For the overview of the main parameters discussed in available studies, see Table 1.

Table 1 Overview of decarbonization targets for Slovakia from different sources by 2030 and 2050.

	Targets by 2030			**Targets by 2050**	
	Analyza fit for 55 (EIP 2022)	NECP (2025)	Joint Research Centre (2019) Baseline scenario	(Joint Research Centre (European Commission) et al., 2019) Baseline scenario	Dokupilová & Repíková 2024 (full decarbonization)
Emissions reduction	-55% compared to 1990	-55% compared to 1990	-40% compared to 1990	-58% compared to 1990	
Emissions reduction in the current ETS sectors			-27% (c. to 2005)	-54% compared to 2005)	
Emissions reduction in non-ETS sector (also called ESD – effort sharing sectors)	+7% if WEM; -22,7% if WAM, compared to 2005	- 20% compared to the 2005 level	-8% compared to 2005)	-26% compared to 2005)	
Share of RES in energy production	23-24%	19,2% (23%)	14,7%	26,9%	
Share of RES in electricity production			25%	46,5%	51% compared to 1990
Final energy production		-12% compared to the 2020 level			
Final energy consumption	-4%	-28% compared to 1990	-23% compared to 1990	-25% compared to 1990	-38% compared to 1990
Nuclear energy share of energy consumption	60%				
Final electricity consumption					+83%
Final electricity consumption					Industry 40%, Buildings 32%, Transportation 17%

Transportation		29% increase compared to 2005			60% electricity consumption, 20% biofuels, the rest hydrogen and e-Fuel
Buildings					Decrease in energy demand by 40% (26.4TWh in 2050), 73% reduction in heating

Source: own compilation based on the above-mentioned sources

1.1. Effects of decarbonization on employment in the literature

In the DEEPLAB project, we aim to analyse the employment effects of the deep decarbonisation in Slovakia. Therefore, in the following part, we summarise studies dealing specifically with the employment impacts of decarbonisation on the whole economy and specific sectors such as the energy sector and its subsectors or the automotive sector.

There are few studies analysing the impact of the decarbonisation of the Slovak economy on the labour market. The most important from the policy-making perspective is the Slovak NECP, which is backed by the CGE macroeconomic study incorporating the Compact-PRIMES model for Slovakia with other macroeconomic indicators to simulate impacts of measures on the economy, including the labour market. The model implies that measures previewed in the NECP to mitigate climate change will decrease aggregate labour demand in 2040 by -0,8%, in 2045 by 1,2% and by -1% in 2050. This, in effect, will reduce real wages by almost 10% by 2050 compared to the baseline scenario (MH SR, 2023).

Besides the impact study of NECP on the whole economy, few studies look at the impact of decarbonisation on specific sectors such as renewable energy source installation and maintenance or the automotive industry. The Slovak Association of Sustainable Energy (SAPI) published a study in 2024 on employment demand induced by the increased installations of renewable energy sources, including solar, wind energy, and heat pump installations. (SAPI, 2024)Distinguishing between direct, indirect, and induced job creation, it combines the employment factors approach with input-output modelling. The study expects around 50% of the jobs created in the RES sector by 2030 if the policies set in the NECP scenario hold. 43% of the jobs created are for heat pump production, installation, maintenance, and sales, 29% are for windmills, and 29% are for photovoltaic panels and their value chain.

The employment factor of the installed capacities is the ratio between the number of full-time equivalents and megawatts of installed capacity. The Slovak study suggested the employment factor for solar installations at 9.17 FTE/MW, and 4,49 for wind power installations in the whole value chain (see Table 2). RES are expected to create more jobs in the phase of installations and in the maintenance (Hille & Möbius, 2019; Ram et al., 2020), but in the case of Slovakia, the wholesale trading is the main source of employment in the value chain, along with imports and installations (see Table 2).

Table 2 Employment factors of wind and solar energy installations

	Solar 2030	Wind 2030
Import	2,9	0,2
Manufacturing	1.08	0
Wholesale	3,62	0,48
Customer sales	0,64	0,48
Installation	1,71	1,79
O&M	0,26	1,53

Total	9,17	4,49

Source: SAPI (2024)

Geographic displacement might be an important factor in energy transformation, determining its locally specific effects. (García-García et al., 2020)The literature also highlights that RES and other low-carbon sources are capital-intensive energy sources, which will boost employment levels and electricity prices to some extent. Thus, the net effects are expected to be positive for the energy sector, although prices might increase.

Another sector study estimated the employment effects of the energy sector transition in the EU countries in a hypothetical scenario of deployment of 100% of renewable sources (Černý et al., 2021). For Slovakia, the transformation of the energy sector to 100 % renewables would mean an increase in workplaces by 216 % by 2030, compared to 2015 and by 165 % by 2050. The EU 2016 reference scenario also suggests a positive effect on employment, but in lower terms, predicts an increase by 31 % in 2050 compared to 2015 employment levels.

For the purposes of our study, we will use as a starting point data from Černý et al (2021) and combine it with the above-cited SAPI study from 2024 for the data on employment factors (seeTable 3). These can, however, be further revised during the interviews phase.

Table 3 Jobs in the energy sector per MW installed for Slovakia

Energy type	**Net Installed Capacity in MW (EU Reference Scenario 2020)**	**(Direct) Employment in 2020 (Exiobase)**	**Employment factors per MW of installed capacity**
Production of electricity (all)	6707	23226	3,46
Production of electricity by nuclear	1940	13457	6,94
Production of electricity by biomass (Waste)	766	315	0,41
Production of electricity by hydro - total (excluding pure pumping)	1608	2326	1,45
Production of electricity by wind (onshore)	6	3	0,57 (4,49 in 2030 based on SAPI, 2024)
Production of electricity by wind (offshore)	0	0	0
Production of electricity by solar	537	668	1,24 (9,17 in 2030 based on SAPI, 2024)

Production of electricity by geothermal	0	0	0
Production of electricity by coal (solid fossil fuels)	944	4162	4,41
Production of electricity by petroleum	84	311	3,7
Production of electricity by gas	823	1729	2,1

Source: own compilation based on Černý et al (2022), Table 1

For the **automotive industry**, in 2022, Globsec Slovakia, in collaboration with Cambridge Econometrics and the Slovak Electric Vehicle Association (SEVA), suggested that the business-as-usual scenario would mean a 10 % drop in GDP compared to the best-case scenario and 4,5 % decrease in the employment level compared to 2020. The best-case scenario means that batteries for electric vehicles are fully produced in Slovakia for automakers based in the country. In that case, the drop in employment would be only 0,3% but this would require significant investments into battery production and EVs facilities. Slovakia is heavily dependent on the automotive industry, as the sector contributes by 13% of GDP, 54% of industrial production (compared to 33 % in Hungary and 31 % in Czechia), 33 % of industrial exports and 10% of the employed population (approximately 275 000 jobs between Tier 1 (177 000) and Tier 2 and services with 98 000 jobs). Capital intensities and expected production volumes will be further investigated during the interviews.

2. Identification of relevant sectors

Any choice of novel technologies first requires the selection of industrial sectors subject to deep decarbonisation. In selecting specific sectors, we looked at three primary indicators:

- the importance of a specific sector in any further production
- the total of the current employment of the sector, and
- the level of its current carbon emissions.

To select relevant sectors of economic activity with hard-to-abate emissions, we thus consulted academic and professional literature in combination with available data sources, both from the EXIOBASE database and the Slovak National Inventory Report for 2024. It is also important to note that since the selection criteria are focused on the current levels of employment and emissions, we can not include sectors with potential to grow. A specific case is **the manufacturing and maintenance of heat pumps**, which is an important production sector that will contribute to decarbonisation, but it does not fit the focus of our study, because it is not hard to abate industry. **In the future, the sector´s employment potential should be studied separately.**

Academic and professional literature is conclusive on sectors which are difficult to decarbonise, and at the same time they are important because of producing basic key inputs into the production of other sectors, as well as the non-negligible numbers of employees within these sectors which are: steel industry, the chemical industry (plastics and fertilisers), the production of cement, production of energy, and the automotive sector (BCG, 2021; Witecka, 2020; Material Economics, 2019). Production within all these sectors is notably quite energy-intensive, while simultaneously contributing to global greenhouse gas (GHG) emissions substantially (Diesing et al., 2025). Moreover, the specificity of the automotive sector is its position in producing automobiles as one of primary means of mobility, where the use of currently dominant technology (internal combustion engine vehicles) produces a significant amount of greenhouse gas emissions during their life cycle (Searle et al., 2021).

In the Slovak context, these sectors likewise emit significant emissions while providing substantial employment across the country. Despite considerable efforts of the industry to decarbonise, Slovak industry has still high emission intensity, accounting for 39 percent of national emissions (Dokupilová & Repíková, 2025). The study specifically highlights several hard-to-abate industries, including the metal and steel industry, chemical and petrochemical industries, the cement industry, and the automotive industry, among others, as industries of interest for decarbonisation (Dokupilová & Repíková, 2025). Given the presence and importance of the paper industry, we have included also paper production industry.

Concurrently, these sectors represent major loci of employment in the context of Slovakia. This is visualised in Table 4.

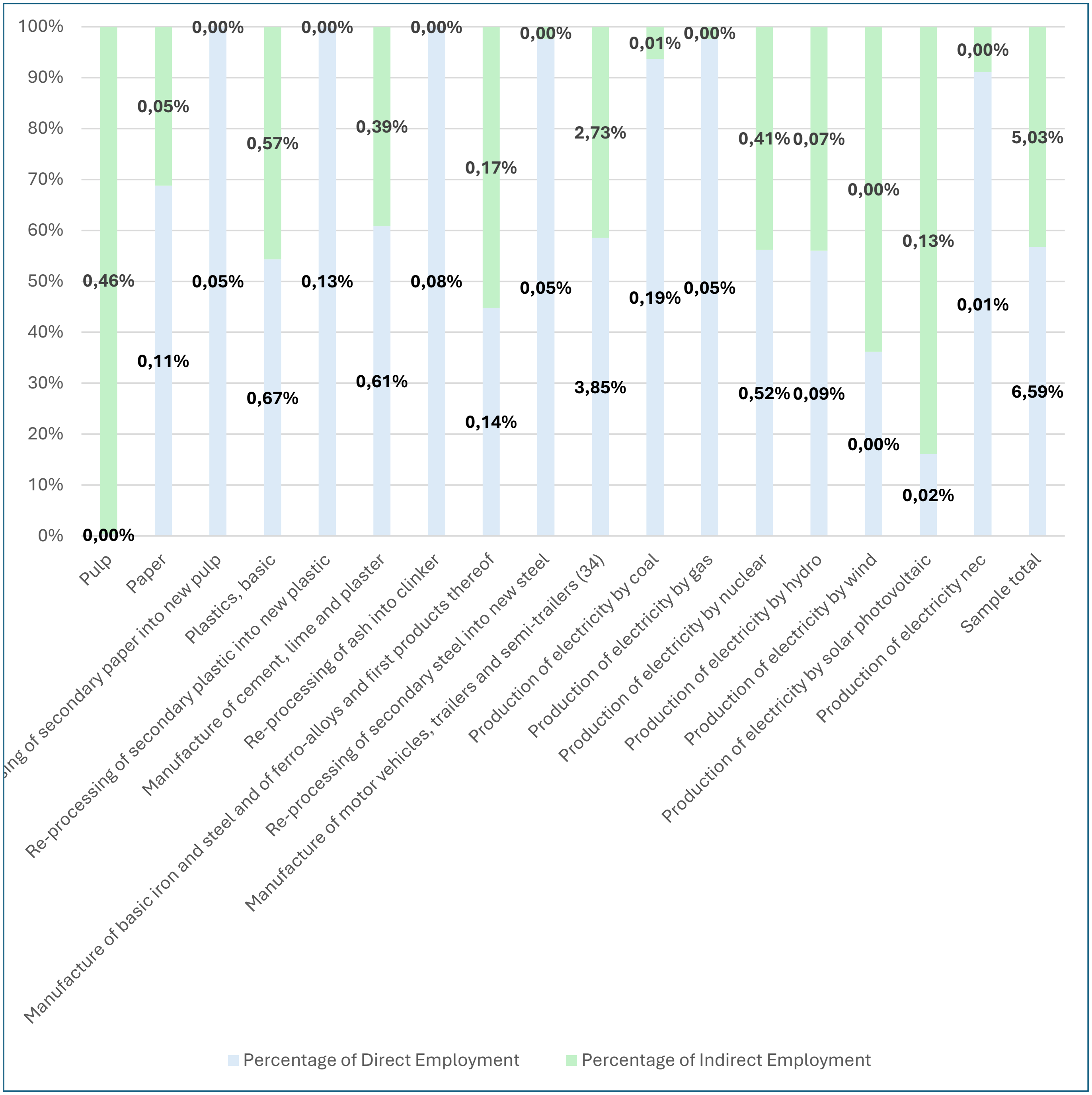
Table 4 Employment and GHG emissions in the hard-to-abate industries (2023)

Economic activity	**Employment**	**Percentage of total employment**
Industry Total	**387 822**	**14,82%**
Manufacture of motor vehicles	74 763	2.86%
Manufacture of chemicals	6 937	0.27%
Manufacture of basic metals	20 927	0.80%
Manufacture of other non-metallic products	12 791	0.49%
Electricity, gas, steam supply	15 971	0.61%
Manufacture of paper and paper products	6 765	0.26%

Source: Slovak Statistical Office (2024) *and own calculations*.

Moreover, the latest version of the EXIOBASE database from 2020, used as a central source of data within our analysis, provides a more detailed look at both the share of employment and emissions in a more detailed subdivision of direct and indirect employment. The indirect employment includes employment identified along the value chains (upstream and downstream) (see Figure 3)Figure 3 Direct and indirect employment in sectors of focus in Slovakia (as percentage of total Slovak employment in 2019).

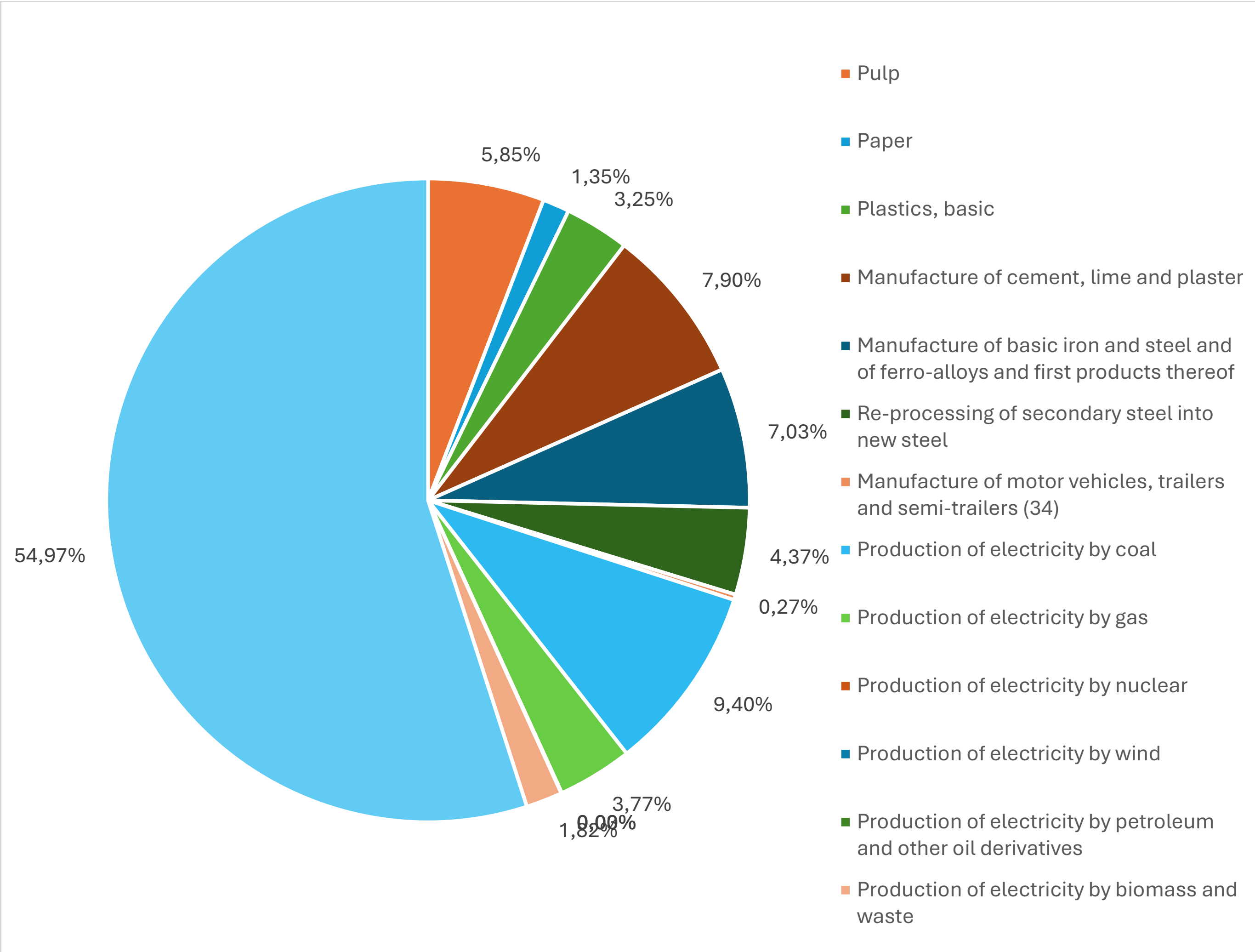
Figure 3 Direct and indirect employment in sectors of focus in Slovakia (as percentage of total Slovak employment in 2019)



Source: Own calculations, based on EXIOBASE, v.3.9.4 (Stadler et al., 2018).

In the following Figure 4 we show the composition of emissions in the covered sectors as a percentage of all emissions reported in the EXIOBASE for Slovakia. In our study, we plan to cover 45% of emissions from energy production and industrial production in Slovakia. For detailed contribution of our sectors of interest, see Figure 4. Detailed tables are in the Annex 1 of this report.

Figure 4: Direct CO2 Emissions of covered sectors as a percentage of total Slovak CO2 emissions in EXIOBASE.



Source: Own calculations, based on EXIOBASE, v.3.9.6 (Stadler et al., 2018).

To summarise, data from EXIOBASE showcase that most of the hard-to-abate sectors focused on within the deep decarbonisation literature together account for approximately 6,59% of direct employment in Slovakia. Indirectly, they account for approximately 11,62% of Slovak employment (for details see Table 13 and Table 14 in the Annex 1). In terms of CO2 emissions, the sectors together account for approximately 45,03% of total Slovak CO2 emissions and both directly and indirectly contribute to circa 53 per cent of emissions. This underlines their key position as major sources of both employment and emissions in the context of Slovakia. A particularly notable position is held here by the automotive sector, which represents the largest portion of both direct and indirect employment within the selected sectors, with a relatively lower share of emissions stemming from production.

3. Identification of relevant technologies for different sectors

This section presents selected low-carbon technologies available for individual modelled sectors to decarbonise. In the modelling, we use the principle of studying the impact of decarbonization at the source, thus the exploration of available technologies is at the heart of our work and input into the model. The technologies discussed here are selected based on the concept of the Technology Readiness Level (TRL), which is a scale used to assess the maturity of a technology, from initial concept to full commercial deployment. It consists of nine levels, ranging from TRL 1 (basic research and idea formulation) to TRL 9 (fully operational and proven technology in real-world conditions)(IEA, 2024b).

- **TRL 1-3:** Early-stage research and proof of concept.
- **TRL 4-6:** Prototype development and testing in controlled environments.
- **TRL 7-9:** Demonstration, validation, and full-scale commercial application.

The selection of technologies is based on the International Environmental Agency (IEA) and its interactive database of assessment of technologies supporting the decrease in emissions. The ETP Clean Energy Technology Guide (IEA, 2024b). In general, our research includes technologies between 4 and 9, but mostly those reaching full maturity and adoption, because early-stage technologies represent an insecure path to decarbonization. We apply the principle of studying the impact of decarbonisation at the source.

Other sources used for technology selection were chosen based on detail, relevance, and thematic scope. The selection focused on studies that explore the potential application of these technologies by 2050, aligning with this study's timeframe and ability to analyse the cost structure of the respective production processes, ensuring their applicability in constructing the IO model used in this study.

Technological changes are modelled by inserting novel technological processes within the framework of the input-output model. These technological production functions represent the operating expenditures associated with industrial production and allow us to capture the diversity of inputs and demand for inputs from other sectors for each novel modelled technology. The different structure of inputs interacts with the extension data to alter relevant data; for instance, the demand for labour in terms of skill and gender.

Subdividing each sector to include novel production technologies, we utilise technology-specific production functions constructed through operational expenditure data. This data is combined with concordance matrices, linking operational expenditure items for each novel modelled technology to corresponding industrial sectors as per the NACE rev.1 division. In doing so, we construct the technological production functions for these sectoral subdivisions.

Because of their notable position in relation to employment and emissions, we will explore diverse scenarios of implementing low-carbon technologies and their implications for employment and the labour market in these sectors.

Regarding the choice of technology, we have conducted a relatively extensive literature review on low-carbon technologies and their overall technological readiness for implementation in production.

The following subsections cover each sector and the possible low-carbon technologies that may be implemented within it to lower carbon emissions.

3.1. Electricity generation sector (NACE 19, 35)

In terms of technology availability, we model decarbonisation of the energy sector on well-known and widely used technologies of renewable sources and low-carbon sources. In general, the energy sector is relatively easy to decarbonise by 2050 if the availability of technologies is considered; however, this is limited by the available capital. Thus, the primary attention should be paid to achieving the optimal mix of available technologies and their capital intensity. In practice, the mix of renewables and low-carbon technologies is considered.

The demand for electricity is expected to grow by 20–120% by 2050 and 120–440% by 2100 (Bistline & Blanford, 2021). Furthermore, electricity is expected to supply 25–45% of total energy demand by mid-century and potentially up to 70% by 2100 (Bistline & Blanford, 2021). For Slovakia to fully decarbonise, the expected increase in electricity consumption is by 83% to reach full decarbonization by 2050 (Dokupilová and Repíková 2025).

The literature discusses the main dilemmas related to energy sector decarbonisation, mostly with respect to the share of renewables from the sun, wind and water. The literature review recognised the **two main approaches** to reducing carbon emissions in the electricity sector (Alotaiq, 2024):

1. One that primarily or entirely relies on variable renewable energy sources (VRES), such as wind and solar power, with support from energy storage (Aghahosseini et al., 2020; Barasa et al., 2018; Bogdanov & Breyer, 2016; Child et al., 2019; Hrnčić et al., 2021; Jacobson et al., 2017; Kroposki, 2017)
2. Or the second, which relies on a broader range of low-carbon resources (LCS) such as nuclear, geothermal and biomass, combined with mitigation technologies such as carbon-capture and storage for fossil fuel resources (Alotaiq, 2024)

According to Alotaiq (2024), the literature consensus is that the increase in the shares of VRES above 80% poses challenges related to the instability of the resources and associated electricity grid transmission capacities and the need for electricity storage capacities, which is a costly solution. At the same time, it is emphasised that the higher the share of VRES implemented, the higher the emissions reduction.

The drawbacks of the LCS are:

- Immature phase of carbon capture technologies (still in the demonstration phase) (Duan et al., 2022; Wang et al., 2021).
- There are concerns about net life-cycle GHG benefits (Thakur et al., 2014)
- Hydroelectric power is geographically limited and carries environmental impacts, and conventional geothermal energy is restricted to specific locations (Botelho et al., 2017). However, but of these sources are available in Slovakia and are possible to implement
- Enhanced or engineered geothermal systems, which have the potential to unlock widespread resources, are not yet commercially available (Olasolo et al., 2016).

Taking into account the drawbacks of the LCS implementation, one of the scenarios we implement is the scenario considering 100% RES implementation. Despite unrealistic in the conditions of Slovakia, it aims to capture the full employment potential of RES.

In terms of other scenarios, there is a wide variety of options; the expansion of the country's already significant nuclear sector, the further development of renewable sources of energy, including hydro, solar, wind, and geothermal power generation. All of these represent viable and mature or almost mature options in terms of decarbonisation of the Slovak energy sector, and thus, all are included to varying degrees as part of the scenarios we adopt in our analysis.

3.2. Iron and Steel industry

Literature on novel technologies within the iron and steel industry to enable a low carbon transition highlight several possibilities on how to achieve such transformation. These involve both primary and secondary steelmaking. This research operates both technologies radically different from today's predominant technologies of production as well as technologies more similar to the predominant ones.

Thus, technologies such as the direct reduction of iron with either natural gas or green hydrogen together with electric arc furnaces (DRI-EAF) or electrowinning constitute two alternatives, while the equipment of traditional basic oxygen blast furnaces (BF-BOF) with carbon capture and storage technologies (CCS) constitutes another (Agora Industry et al., 2024; Lopez et al., 2022; McKinsey and Company, 2022; Müller et al., 2021). Other approaches focus on less ambitious technological changes, including the substitution of key components to reduce emissions, such as using charcoal in the BF-BOF process, or biomass products that substitute coal or coke (Gielen et al., 2020; Energy Transitions Commission, 2018).

Given the time horizon of this study and its aim of focusing on significant, lasting reduction of emissions from hard-to-abate sectors, we have selected the following most-promising technologies, based on the literature and on their technology readiness level. In general, given low CO2 emissions, flexibility in utilisation of various mixtures of existing (natural gas) and novel (hydrogen) fuels in the steelmaking process, we include the H-DR EAF process (Agora Industry et al., 2024; Müller et al., 2021; Fischedick et al., 2014). Second, reflecting the possibility of a slower pace of transformation, we include smelting reduction with the use of CCS (Fischedick et al., 2014). Third, we include the integrated steel mill for reference, as well as for the 'with existing measures' scenario that we adopt as part of the modelling.

The list of these technologies may be seen in the Table 5 below:

Table 5 Low-carbon steelmaking technologies were modelled in the analysis.

Technology	Technology Readiness Level
Hydrogen Direct Reduction (H-DR) with Electric Arc Furnace	6 (Full prototype at scale)
Steel smelting with the use of CCS	7 (Pre-commercial demonstration)

Source for TRL: IEA (2024b) and Wesseling et al. (2017).

3.3. Chemical industry (ammonia for fertilisers)

A key component and major source of carbon emissions for fertilisers is ammonia, producing circa 44 Mt (Megaton) of CO_2 per year; its decarbonisation is thus a priority. (Material Economics, 2019). As with the previous industry, there are a plethora of options available, utilising electrification, low-carbon ammonia, or other means: CCS with steam methane reforming, electrification of steam crackers, or the use of water electrolysis in the production of ammonia (Boyce et al., 2024; Material Economics, 2019).

In general, water electrolysis is considered to be a key technology in the production of hydrogen for the production of ammonia, especially if utilising electricity from renewable sources (Boyce et al., 2024). In addition, green hydrogen production is actively pursued as a decarbonisation solution by one of the major Slovak fertiliser producers, Duslo Šaľa (Jenčová, 2024). Considering its pursuit by Duslo, the overall low CO_2 product, and its key position in decarbonization overall, we choose water electrolysis as one of the modelled technologies. Simultaneously, we select the use of steam methane reforming together with CCS as a second option, due to its potential to be utilised as a bridging technology during a slower pace of transformation.

Table 6 Low-carbon ammonia production technologies modelled in the analysis.

Technology	Technology Readiness Level
Steam methane reforming with CCS (high capture)	5-6 (Large prototype – full prototype at scale)
Water electrolysis	8-9 (Commercial operation in relevant environment)

Source for TRL: for SMR with CCS IEA (2024b), for water electrolysis Campo Schneider et al. (2024) and Gailani et al. (2024).

3.4. Chemical industry (plastics)

Plastics constitute a basic component of a great variety of products used in everyday life, underlining the importance of attempting to decarbonise their production process. The literature identifies a fair number of ways to achieve this goal, including alterations to the steam cracking process (decarbonised electricity, CCS, carbon-capture utilisation (CCU), electrification), use of alternative feedstocks (synthetic, biomass), or diverse types of recycling (mechanical, chemical), among other options (Gabrielli et al., 2023; Kloo et al., 2023; BCG, 2021; Material Economics, 2019; Energy Transitions Commission, 2018).

In the plastics sector, we attempt to capture a combination of all these approaches, choosing to include steam cracking with CCS, electrification of steam cracking, as well as alternative feedstocks and incorporation of recycling. These processes are then combined to varying degrees in the adopted scenarios, in line with how technologies could be used in the future in the sector (Kloo et al., 2023).

Table 7 Low-carbon technologies in the plastics sector modelled in the analysis.

Technology	Technology Readiness Level
Electrified steam cracking with CCS (high capture)	5 (Large prototype)

Alternative feedstocks (biomass, synthetic)	5-6 (Large prototype – full prototype at scale)
Recycling (mechanical, chemical)	9 (Commercial operation in relevant environment)

Source for TRL: for recycling IEA (2024b)*, for else Gailani et al. (2024).*

3.5. Automotive industry

The automotive industry has already begun its slow shift toward more environmentally friendly production through its focus on the development of, among other technologies, battery electric vehicles (BEVs), and hydrogen fuel-cell vehicles (H-FCV) (IEA, 2023; McKinsey and Company, 2022; Searle et al., 2021; Cambridge Econometrics & Element Energy, 2018). Moreover, the combination of internal combustion engine (ICE) vehicles with biofuels represents another avenue that the industry has been exploring (IEA, 2023; Searle et al., 2021). Together, these alternative technologies represent a mix of possibilities in terms of modelling.

Once again, considering the goal of deep decarbonisation and significant reduction of CO2 emissions together with technology readiness level, our analysis will focus on one technological alternative, which is being rapidly developed and improved across the automotive sector: BEVs. BEVs represent a highly developed technological option with low emissions during use, securing its place as a premier technology for mobility in the green transition.

Table 8 Low-carbon vehicle technology modelled in the analysis.

Technology	Technology readiness level
Battery electric vehicles (BEV)	8-9 (Commercial operation in relevant environment)

Source for TRL: IEA (2024b) *and Cambridge Econometrics and Element Energy (Cambridge Econometrics & Element Energy, 2018).*

3.6. Cement production

Cement is equally a basic foundational block for any construction in general and a highly-emission intensive product. There are numerous options for the decarbonisation of cement production, including electrification, CCS, recycling of fuels, substitution of various components (materials, fuels, and similar), or recarbonation processes (Marmier, 2023; Rissman et al., 2020; Bataille et al., 2018; Energy Transitions Commission, 2018).

For our study, we have chosen two alternative technologies for the purposes of modelling. First, there is the electrification of the cement kiln together with direct separation of CO2 through CCS; second, there is the use of oxyfuel together with CCS in the cement production process. Given emissions within the cement production process come to a large extent from the decarbonation process of CaCO3, there is broad agreement that CCS will play the main role in the decarbonisation of the cement industry (Quevedo Parra & Romano, 2023; Cembureau, 2020; IEA, 2020, 2019).

The first option combines the reduction of remaining emissions from fuel combustion together with direct separation that produces a pure stream of CO2 for CCS to capture. In turn, the second option uses pure oxygen to increase CO_2 concentration in the combustion chamber for purposes of CCS (Quevedo Parra & Romano, 2023).

Table 9 Low-carbon technologies for cement, lime and plaster producion

Technology	Technology readiness level
Electrification of kiln and direct separation with CCS	6 (Full prototype at scale)
Use of oxyfuel and CCS	5 (Large prototype)

Sources for TRL: IEA (2024b).

3.7. Paper and Pulp industry

The paper and pulp industry likewise plays a key role in virtually all facets of daily life. Here, plenty of technological pathways enable deep decarbonization; from alternative fuels and feedstocks, electrification, to CCS (Diesing et al., 2025; Furszyfer Del Rio et al., 2022; Onarheim et al., 2017).

For the purposes of the study, we chose the technological options outlined by Diesing et al (2025) for this sector, namely fuel substitution with biomass, electric heating combined with paper recycling, and CCS. In general, paper mills already often use biomass as a fuel substitute where possible, while CO_2 emissions only arise from paper mills where fossil fuels are used in heating (Diesing et al., 2025). Thus, clean electricity used by heat pumps or electric boilers within the industry can cut emissions significantly. Similar savings in terms of emissions apply in the case of paper recycling.

Table 10 Low-carbon technology for the paper and pulp industry

Technology	Technology readiness level
Fuel substitution with biomass	9 (Commercial operation in relevant environment)
Electric heating and paper recycling	9 (Commercial operation in relevant environment)

Sources for TRL: IEA (2024b).

3.8. Production of Aluminium

While the production of primary aluminium has been drastically reduced in Slovakia in recent years, secondary production still continues unabated. Despite this complication, we have chosen to include the sector within our modelling, as recovery of the industry could be achieved provided that energy prices decrease to sufficient levels. After steel, aluminium is the second most used metal, underscoring its importance in industrial production. In terms of the technological options identified for the decarbonisation of the sector: use of alternative anodes, electrification, mechanical vapour recompression, incorporation of clean hydrogen, or CCUS, among other processes (Diesing et al., 2025; Lovro, 2024; Mission Possible Partnership, 2022; Mission Possible Partnership & McKinsey and Company, 2022; World Economic Forum & Accenture, 2020).

Here, we choose three technologies: defossilised electricity supply with inert anodes, secondary production and recycling, and CCS. While the first option has the potential to drastically reduce emissions in the long-term, CCS represents a potential solution 'in-between' (Lovro, 2024). Recycling and secondary production can likewise help reduce emissions through an increased rate of aluminium recovery.

Table 11 Low-carbon technology for aluminium production

Technology	**Technology readiness level**
Defossilised electricity supply and use of inert anodes	9 for defossilised electricity supply (Commercial operation in relevant environment) 7 for use of inert anodes (Pre-commercial demonstration)
Hall-Heroult process with CCS	7 (Pre-commercial demonstration)
Secondary production of aluminium and recycling	9 (Commercial operation in relevant environment)

Sources for TRL: IEA (2024b).

In the case of the selected sectors mentioned above, the interviews will further finetune the selection of technologies to be considered in modelling. The important precondition for the technology to be implemented into the model is data availability regarding its capital intensity, operational costs and expected lifecycle.

4. Choice of scenarios

In practical terms, modelling different decarbonisation technologies involves edits within input-output elements and tables to subdivide existing sectors into original production technologies and novel production technologies, while adjusting their shares in production according to the modelled year. These shares will be adjusted according to the corresponding scenario that we are modelling for that particular year. In this methodology, we build upon the work of several authors (Černý & Bruckner, 2023; Černý, Bruckner, et al., 2022; Černý et al., 2021b)

For the purposes of modelling alternative technological futures, we have identified four representative scenarios of technological development toward a deep decarbonisation of hard-to-abate industries. These scenarios are modelled through several milestone years – 2030, 2040, and until the end date, 2050. The gradual development of the share of each production technology will be provided both from consulted academic sources, as well as from discussions with stakeholders and social partners. At this point of the analysis, this is a work in progress and might change during the consultations with experts and stakeholders. The scenarios are briefly described in the table below.

Table 12 Modelled scenarios with sources of assumptions

Scenario

Scenario 1: 100% renewables	
Scenario 2: CCS and nuclear/renewables mix	
Scenario 3: Recycling and nuclear/renewables mix	
Scenario 4: With existing measures (WEM)	

Source: authors

The **first scenario is called "100% renewables"** and builds upon the assumption of gradual movement to the use of 100% renewable energy (wind, hydropower, solar, geothermal). For other sectors, it assumes the use of non-CCS technologies (except for cement production, where CCS is used actively with other measures to provide for maximum efficiency in emission reduction) and some degree of recycling for technologies where it is possible. It is the only scenario where no nuclear energy is used.

Alternatively, 80% of RES is possible to assume as the largest share in electricity production, while the rest are low-carbon sources and nuclear power. At the same time, this assumes high electrification of production in the industry, supplemented by CCS in selected industries (typically cement).

The **second scenario**, **CCS and nuclear/renewables mix**, assumes a slower transformation and predicts a gradual switch to a combination of CCS and non-CCS technologies in production, together with an energy mix emphasising nuclear, wind, solar, hydropower, and geothermal electricity production.

The **third scenario is recycling and nuclear/renewables mix,** and models a maximum rate of recycling, emphasising its role within production together with relevant technologies. As with the second scenario, it focuses on a mix of non-nuclear electricity production with a large role for nuclear power.

The **fourth and last scenario** models development with existing measures previewed in NECP. It assumes changes in the adoption of technologies and presumes and changes in the energetic mix, based on the current version of NECP.

5. Modelling Approach

5.1. Input-output model

For the purposes of the project, the quantitative section utilises a simple input-output model to capture the diverse changes in employment and the Slovak labour market associated with the adoption of low-carbon production technologies.

Specifically, an input-output model refers to an analytical framework developed first by Wassily Leontief in the first half of the twentieth century (Miller & Blair, 2009). An input-output model involves a system of linear equations representing the flow of transactions from one sector of the economy to another sector for all sectors of the economy (Markandya et al., 2016; Miller & Blair, 2009). It is also accompanied by relevant data on total consumption, total output, and is often extended by detailed data covering socio-economic accounts (Miller & Blair, 2009).

As such, in this outlined form, an input-output model includes several key elements (Mundaca et al., 2015; Miller & Blair, 2009):

a) Inter-industry transaction matrix

The inter-industry transaction matrix contains information on the transactions between sectors of the economy, expressed in monetary terms. The rows represent the production of a given sector produced for consumption by all sectors within the economy of a geographical region. In turn, the columns represent the consumption of a given sector from sectors within a geographical region. It is denoted by the capitalised letter Z.

b) Final demand matrix

The final demand matrix describes the consumption of the public sector, households, non-governmental organisations, as well as capital creation, and changes in inventories and rarities. Within the utilised multiregional input-output tables, it is denoted by the capitalised letter Y.

c) Total output vector

This vector describes the total output of each sector of the economy. It is denoted by the non-capitalised letter x.

d) Extension matrix

The extension matrix contains detailed data on additional socio-economic activities or phenomena, including employment, emissions, energy-use, material-use, or land-use, among others. Moreover, it may include added-value rows, which contain information on taxes, subsidies, wages, and other relevant topics. Within the utilised multiregional input-output tables, it is denoted by the capitalised letter E.

The data for input-output modelling come from the system of national accounts and supply-use tables, covering a specific geographic area within a specific time frame. While the time frame is usually a year, the geographic scope may differ and can include a specific state, a region, or a larger geographic area.

We build upon the prior work and methodology of Černý et al. (Černý & Bruckner, 2023; Černý, Bruckner, et al., 2022; Černý et al., 2021b) Relating to the IMPACTECH project. The IMPACTECH model is a multi-regional input-output model which allows for modelling technological changes in production and their impacts upon demand for labour (Černý, Martišková, et al., 2022; Černý & Bruckner, 2023). We adapt this model to the context of Slovakia and its economic landscape and specificities, while maintaining the data source and the broad method. As such, this study utilises data from the EXIOBASE database, an environmentally-extended multi-regional input-output database (Stadler et al., 2018).

As such, we combine input-output modelling with real-world data to achieve maximum veracity in terms of results (Lecocq et al., 2022b). This involves not only the previously mentioned interviews with key stakeholders to assess the realism of the assumptions, but also consultation of data within the selected database with available data from available sources, such as Eurostat or the Slovak Statistical Office.

In line with this approach, we first gather data from interviews and data sources to check whether the assumptions adopted within the various scenarios hold true, or whether any assumptions should undergo further scrutiny. In particular, we exogenously estimate industry outputs for the followed years and followed industries, sourcing information from relevant studies and adapting it to fit the context of Slovakia. Part of this process includes adjusting the development of employment in line with current trends affecting employment and the labour market, namely digitalisation and automation. Adjusting the approach of Černý, Martišková, et al. (2022), we start with an initial prediction of the development of these trends which is then consulted with and corrected by stakeholders. This method allows for the capturing of a greater degree of detail of expected developments within each sector directly from stakeholders within the modelled industries.

Following this, we proceed with the above-mentioned subdivision of industries into alternative decarbonisation technologies, which are built through technology-specific production functions. These are, in turn, built via information from academic sources that are, once again, cross-checked and consulted with stakeholders. The subdivision of industrial sectors represents the diverse input factors which are utilised by alternative technologies (constituting alternative technology of production), which then interact with employment data to provide employment data for each new technology of production and sectors connected to it (Černý et al., 2022).

Based on the inter-industry transaction matrix Z, we create the technical coefficient matrix A, which itself serves to create the Leontief matrix L. Each column of the technical coefficient matrix A represents an individual technical production function for each of the sectors. In turn, the Leontief matrix is also known as the *Leontief inverse* or as the total requirements matrix, representing the total requirements of output for satisfying an additional unit of final demand (Miller & Blair, 2009). The process for this operation is described in *Formula 1* and *Formula 2*.

$$A = Z(\hat{x})^{-1}$$

(1)

$$L = (I-A)^{-1}$$

(2)

This matrix is itself used to calculate the effects of changes in production on selected indicators. To calculate these changes, our approach works by creating the intensity matrix M using the extension matrix E which represents the intensity of followed indicators per unit of output. Specifically, the indicators are employment by skill level (high-, medium-, low-skill), gender, consumption of fixed capital, and other relevant indicators. These interact together with the vector of total output, denoted as x. *Formula 3* shows this interaction:

$$M = E(\hat{x})^{-1}$$

(3)

L interacts with elements *m* of the intensity matrix and with estimated outputs for each modelled year. Each element of the intensity matrix represents the followed indicators (*d*) for each sector (*j*). *Formula 4* shows how the footprint is calculated from this interaction.

$$R^t_d = m^j_d L x^t$$

(4)

In other words, results (*R*) for each followed indicator (*d*) and sector (*j*) within each followed year (*t*) are the result of interaction of elements of the intensity matrix for each followed indicator (m^j_d), the Leontief matrix (*L*) and the total output vector for each followed year (x^t).

5.2. Limits of the chosen methodology

While input-output models in general constitute a powerful tool for the estimation of direct, indirect, or induced effects of various final demand or output changes upon the economy, they are not without their limitations. In this section, we shortly highlight some of such limitations of our adopted approach. The primary issues, as highlighted by (Černý et al., 2021b; Duchin, 1998; Markandya et al., 2016) and others are as follows:

1. **Unlimited production capacities (unconstrained supply) -** Given the nature of input-output tables, there is no specification of constraints upon the production capacities of each sector. As long as a particular output is deemed possible by the authors, this can be represented within the model. Within our approach, we seek to partially overcome this limitation through qualitative data gathering, through which we will receive direct input from stakeholders on, among other information, the viability of assumptions for production.

2. **Fixed structure of inputs** – The structure of inputs into a particular sector to produce a particular level of output does not change within an input-output table. Broadly, this means two things: a) homogeneity of production technology across the industry, b) lack of change of this production technology over time. We partially address this issue through modelling concrete technological alternatives as specific sectors within the model, with their own structure of inputs that informs production. In addition, these are likewise informed by stakeholder interviews and co-creative workshops, allowing for a measure of realism and use of real-world data.

3. **Fixed relationship between amount of goods and price –** The price for one unit of industry output will always remain the same. In practical terms, this disallows for accounting for certain phenomena, such as inflation or sudden shocks. For this reason, the prices for goods and services within the model always correspond to the prices of the starting year.

This combination of factors necessitates high attention of the researchers in the process of data collection and selection. Given the fixed structure of inputs, selection of decarbonisation technologies must be undertaken with particular care to at least attempt to somewhat accurately predict future technological trends.

Moreover, data interpretation must always be undertaken in reference to the prices of the original year of the analysis, as well as with care in regard to the total number provided by the model. As the model only approximates the results based on mathematical equations and cannot account for unexpected events, rapid technological innovations or developments, or other associated factors, the results may be slightly under- or overestimated. Despite this, the results provide a useful indication of possible future trends and their development, given the defined parameters.

6. Stakeholders interaction methodology

In this part we suggest data categories which we will try to gather with the stakeholders in the interviews, and suggest the outline of the semi-structured interviews with the stakeholders and suggest the scenario for co-creative workshops.

6.1. Interviews

During interviews, we use supportive material in the form of tables, graphs and visualisations of scenarios to support our debate about the modelling. We use semi-structured interviews and the questionnaire thus can be extended by additional questions during the interview. Interviews are recorded and transcribed, and notes are taken during the interviews. Interviews last between 30 to 60 minutes and are conducted online or in person. The structure of the interview evolves around four topics:

1. What are the implications of the presented scenarios in the given sectors for the respondent
2. What are the recent developments in the industry and what policies are developed to help employees to successfully undergo the transformation process
3. What are the barriers to speed up transformation
4. What are the needs of labour heading the industry decarbonization and digitalization.

Interview questionnaire - experts:

1. **Methodology:** We explain the methodology and approach to sector selection:
   - Do you consider selected sectors relevant? Why yes, if no, what can be added?
   - Where do you see the biggest obstacles to decarbonisation in the selected sectors? Why?
2. **Scenarios:** We show proposed scenarios, highlighting issues we have to select scenarios and its assumptions:
   - Which scenario do you consider the most probable when it comes to decarbonisation?
   - Which would be the one you would consider ideal in the case of Slovakia?
   - Which is the most important to analyse/compare/interest you the most?
3. **Labour impacts:** We show what impacts we have found in the literature (and sources).
   - Do you know about relevant studies that analyse decarbonisation impacts on labour?
   - Which scenario do you expect to have the highest impact on labour? In what sense (quantity – demand, or quality – requalification)
4. **Policies and barriers:**
   - What are the barriers to speeding up transformation?
   - What policies would you consider important to implement?
     - What policies are developed to help employees successfully undergo the transformation process?

- What would you recommend workers to do to be employed in the decarbonised economy?
-

Interview questionnaire – industry practitioners:

1. **Methodology:** We explain methodology and approach to sectors selection**:**
   - Do you consider selected sectors relevant? Why yes, if no, what can be added?
   - Where do you see the biggest obstacles to decarbonisation in the selected sectors? Why?
2. **Current state of the art in a specific sector:**
   - How do you perceive the development? What technologies are the most probable to be implemented, and what are the biggest obstacles
   - Are you able to provide some of the following information for technologies considered?
     - **Renewable energy sector** – approximate operating expenditures, and capital expenditures, more detailed employment figures – labour composition and future development, wages, impact of automation/digitalisation/robotisation.
     - **Automotive sector –** approximate operating expenditures (at least percentages), capital expenditures (at least approximate percentages), impacts of automation/digitalization/robotization.
     - **Chemicals sector -** approximate operating expenditures (at least percentages), capital expenditures (at least approximate percentages), impacts of automation/digitalization/robotization. Scenario assumptions – what should we alter?
     - **Basic plastics sector -** approximate operating expenditures (at least percentages), capital expenditures (at least approximate percentages), impacts of automation/digitalization/robotization.

3. **Scenarios**: We show proposed scenarios, highlighting issues we have to select scenarios and its assumptions:
   - Which scenario do you consider the most probable when it comes to decarbonisation?
   - Which would be the one you would consider ideal in the case of Slovakia?
   - Which is the most important to analyse/compare/interest you the most?
   - Development of the sector and external conditions relevant for its development in the next years, until 2050.

4. **Labour impacts:** We show what impacts we have found in the literature (and sources).
   - What is expected labour impact in your sector, by 2030 and 2050?
   - Show current labour compositions and discuss:
   - What is the expected labour composition by 2030 and by 2050?
   - Do you know about relevant studies that analyse decarbonisation impacts on labour?
   - Which scenario do you expect to have the highest impact on labour? In what sense (quantity – demand, or quality – requalification)

5. **Policies and barriers:**
   - What are the barriers to speeding up transformation?

- What policies you would consider important to implement?
- What policies are developed to help employees successfully undergo the transformation process?
- What would you recommend to workers to retain employment in the decarbonised economy?

Interview questionnaire – labour experts

1. **Methodology:** We explain the modelling methodology and approach to sector selection:
   - Do you consider selected sectors relevant? Why yes, if no, what can be added?
   - Where do you see the biggest obstacles to decarbonisation in the selected sectors? Why?
2. **Scenarios:** We show proposed scenarios, highlighting uncertainities we have to select scenarios and their assumptions:
   - Which scenario do you consider the most probable when it comes to decarbonisation?
   - Which would be the one you would consider ideal in the case of Slovakia?
   - Which is the most important to analyse/compare/interest you the most?
3. **Labour impacts:** We show what impacts we have found in the literature (and sources).
   - Do you know about relevant studies that analyse decarbonisation impacts on labour?
   - Which scenario do you expect to have the highest impact on labour? In what sense (quantity – demand, or quality – requalification)

4. Policies and barriers:
   - What are the barriers to speeding up transformation?
   - What policies you would consider important to implement?
   - What policies are developed to help employees successfully undergo the transformation process?
   - What would you recommend workers to retain employment in the decarbonised economy?

7. Co-creative workshops scenarios

Workshops are planned for the first quarter of 2026. Thus, we propose a general aim and structure, but details will be provided before the meetings. Three workshops are planned: two in person and one online.

7.1.Workshop framework

Workshop goal:

The model is expected to identify significant changes in the labour composition demanded by the industry. The goal of the workshop will be to introduce the results of the model and collaboratively identify and develop promising strategies and policy solutions to ensure a just transition for workers and appropriate changes in the education system and the system of actors' collaboration.

Sub-goals:

1. Introduce the model results to policy-makers and stakeholders.
2. Gather feedback on presented scenarios and use them as a starting point to discuss policies needed
3. Identify existing challenges in the implementation of decarbonisation policies.
4. Develop promising strategies and actionable recommendations for decarbonisation policies in Slovakia.

Workshop process:

1. Involve: Set a common ground and get participants to know each other.
2. Share: Share research results
3. Ideate: Discuss policy strategies of decarbonisation.
4. Continue: Give an outlook on what the next steps are.

Participants

- 10 persons (+ 3 project members)
- Former interviewees and beyond

Roles of the workshop team

- one person who facilitates the workshop
- one person who presents the project result & moderates the discussion
- one person who does the documentation, looks at the chat and answers technical questions

Outputs of the workshop

- Mural or PPT workshop-documentation about agreed approaches

7.2. Workshop scenario

Expected duration: 3 hours

Goal	Content & Method
INVOLVE: Welcome & Short workshop introduction Create a common understanding of the workshop goal Get to know each other	Introduction - Present Agenda - Aim of the workshop - Present the project team + workshop facilitators - Explain the background and context of the workshop (project, funding, institutional background) - Explain the co-creative approach

SHARE: Project presentation & main research findings Participants get the opportunity to clarify open questions	Research and model results presentation and discussion about results Q&A
IDEATE: Participants	Participants discuss the most promising strategies for decarbonisation policies focused on employees (and future employees)
CLOSE: Wrap up and next steps	Summarize what happened in the workshop and what were main takeaways. Outlook: - How will you use the ideas and insights in the further project – What do you plan to do with the results?

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ANNEX 1 Industries identification

The selection of modelled sectors and technologies is based on several key criteria, including their impact on emissions, employment, and data availability:

- **Considering significant technological shifts in decarbonization**, including impacts on supply chains and indirect labor demand.
- **Direct and indirect contributions to CO_2 emissions in Slovakia**, assessing their significance in overall emissions.
- **Direct and indirect employment impact in Slovakia**, evaluating sector contributions to job creation.
- **Availability of sufficiently detailed data** for the selected modeled sectors and technologies.

NACE sectors Eurostat	Employment level in ths., 2023	Share on total employment 2023
Manufacture of paper and paper products (C17)	10,4	0,41%
Manufacture of coke and refined petroleum products (19)	6,8	0,27%
Manufacture of chemicals and chemical products (C20)	12,6	0,49%
Manufacture of rubber and plastic products (C22)	32,3	1,26%
Manufacture of other non-metallic mineral products (C23)	18,8	0,73%
Manufacture of basic metals (C24)	23,7	0,93%
Manufacture of machinery and equipment n.e.c. (C28)	60,6	2,37%
Manufacture of motor vehicles, trailers and semi-trailers (C29	128,3	5,01%
Manufacture of other transport equipment (C30)	9,9	0,39%
Electricity, gas, steam and air conditioning supply (D35)	27,9	1,09%
Land transport and transport via pipelines (H49)	106	4,14%
Water transport (H50)*	2,9	0,11%
Air transport (H51)*	2,9	0,11%
Total selected	**443,1**	**17%**

Source: Eurostat

Sectors - EXIOBASE	Total (indirect and direct employment) in Slovakia in EXIOBASE (in 1000 persons)	Direct Employment in Slovakia in EXIOBASE (in 1000 persons)
Pulp	25 (1.02%)	4,286 (0.17%)
Paper	5,3 (0.21%)	2,568 (0.05%)
Re-processing of secondary pulp into new pulp	1,2 (0.05%)	1,218 (0.10%)
Plastics, basic	24,6 (0.98%)	16,293 (0.65%)
Re-processing of secondary plastic into new plastic	0	0
N-fertiliser	3,2 (0.12%)	1,906 (0.08%)
Manufacture of cement, lime and plaster	28,9 (1.15%)	16,161 (0.64%)
Re-processing of ash into clinker	0	0
Aluminum production	11,6 (0.46%)	6,055 (0.24%)
Re-processing of secondary aluminium into new aluminium	0	0
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	7,5 (0.3%)	3,554 (0.14%)
Re-processing of secondary steel into new steel	1,4 (0.05%)	1,464 (0.06%)
Manufacture of motor vehicles, trailers and semi-trailers (34)	249,7 (9.94%)	102,512 (4.08%)
Production of Electricity - All sources	32,4 (1.29%)	22,970 (0.91%)
Sum Total	**391,9 (15.6%)**	**179,242 (7.14%)**

Sectors - EXIOBASE	Total (indirect and direct) CO_2 emissions (in kt. CO_2)	Direct CO_2 Emissions (in kt. CO_2)
Pulp	1,09%	75,92 (0.35%)
Paper	0,12%	4,77 (0.02 %)

Re-processing of secondary pulp into new pulp	0,00%	0 ()
Plastics, basic	4,64%	884,95 (4.08%)
Re-processing of secondary plastic into new plastic	0,00%	0
N-fertiliser	1,71%	345,69 (1.60%)
Manufacture of cement, lime and plaster	8,79%	1235,34 (5.70%)
Re-processing of ash into clinker	0,00%	0
Aluminium production	1,02%	3,69 (0.02%)
Re-processing of secondary aluminium into new aluminium	0,00%	0
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	8,64%	1808,32 (8.35%)
Re-processing of secondary steel into new steel	2,62%	567,40 (2.62%)
Manufacture of motor vehicles, trailers and semi-trailers (34)	5,37%*	19,89 (0.09%)
Production of Electricity - All sources	19,41 %	3836,54 (17.71%)
Sum Total	**53.51%**	**8782,56 (40.54%)**

Table 13: Direct and indirect employment of covered industries in Slovakia in EXIOBASE (as percentage of total Slovak employment).

Industries in EXIOBASE	Direct employment (% of total)	Indirect employment (% of total)
Pulp	0,00%	0,46%
Re-processing of secondary paper into new pulp	0,05%	0,00%
Paper	0,11%	0,05%
Plastics, basic	0,67%	0,57%
Re-processing of secondary plastic into new plastic	0,13%	0,00%
Manufacture of cement, lime and plaster	0,61%	0,39%
Re-processing of ash into clinker	0,08%	0,00%
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	0,14%	0,17%
Re-processing of secondary steel into new steel	0,05%	0,00%
Manufacture of motor vehicles, trailers and semi-trailers (34)	3,85%	2,73%
Production of electricity by biomass and waste	0,01%	0,01%
Production of electricity by coal	0,19%	0,01%
Production of electricity by gas	0,05%	0,00%
Production of electricity by Geothermal	0,00%	0,00%
Production of electricity by hydro	0,09%	0,07%
Production of electricity by nuclear	0,52%	0,41%
Production of electricity by petroleum and other oil derivatives	0,01%	0,03%
Production of electricity by solar photovoltaic	0,02%	0,13%
Production of electricity by tide, wave, ocean	0,00%	0,00%
Production of electricity by wind	0,00%	0,00%
Production of electricity nec	0,01%	0,00%
Total	**6,59%**	**5,03%**

Source: Own calculations, based on EXIOBASE, v.3.9.4 (Stadler et al., 2018).

Table 14: Direct and indirect emissions of covered industries in Slovakia in EXIOBASE (as percentage of total Slovak emissions).

Industries in EXIOBASE	Indirect emissions (% of total)	Direct Emissions (% of total)
Pulp	0,62%	5,85%
Re-processing of secondary paper into new pulp	0,00%	0,00%
Paper	0,32%	1,35%
Plastics, basic	0,55%	3,25%
Re-processing of secondary plastic into new plastic	0,00%	0,00%
Manufacture of cement, lime and plaster	0,70%	7,90%
Re-processing of ash into clinker	0,00%	0,00%
Manufacture of basic iron and steel and of ferro-alloys and first products thereof	0,36%	7,03%
Re-processing of secondary steel into new steel	0,00%	4,37%
Manufacture of motor vehicles, trailers and semi-trailers (34)	2,31%	0,27%
Production of electricity by biomass and waste	0,01%	1,82%
Production of electricity by coal	0,04%	9,40%
Production of electricity by gas	0,00%	3,77%
Production of electricity by Geothermal	0,00%	0,00%
Production of electricity by hydro	0,15%	0,00%
Production of electricity by nuclear	0,71%	0,00%
Production of electricity by petroleum and other oil derivatives	0,03%	0,03%
Production of electricity by solar photovoltaic	0,28%	0,00%
Production of electricity by tide, wave, ocean	0,00%	0,00%
Production of electricity by wind	0,00%	0,00%
Production of electricity nec	0,00%	0,00%
Total	**6,09%**	**45,03%**

Source: Own calculations, based on EXIOBASE, v.3.9.4 (Stadler et al., 2018).

ANNEX 2 Available technologies for decarbonisation

List of selected technologies for decarbonization and expected costs comparisons

Sector	Type of production	Technology	Technology (in Slovak)	Level of readiness (in 2024)	Readiness progress since 2020	Comparison of current production costs (1 = currently the cheapest available technology)*
Iron and steel production	Primary	Integrated mill (BF-BOF) (current technology)	Integrovaný mlýn			1
	Primary	Hydrogen direct reduction (H-DR)	Priama redukcia vodíkom	6. Full prototype at scale	Stagnation	1,18
	Primary	CO2 capture (CCUS (Carbon Capture, Utilization, and Storage) in the iron smelting	Redukcia tavenia pomocou CCS	7. Pre-commercial demonstration	Stagnation	1,1
	Secondary(recycling)	Electric arc furnance (EAF)	Elektrické pece	5-6 Full prototype at scale	Improved in 2022	
Production of cement and concrete	Primary	Ordinary Portland Cement (current technology)	Bežný portlandský cement	9 Implemented technology		1
	Primary	Direct separation (CCUS)	Priama separácia (CCUS)	6-7. Full prototype at scale, Pre-commercial demonstration	No development since 2020	1,73
	Primary	CCUS with oxy-fuelling	CCUS s kyslíkovým palivom	6. Full prototype at scale	Stagnation	2,14
Plastics production	Primary	Steam cracker (current technology)	Parné krakovanie	9 Implemented technology		1
	Primary	Steam cracker electrification + CCUS + CCUS end-of-life cycle	Elektrické parné krakovanie + CCUS na konci cyklu	5. Large prototype	No development since 2020	1,33
	Primary	Use of biomass	Vstupné suroviny z biomasy	5-8 (dependent on the subsector)		1,47
	Secondary (recycling)	Solvent dissolution to extract virgin-quality polymer	Rozpúšťanie rozpúšťadlom na extrakciu polyméru v panenskej kvalite	8. First of a kind commercial	No development since 2020	
	Secondary (recycling)	Chemical depolymerisation for PET	Chemická depolymerizácia pre PET	8. First of a kind commercial	No development since 2020	
Production of fertilisers	Primary	Methane pyrolysis (for ammonia) current technology	Metánová pyrolýza (na výrobu amoniaku) – súčasná technológia	9 Implemented technology		1
	Primary	Methane pyrolysis (for ammonia) (SMR) with CCUS				1,32
	Primary	Electrolytic hydrogen-based produced with variable renewables (ammonia)		8. First of a kind commercial	No development since 2020	1,79
Paper and Pulp production	Primary	Boilers with CCUS		5. Large prototype	Available since 2022	
	Secondary (recycling)	Pyrolysis of by-product streams		9. Commercial operation in	Available since 2022	

				relevant environment		
Vehicles production		Combustion engines		9 Implemented technology		1
		Electric cars: Hybrid + Plug-in hybrid + Battery + Battery cells		8-9. First of a kind commercial, Commercial operation in relevant environment	Improved in 2022	1,45**

Source: Own compilation using data (IEA, 2024b) and based on (Černý, Martišková, et al., 2022), *Data no costs based on the (Material Economics, 2019), ** for cars (Miller, 2020; Soulopoulos, 2017)