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Investments needed for achieving climate neutrality in Austria and their economic implications

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Abstract
Achieving net zero greenhouse gas emissions until 2040 or 2050 as envisaged in different climate agreements and targets on the national and the European levels implies the socio-ecological transformation of our socio-economic system and significant investment in the industrial production processes, housing insulation, the electrification of road transport, renewable energy sources and the electricity grid. In this paper, we present investment requirements in Austria to achieve climate neutrality by 2040 or 2050, respectively, in different climate neutrality scenarios. The energy, industry, transport and building sectors play a central role. Regarding the financing of these investments, the study looks at how the instruments and framework conditions for private and public funding should be organised. One important instrument to achieve net zero emissions is an increasing emission price, together with a stable and strict climate mitigation policy framework. These emission prices may raise the operation costs of Austrian companies. We estimate the paths of operating costs for the Austrian manufacturing sector and its sub-sectors, based on projections for the CO_2 price, the prices of fossil fuels, and projections of the change in energy sources used in the different industries, e.g. the substitution of oil and gas with renewable energy sources and electricity. Then we estimate by how much the rise in energy costs impacts on the competitiveness of Austrian companies, measured via changes in exports of the manufacturing sector. The estimations and simulations until 2050 show that some energy-intensive industries come under pressure, if other important countries like the USA und China are not confronted with rising energy costs. These results are valid for the energy price paths assumed in the transition scenario towards climate neutrality. The short period of data available for the econometric estimations in combination with the long simulation horizon call for a careful interpretation of the results. Rather than stressing the quantitative

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results, the focus should lie on the order of magnitude and on qualitative interpretations. Particularly sudden and sharp increases of energy prices have the potential to impair on the competitiveness of the affected economies.

Keywords Climate change · Climate neutrality · Investment needs · Competitiveness · Working conditions

JEL Classification Q43 · Q56 · E37

1 Introduction: climate neutrality scenarios and investment needs

To achieve greenhouse gas (GHG) emissions reductions for climate neutrality envisaged in international agreements and in Austria's national targets, considerable investment will be required by 2040, particularly in industry, transport, electricity generation and transmission, and buildings. In addition, a far-reaching economic and social-ecological transformation is necessary, which raises questions of feasibility, financing and economic impacts. The investment needed to achieve the Austrian climate targets, aspects of financing these large-scale investments, as well as the macroeconomic and social consequences of achieving climate neutrality were analysed in a recent research report (Weyerstraß et al. 2024). This paper builds on this research. Specifically, it addresses climate neutrality scenarios, consequences of rising energy and investment costs on Austrian exports, as well as issues of financing the investment.[1]

Global and country-specific estimations of investment needed for achieving climate neutrality range from 1 to 4.5% of GDP. The Stern report (Stern 2007) estimated that the investment needed globally to sustainably reduce GHG emissions amount to roughly 1% of annual global GDP. More recent European estimates indicate that across the EU, an additional investment of around 650 billion euro or around 4.5% of EU-wide GDP per year is needed until 2030 in order to achieve the climate policy goals by 2030 or climate neutrality by 2050 (European Commission 2018). Methodologically, these estimations are based on climate protection and GHG emission scenarios, comparing business-as-usual scenarios with several projections with different strategies and goals to achieve climate neutrality and to restrict global warming to 1.5 °C, with a chance to omit an overshoot of 2 °C, according to the Paris agreement.

1.1 Scenarios for energy consumption and greenhouse gas emissions

The WEM (with existing measures) scenario of the Environment Agency Austria depicts the further development of energy demand and GHG emissions in Austria. Based on previous work by the Environment Agency Austria, two scenarios for

[1] In the research report, additionally social aspects were addressed by conducting interviews with employees and employers regarding impacts of the actions needed to achieve climate neutrality for work conditions. Furthermore, macroeconomic model simulations regarding implications of the climate neutrality scenarios for the income distributions were conducted. For the sake of brevity and because of the focus of this paper, these aspects are not tackled here.

achieving climate neutrality by 2040 were created as part of the project on which this paper is based: the KN40 scenario and the KN40/50 scenario Krutzler et al. (2023). Together with other legislations and subsidies, the CO_2 price is an important measure to reduce energy consumption and increase the use of renewable energy sources. A supplementary measure in the KN40 and KN40/50 scenarios is the use of carbon capture and storage/use (CCS/U) in industrial plants (of process emissions that are difficult to avoid) after 2035. In the case of waste heat utilisation, the energy required for this is largely included in the KN40 and the KN40/50 scenarios. The KN40/50 differs from the KN40 in particular due to higher GHG emissions in the sectors in the EU emission trading system (EU-ETS) in 2030 and 2040. In 2050, the emissions are the same in the two scenarios. Both scenarios achieve the target applicable to Austria for 2030 for the emitting sectors outside the emissions trading system (non-ETS). Table 1 shows the GHG emissions in scenario KN40, while the underlying assumption regarding energy and emission prices can be found in Table 2.

1.2 Investment needs

Total and additional investment needs are shown by emitting sector in Table 3. The uncertainties in the required investment were considered by specifying an upper and a lower value. Additional investment has been calculated by deducting replacement investment (e.g. new blast furnace instead of electric steelworks or hydrogen reduc-

Table 1 Development of greenhouse gas emissions in the KN40 scenario by sector up to 2050. *Sources*: environment agency Austria KN40, environment agency Austria REP-0880, environment agency Austria REP-0856

Million tonnes of CO_2 equivalent	2005	2020	2030	2040	2050
Energy & industry with emissions trading	41.6	32.4	20.5	4.3	1.8
Energy & Industry without emissions trading	5.8	5.3	3.6	0.4	0.3
Energy & Industry Emissions trading	35.7	27.0	17.0	3.9	1.5
Transport	24.6	20.8	13.7	0.3	0
Building	12.7	8.0	3.7	0.2	0.1
Agriculture***	8.3	7.9	5.8	5.3	5.0
Waste management	3.6	2.3	2.0	1.2	0.4
F-gases	1.8	2.2	0.8	0.2	0.2
Greenhouse gas emissions in accordance with the Climate Protection Act (without emissions trading)*	56.8	46.5	29.6	7.6	6.0
Total greenhouse gas emissions**	92.6	73.6	46.5	11.5	7.5

$_2$* Target 2030 in the non-ETS sector 29.6 million tonnes of CO_2-eq (CO_2 equivalent)

**GHG without consideration of the Land Use, Land Use-Change and Forestry (LULUCF) target. Use of CCS evident from 2040; the remaining emissions must be offset using LULUCF, further CCS/U, biomass CCS or Direct Air Carbon Capture and Storage (DACCS) to achieve net zero emissions. Due to the many technical, legal and financial uncertainties surrounding these offsetting technologies, a financial estimate was not meaningful. For this reason, zero was not shown in the table

*** There is no Transition scenario available for the agriculture sector, which deals in particular with the aspects of adapting production methods to climate change and the challenges of supplying food to a growing population as climate change progresses, the interactions with the higher biomass requirements of other sectors, the adaptation of support measures to climate protection requirements and adequate prices for high-quality and regional food. For this reason, no investment costs could be specified for this sector. The WAM + scenario from the Environment Agency Austria REP-0856 is shown

Table 2 Price assumptions in the climate neutrality scenario. *Sources*: European Commission, statistics Austria, environment agency Austria

Parameter	2020	2030	2040	2050
International oil price [$Euro_{2020}$/GJ]	6	15	16	20
International natural gas price [$Euro_{2020}$/GJ]	3.1	11.3	11.3	11.8
International coal price [$Euro_{2020}$/GJ]	7	7	8	8
Electricity price households/traffic [$Euro_{2020}$/GJ]	47	58–64	65–71	65–71
Electricity price industry [$Euro_{2020}$/GJ]	29	33–37	34–38	34–38
Hydrogen price [$Euro_{2020}$/GJ]	56	54–58	48–52	45–49
CO_2 price EU emission trading system (ETS) [$Euro_{2020}$/t CO_2]	24	200	400	500
CO_2 price non ETS sectors [$Euro_{2020}$/t CO_2]		200	400	500

Table 3 Total and additional investment by sectors, 2024–2040 (scenario KN40, billion euro, price basis 2024).*Sources*: environment agency austria: total investment and additional investment, Vienna university of technology: distribution between private and public sector; rounding differences are not equalised. The allocation to private and public sector refers to the lower value of total investment. Service companies and their investment costs are included in the buildings and transport sectors

Total investment							Additional investment	
	Private sector		Public sector		Total		Total	
	Companies	Households	State sector	Public enterprises	Lower value	Upper value	Lower value	Upper value
Industry	16.0	0.0	0.0	0.0	16.0	28.0	8.6	15.4
Energy	20.3	5.7	0.8	128.9	155.9	174.5	38.5	83.0
Transport	94.9	63.7	84.0	30.3	273.0	391.8	45.1	65.3
Building	30.4	230.1	22.2	21.2	303.8	438.3	10.3	15.0
Total	161.7	299.5	107	180.4	748.7	1032.6	102.5	178.7

tion; energy: renewal/maintenance of power lines, gas combined heat and power (CHP) instead of wind or photovoltaic) or investment already included in the WEM scenario from total investment.

Compared to the other sectors, industry is characterised by lower total investment needs while additional investment is comparable to the building sector. Investment in the energy sector is split almost equally between renewable energy sources and the grid infrastructure, with the much larger electricity grid dominating over the hydrogen and CO_2 grids. Total investment in the transport sector is of the same order of magnitude as for buildings. In these two sectors, additional investment is low compared to total investment. In the buildings sector, additional investment in refurbishment in the KN40 scenario is partially offset by reduced investment in new construction; the higher refurbishment rate in the KN40 requires less new construction than in the WEM scenario. Additional investment in the transport sector is based on the projection that price parity between electric cars/e-trucks and combustion vehicles should be achieved in the foreseeable future. Based on international studies, this price parity is assumed between 2028 (cars) and 2032 (trucks).

2 How to finance the necessary investment?

In the previous section, investment needed in the different sectors of the Austrian economy to achieve climate neutrality by the year 2040 were identified. There, two distinctions were made: one between total and additional investment, and one between the private and the public sectors. In the context of our study, only additional investment might put a burden on the economy, since some investment for replacing deployed capital goods would have to be made regardless of climate targets. The additional investment will partially have to be made by the public sector, and this spending may be financed by raising taxes, by reducing other spending (especially fossil investments and environmentally counter-productive subsidies), or by additional debt. Additional investment by industry might impair Austria's international competitiveness by raising investment or operating costs or by reducing profits, but operating costs would increase even more if emissions are not reduced, and hence a higher price for CO_2 emissions would have to be paid.

The existing studies consistently show that the funds required for decarbonisation are available both in the public and the private sectors, especially considering the necessary redirection of the currently still considerable fossil investment towards the socio-ecological transformation (e.g. Egli et al. 2022; Polzin and Sanders 2020; Sanders et al. 2022). Therefore, it cannot be assumed that there is a general lack of resources, but rather that the legal, institutional, political and economic frameworks for investment in decarbonisation need to be significantly improved. This includes, in particular, a strict, reliable, stringent and coherent climate protection policy that, above all, eliminates both short-term and longer-term uncertainties for private decision-makers (private households, companies) with appropriate standards. Additional investment to achieve climate neutrality in Austria requires financial means that appear manageable both in nominal terms in relation to both GDP and total capital formation in the Austrian economy. As an example, the government sector would have to increase investment by 0.3 to 0.5% in relation to GDP. Regarding financing, attention must be paid to the various framework conditions. For example, given the high budget deficit in Austria, the fiscal policy scope for higher government investment is currently virtually non-existent, but may be created by redirecting existing funds (direct spending, direct and indirect fossil subsidies) towards decarbonisation.[2] Companies may face difficulties in terms of competitiveness, if, contrary to European and international agreements, significantly lower decarbonisation investment is made in other industrialised countries with which the Austrian economy is in competition. Finally, financing may be more difficult for certain groups (e.g. households with below-average incomes, small companies) due to their individual situation (liquidity problems, socially unequal burdens, legal and institutional barriers).

[2] In addition, there might be significant economic gains from decarbonisation, such as benefits of increased human and ecosystem health.

3 Climate neutrality and economic competitiveness

As a small, open economy, Austria faces strong international competition. Changes in energy prices or high investment to achieve climate neutrality therefore influence competitiveness. This is particularly true if production costs in Austria rise relative to those abroad. Influences of environmental protection measures on international competitiveness have extensively been analysed in theoretical and empirical studies. According to the Porter hypothesis, strict environmental regulations can induce efficiency and encourage innovations that help improve competitiveness (Porter 1991; Porter and van der Linde 1995). The hypothesis suggests that strict environmental regulation triggers the discovery and introduction of cleaner technologies and environmental improvements, the innovation effect, making production processes and products more efficient. The cost savings that can be achieved are sufficient to overcompensate for both the compliance costs directly attributed to new regulations and the innovation costs.

Numerous studies have been published analysing the Porter hypothesis theoretically and empirically. Based on a literature review, Ambec et al. (2011) conclude that on the empirical side, on one hand, the evidence about the “weak” version of the hypothesis (stricter regulation leads to more innovation) is fairly well established. On the other hand, the empirical evidence on the strong version (stricter regulation enhances business performance) is mixed, with more recent studies providing more supportive results. In Andersen and Eikins (2009), the Porter hypothesis is studied. In an empirical investigation based on panel data covering 56 industry sectors throughout Europe over the period 1990–2003, it is estimated how changes in real carbon-energy taxes and real energy prices affect competitiveness measured via unit energy costs and unit wage costs and economic performance expressed in terms of value added. If the industries experience a lasting impact on unit energy costs leading to significantly lower output as a consequence of a tax-imposed increase in real energy prices, this would be a clear indication that this outcome resulted because the energy taxes reduced their competitiveness. However, the authors do not find detrimental effects of energy taxation on economic activity. Hence, the Porter hypothesis cannot be rejected in the specific case studied. Andersen et al. (2007), find that several countries increased their competitive advantage in specific sectors compared to the rest of the world during a period in which they implemented some kind of tax shifting by increasing energy-related taxes and reducing other taxes. Faiella and Mistretta (2022) are more pessimistic. They model the relationship between firms’ foreign sales and unit energy costs in a gravity model setup and find that an increase in unit energy costs reduces bilateral exports; euro-area countries show the largest negative effects. The authors claim that their empirical findings strengthen the case for establishing a global carbon level playing field such as an EU-level carbon border adjustment, or other forms of EU low-carbon exports support.

Own calculations as part of a previous research project show that other EU countries are both the most important export markets and competitors for most sectors of the Austrian economy (Reiter et al. 2024). Insofar as increased climate protection investment is undertaken worldwide, this is neutral in terms of the competitiveness of individual economies. If ambitious climate protection targets that lead to higher production costs were to be pursued in the EU, Austria's competitiveness would not be jeopardised in comparison with its most important competitors, but the EU would fall behind globally and Austria would indirectly lose out as a supplier to, e.g., the German industry which faces global competition.

The energy price paths on which the above-mentioned climate neutrality scenarios are based must therefore be seen in the context of energy price projections for other regions, particularly Asia and the USA. In general, the national climate protection scenarios are based on the assumptions regarding the price development of fossil fuels (oil, natural gas and coal) recommended by the European Commission in May 2022. The scenarios also essentially follow the EU recommendations for the CO_2 certificate price in the EU-ETS. The electricity prices, whose importance will increase significantly during the transformation, are based on assumptions regarding the electricity production costs of different technologies and their effects on the electricity price. A differentiated picture emerges internationally. While oil and coal prices are largely standardised globally, natural gas prices, at least those for gas transported via pipelines, can vary significantly depending on the region. In contrast to pipeline-bound natural gas, liquefied natural gas (LNG) is traded on global markets, implying that the price is more equally worldwide than the price of pipeline-bound natural gas. In addition to the assumptions regarding the costs of fossil fuels and the emission price, the main determining factors are assumptions regarding the implementation of climate protection measures in other countries and regions.

To the extent that increased climate protection leads to higher energy costs (e.g. via the CO_2 price) in individual economies relative to the rest of the world, this jeopardises competitiveness without implementing a border adjustment mechanism. Therefore, if the EU undertakes more ambitious climate protection efforts than other countries, this would put companies in the EU at a disadvantage compared to their global competitors. Increased climate protection in the EU should therefore be accompanied by a well-functioning Carbon Border Adjustment Mechanism (CBAM). Even if there is a CBAM, increased climate protection in the EU, which leads to higher production costs, still affects the competitiveness of the European industry. This is partly because CBAM affects the cost of imports from countries with lower or no emissions prices but not exports from the EU to other regions. European companies that face higher production costs due to CO_2 prices will therefore compete with suppliers from countries with lower CO_2 prices on third markets. In addition, there will be a redistribution of resources to the sectors covered by the CBAM. Prices within the EU rise and intra-EU trade becomes more attractive compared to extra-EU trade. Improved terms of trade (i.e., the ratio between export and import prices) lead to a real appreciation of the euro, which dampens exports in general. As a result, a measure to ensure the competitiveness of certain sectors has a negative impact on the competitiveness of other sectors in the EU (Breckenridge and Baily 2024).

It should be noted that energy is only one of several production factors. Especially energy-intensive sectors might be particularly affected by an increase in energy costs relative to other countries. For many companies, however, the availability of well-trained skilled labour is at least as important as access to cheap energy. Security of supply, i.e. the certainty that electricity and energy sources such as hydrogen or biomethane will be available almost without interruption, is also an important aspect of Austria's future as a business location.

4 Empirical investigation

4.1 Modelling approach

The main features of the empirical analysis are based on Astrov et al. (2015). There, the effects of changes in energy intensity and energy cost shares on the competitiveness of industry were measured by estimating a panel data model for the period 1995–2007. In this model, exports (intra- and extra- EU) were used as the dependent variable. The model was estimated in first differences with fixed effects for countries and industries to account for unobserved heterogeneity between countries and industries and thus explained the export dynamics of each industry in each country over time. In addition to the main variables (i.e. energy intensity and energy cost shares), the model included control variables that are commonly used to explain exports, such as labour productivity, the share of high and medium-skilled labour, capital intensity, wages, and the size of the economy. Our own empirical analysis deviates in some aspects from the approach in Astrov et al. (2015) as the wage-related variables (with the exception of unit labour costs) and the size of the economy proved to be insignificant in our estimations. Astrov et al. (2015) use total exports by manufacturing sector, i.e. not bilateral exports between country pairs. An alternative approach would be a gravity model as in Faiella and Mistretta (2022). Such a gravity model explains exports between pairs of countries by GDP in the exporting and the importing country as well as various factors affecting trade costs in a broad sense. Such factors may include tariffs, membership in a customs union or a currency union as well as the distance between the exporting and the importing countries. A review of the gravity model may be found in Anderson (2011). However, a gravity model requires bilateral exports, which we do not have at hand. Instead, we base our analysis on one consistent data base, namely international input-output tables. An advantage of our approach compared to other studies in the literature is that while we have a panel with seven countries, we estimated the equations for each manufacturing sub-sector separately, thereby getting sector-specific influences of the costs and global demand. However, while this enables a detailed sub-sector specific analysis, the number of observations is relatively small, and during the observation period there have been significant changes in the unit cost variables from one year to the next, giving rise to quite large standard errors for some estimated coefficients.

Summing up, in the present paper, a panel econometric model is used to explain the growth in exports for each branch of the manufacturing sector by costs and foreign demand. The latter is approximated by the index of world trade in goods, an index published on a monthly basis by the CPB Netherlands Bureau for Economic Policy Analysis.[3] Regarding costs, unit energy costs, unit material costs, and unit labour costs were considered. Each of these three cost categories enters the model

[3] https://www.cpb.nl/en/the-cpb-world-trade-monitor-technical-description-update-2020.

as the ratio between the costs in a respective county to the average of all countries included in the models. The panel includes the following seven countries: Austria, Germany, Italy, France, Spain, USA, China. For this country model, the following equations were estimated:

$$\log(X_{Ai})_t; = c_i + \alpha_{1,i} log\left(\frac{UEC_{Ai,t}}{AVUEC_{i,t}}\right) + \alpha_{2,i} log\left(\frac{UMC_{Ai,t}}{AVUMC_{i,t}}\right) + \alpha_{3,i} log\left(\frac{ULC_{Ai,t}}{AVULC_{i,t}}\right)$$
$$; \quad +\beta_i \log(WTRADE)_t + \gamma_i Dummy2022$$

The variables have the following meaning:

- log: Natural logarithm
- X_{Ait} : Exports of product *i* from country *A* at time *t*
- $UEC_{Ai,t}$: Unit energy cost for the production of product i in country A at time t
- $UMC_{Ai,t}$: Unit material cost for the production of product i in country A at time t
- $ULC_{Ai,t}$: Unit labour cost for the production of product i in country A at time t
- $AVUEC_{Ai,t}/AVUMC_{Ai,t}/AVULC_{Ai,t}$: Respective average over all countries included
- $WTRADE_t$: World trade volume in goods at time t
- Dummy2022: A variable that is 1 in 2022 and 0 in all other years
- c_i: Constant
- $\alpha_{1i}, \alpha_{2i}, \alpha_{3i}, \beta_i, \gamma_i$ Parameters

The dependent variable is (the natural logarithm of) total exports of sector i from country A. The constant c and the parameters α, β and γ are estimated using panel econometric methods with annual data for the period 2010 to 2022. Since in 2022 energy prices in Europe rose sharply in the context of the Russian invasion of Ukraine, a dummy variable for this year was included in those equations in which it was significant.

The most important determinant of exports for the further analysis is unit energy cost (UEC). These are calculated as the costs of purchased energy divided by gross value added in the respective sector. The energy costs are calculated from the intermediate inputs purchased from the energy supply sector and the coking plant & mineral oil processing sector, following Germeshausen and Löschel (2015). The energy costs do not include prices of detailed energy sources such as coal or firewood themselves, as these are only recorded in aggregate together with non-energy inputs in the data sources and therefore cannot be differentiated from the latter. In-house production of energy is also not included, as this is not recognised as an intermediate input.

The unit energy costs are calculated according to the following formula:

$$UEC_{i,L} = \frac{\sum_{j=Energy\ supply,\ Coking} Intermediate_{i,j,L}}{GVA_{i,L}}$$

- $UEC_{i,L}$: Unit energy costs in sector i in country L
- $Intermediate_{j,L}$: Intermediate consumption of sector i from the sectors j = Energy supply and Coking & petroleum refining in the country L

- $GVA_{i,\,L}$: Gross value added of sector i in country L

In addition to energy input, the equations also consider the cost of purchasing inputs from other sectors (unit material costs) and (unit) labour costs. Unit material costs $UMC_{i,\,L}$ and unit labour costs $ULC_{i,\,L}$ are calculated according to the following formulas:

$$UMC_{i,L} = \frac{\sum_{j\neq\, i} Intermediate_{i,j,L}}{GVA_{i,L}}$$

$$ULC_{i,L} = \frac{Comp_{i,L}}{GVA_{i,L}}$$

The variables have the following meaning:

- $UMC_{i,\,L}$: Unit material costs in country L in sector i
- $ULC_{i,\,L}$: Unit labour costs in country L in sector i
- $Intermediate_{i,\,j.L}$: intermediate consumption of sector i from sectors j with $i \neq j$ in country L
- $Comp_{i,\,L}$: Compensation of employees (gross wages and salaries + employers' social contributions) in sector i in country L

4.2 Data sources

The export data and the data for the calculation of energy, material and unit labour costs are taken from Eurostat's FIGARO ("Full international and global accounts for research in input-output analysis") tables which are inter-country supply, use and input-output tables Eurostat (2024a, 2024b). The FIGARO tables depict global economic interdependencies and are based on official EU data with supplementary information on the most important non-EU trading partners (European Commission 2019). The estimations were conducted for the manufacturing sector and its subsectors as shown in Table 4.

The sectors C19 and C33 were excluded. The former is the energy-producing sector, and the latter is more related to services rather than to the production sector. The country coverage includes the 27 EU Member States, 18 major EU trading partners (Argentina, Australia, Brazil, Canada, China, India, Indonesia, Japan, Mexico, Norway, Russia, Saudi Arabia, South Africa, South Korea, Switzerland, Turkey, the United Kingdom and the USA), and the "Rest of the World".[4] The FIGARO tables currently contain time series for the period 2010 to 2022. The NACE codes are shown in the first column of Table 4. NACE ("Nomenclature statistique des activités économiques dans la Communauté européenne" - Nomenclature of Economic Activities) is the European statistical classification of economic activities.

[4] https://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/information-data#LProzentC3ProzentA4nder.

Table 4 Names of the NACE manufacturing sectors. *Source*: FIGARO tables (European Commission. Statistical office of the European Union., 2019)

NACE code	Designation
C10–C12	Manufacture of food, animal feed, beverages and tobacco products
C13–C15	Manufacture of textiles, clothing, leather, leather goods and footwear
C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of paper and paperboard; manufacture of printed matter
C17	Production of paper and cardboard
C18	Printing and playback of recorded media
C20	Manufacture of chemical products
C21	Manufacture of pharmaceutical products
C22	Manufacture of rubber and plastic goods
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 computers, electronic and optical products
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles and parts
C30	Other transport equipment
C31–32	Manufacture of furniture and other goods

4.3 Estimation results

The estimation results of the panel econometric models are shown in Table 5. As mentioned, the dependent variable is the natural logarithm of exports of manufacturing sub-sector i of country A. We use macroeconomic data, hence there are no bilateral exports between country-pairs, but rather total exports of a sector to the rest of the world. In the table, the first column shows the sector and the second column the constant. In columns three, four and five, the influence of unit energy, material, and labour costs, respectively, on exports are depicted. Column six shows the influence of foreign demand on exports, while column seven contains the coefficient of a dummy variable for 2022.

By using logarithms, the estimated coefficients can be interpreted as elasticities. They therefore show the percentage change in exports if the relative costs or world trade change by 1%. Since the focus of the paper lies on the influence of energy costs (in relation to the competitors of Austrian exports), the modelling strategy was to ensure that in each equation relative unit energy costs were included, at least with the expected negative sign. Unfortunately, in four sectors, these unit energy costs have the expected sign, but the coefficient is insignificant. These sectors are C10–12 (manufacture of food, beverages, tobacco), C18 (printing), C25 (manufacture of fabricated metal products), and C30 (manufacture of other transport equipment). Since the aim of the paper was to identify the influence of changes in energy costs due to increased efforts to combat climate change, e.g. via a rising emission price, unit energy costs were retained in the equations even if they were statistically not sig-

Table 5 Results of the econometric estimations. *Source* own estimates and calculations

	Const.	Log (UEC)	Log (UMC)	Log (ULC)	Log (Wtrade)	Dummy 2022
C10–C12 - Food, beverages	2.695	−0.029		−0.291	1.441	0.199
	0.502***	0.021		0.057***	0.093***	0.03***
C13-C15 - Textiles, clothing	5.966	−0.038			0.759	0.116
	0.456***	0.019*			0.102***	0.03***
C16 – Wood, wood products	7.606	−0.053		−0.176	1.038	0.370
	0.169***	0.015***		0.063***	0.312***	0.039***
C17 - Paper, paper products	8.695	−0.116			0.962	
	0.032***	0.012***			0.159***	
C18 - Printing	3.500	−0.014		−0.218	0.465	
	0.848***	0.043		0.143	0.172***	
C20 – Chemical products	10.240	−0.126			1.436	
	0.116***	0.041***			0.392***	
C21 - Pharmaceuticals	0.298	−0.073			1.911	
	0.554	0.025***			0.118***	
C22 - Rubber and plastic	8.572	−0.142	−0.231		1.146	0.320
	0.177***	0.027***	0.062***		0.322	0.04
C23 - Other non-metallic	7.606	−0.105	−0.289	−0.140	0.709	0.259
	0.188***	0.032***	0.119**	0.074*	0.272**	0.035***
C24 - Basic metals	5.588	−0.177			0.862	0.216
	1.068***	0.013***			0.226***	0.072***
C25 - Fabricated metal	1.029	−0.101	−0.481		1.524	0.203
	1.002	0.08	0.192**		0.197***	0.065***
C26 - Computers, electronic	7.525	−0.214		−0.725	0.927	0.348
	0.268***	0.016***		0.093***	0.175***	0.021***
C27 - Electrical equipment	4.098	−0.027			1.239	0.110
	0.204***	0.01***			0.042***	0.014***

Table 5 (continued)

	Const.	Log (UEC)	Log (UMC)	Log (ULC)	Log (Wtrade)	Dummy 2022
C28 – Machinery, equipm.	10.363	−0.132			1.202	
	0.028***	0.009***			0.212***	
C29 - Motor vehicles	4.004	−0.125		−0.159	1.266	0.080
	0.241***	0.017***		0.03***	0.054***	0.018***
C30 - Other transport	2.309	−0.018		−0.208	1.465	
	0.739***	0.039		0.098**	0.136***	
C31-C32 - Other goods	8.250	−0.142		−0.336	0.774	
	0.669***	0.055**		0.255	0.406*	

The standard errors are indicated below the estimated coefficients. *, **, *** means significance at the 10, 5 or 1% level

Estimation period: 2010–2022. Estimates with fixed effects for the countries

Dependent variable: Log(Exports). UEC: Unit energy costs, UMC: unit material costs, ULC: unit labour costs; Wtrade: world trade nificant. The reason for the insignificance of unit energy costs in these four sectors is probably the combination of a short estimation period due to availability of the FIGARO tables, and a high variation in unit energy costs in the estimation period. As an example, UEC in the food, beverages and tobacco sector (C10–12), rose by 8.7% in 2013, followed by a decline of 26.4% in 2014, an increase of 2.1% in 2015 and another drop by 16.3% in 2016. This erratic behaviour can be caused by each of the components of UEC: the input of energy in the nominator, and real gross value added in the denominator. Energy input in each sector is, as mentioned above, intermediate consumption of the respective sector from the sectors energy supply and coking & petroleum refining. This intermediate consumption in turn is made up of the quantity of purchased energy and the price per energy unit. Gross value added is measured in real terms, implying that it is influenced by GVA at current prices and by the deflator. A sharp rise in energy costs, combined with low short-run substitutability may result in significant increase of the nominator of UEC, and if then GVA decreases, the is reflected in an increase in EUC. If in the following period energy prices decline again, the reverse chain of events may occur. If in such a case exports to not react strongly to these unit energy cost changes, the relationship between the two variables is not significant.

Once a specification with a negative coefficient of unit energy costs had been found, the other variables, i.e. unit material costs and unit labour costs were included provided that they have the expected negative sign and are significant at least at the 10% level. As a result, unit material costs, i.e. the costs of intermediate inputs from all other sectors except for energy, enter the export determination only in three sectors: C22 (manufacture of rubber and plastic products), C23 (manufacture of other non-metallic mineral products), and C25 (manufacture of fabricated metal products). In eight out of the 17 sectors, unit labour costs were found to influence exports significantly negatively. Finally, foreign demand as approximated by an index of world trade in goods entered significantly positively in all manufacturing sectors. However, in as many as eight sectors, it was only the logarithmic change rather than the level of world trade that entered the equations significantly positively.

The influence of relative unit energy costs is largest in sector C26 (manufacture of computers, electronic, optical products) with an elasticity of −0.214. If unit energy costs in this sector rise by 1% in relation to all other countries in the sample, exports decline by roughly a quarter percent, everything else equal. It might be surprising that the manufacture of computers reacts most strongly to energy price changes. The result may be qualified in some respects. Firstly, the difference between the highest and the second-highest elasticities is rather small. Secondly, all estimation results have to treated with caution due to the short estimation period and the in some cases erratic changes in the variables as just mentioned. However, thirdly, the finding that most of the sectors with a high energy intensity react less than other sectors to energy cost changes could also have real reasons: companies in sectors with a high energy intensity might have learned more than other companies to cope with sudden changes in energy prices, while in the sectors with lower energy intensity, changes in energy costs might be faster transmitted to output prices on which buyers abroad react.

The second largest elasticity of −0.177 is found for sector C24 (manufacture of basic metals) which is one of the four most energy-intensive sectors. In the other three most energy-intensive sectors, the following elasticities of exports with respect to relative unit energy costs were found in the econometric estimations: −0.126 for sector C20 (manufacture of chemicals and chemical products), −0.116 for sector C17 (manufacture of paper and paper products), and −0.105 for sector C23 (manufacture of other non-metallic mineral products).

The energy cost elasticities are broadly in line with the literature. Riker (2012) estimates energy price elasticities for 20 US manufacturing industries over the period 2002 to 2006. He finds energy price elasticities of export demand ranging between −0.013 in the tobacco and beverages industry and −0.216 in the primary metals industry. Except for Riker (2012), specific studies on the reaction of exports on energy price changes are scarce. In contrast, numerous papers using vector auto regressive (VAR) or dynamic stochastic general equilibrium (DSGE) models studying economic and welfare implications of energy prices hikes have been published. However, due to differences in the methodologies and in the analysed variables, the results of these studies cannot directly be compared to our results.

Regarding the influence of costs, it should be noted that the models used here explain exports. Business relocations cannot be covered with the existing database. Relocations of parts of the production process can even lead to an increase in imports and exports in the industry concerned, because part of the production would then take place abroad, the corresponding intermediate products would be imported, further processed domestically and then exported as finished goods. While foreign trade would be positively influenced in such a case, domestic value added would fall.

5 Simulations until 2050

5.1 Assumptions on the development of unit energy costs

In this section, we combine the assumptions underlying the climate neutrality scenarios described in Sect. 1 with the models estimated in Sect. 4 to assess the impact of reaching climate neutrality in Austria by the year 2050 on the exports of Austria's manufacturing industries.

For the simulations with the export models up to the year 2050, assumptions on the future development of unit energy costs in the individual sectors are required. This section describes how these paths were derived. The starting point is the unit energy costs for Austria resulting from the FIGARO data up to 2021. Based on this, an estimate was made of how these would change for the individual industrial sectors in the transition scenario (KN40). The following assumptions were made:[5]

- Change in CO_2 prices (see Table 2 in Sect. 1): rising CO_2 prices play a role in unit energy costs, particularly up to 2030. The CO_2 prices of the transition scenario KN40 were assumed to rise to 500 $Euro_{2020}$ /t CO_2 by 2050. $Euro_{2020}$ means at

[5] In practice, of course, many other factors can also play a role, such as changes in taxes on goods or the degree of self-sufficiency, e.g. through own PV systems, which cannot be taken into account due to a lack of information.

prices of 2020.

- Changes in the prices of energy sources: Assumptions on the further development of energy prices were based on the transition scenario KN40.
- Change in the share of energy sources: fossil fuels will be largely replaced by renewables by 2030 and almost completely by 2040.

Data on current sectoral energy consumption and the distribution of energy sources is taken from the "Physical Energy Flow Accounting" (PEFA). The assumptions on the future development of total energy demand and the use of energy sources in total industry are based on the KN40 transition scenario. The additional costs incurred as a result of CO_2 prices, price changes in energy sources and the shift from fossil fuels to renewable energy sources were finally set in relation to the sectoral value added, assuming an annual real growth rate of 1.2% from 2027 and added to the current unit energy costs (base year 2021).

Figure 1 shows an example of the assumed transition from fossil fuels to renewable energy sources in the energy-intensive sectors C17 (paper and cardboard), C20 (chemicals), C23 (other non-metallic mineral products) and C24 (basic metals).

- C17: in 2021, wood products (41%), natural gas (31%) and electricity (20%) were the most important energy sources. It is assumed that the use of natural gas will be reduced by around 2/3 by 2030 and disappear completely by 2040. It will initially be largely replaced by biogenic fuels (wood products) and from 2040 increasingly by electricity.
- C20: currently, natural gas (17%) and electricity (14%) are the most important emission-relevant energy sources (non-energy use was excluded). Here, too, the share of natural gas will be reduced by around 2/3 by 2030 and initially replaced by electricity and from 2030 partly by hydrogen.
- C23: natural gas was also the most important energy source here in 2021 (42%). As high temperatures are required in the lime and cement industries, among others, some of the natural gas is also replaced by hydrogen here.
- C24: here it was assumed that some of the blast furnaces will be replaced by electric arc furnaces by 2030 and the remaining coal-fired blast furnaces by hydrogen technology by 2040.

For all energy-intensive sectors, the transition scenario additionally assumes a decrease in energy use over time due to increased energy efficiency, with the largest reductions in C23 (−47%) and C24 (−36%) by 2050 compared to 2021.[6]

For the other sectors, it was assumed - based on the energy sources remaining in the transition scenario after deducting the energy-intensive sectors - that the consumption of fossil fuels will be significantly reduced (by around 69%) by 2030, and that neither gas nor coal will be used from 2040 onwards. Fossil fuels will be

[6] As our definition of energy unit costs only includes intermediate inputs received from sectors C19 and D35 due to data restrictions, there will be certain distortions in sectors that currently rely heavily on energy sources like wood and coal (e.g. the metal industry C24 or the wood-processing industry C16). While changes regarding the use of such energy carriers in the course of the transition are accounted for in the energy unit cost development, they are not contained in the initial value for 2021.

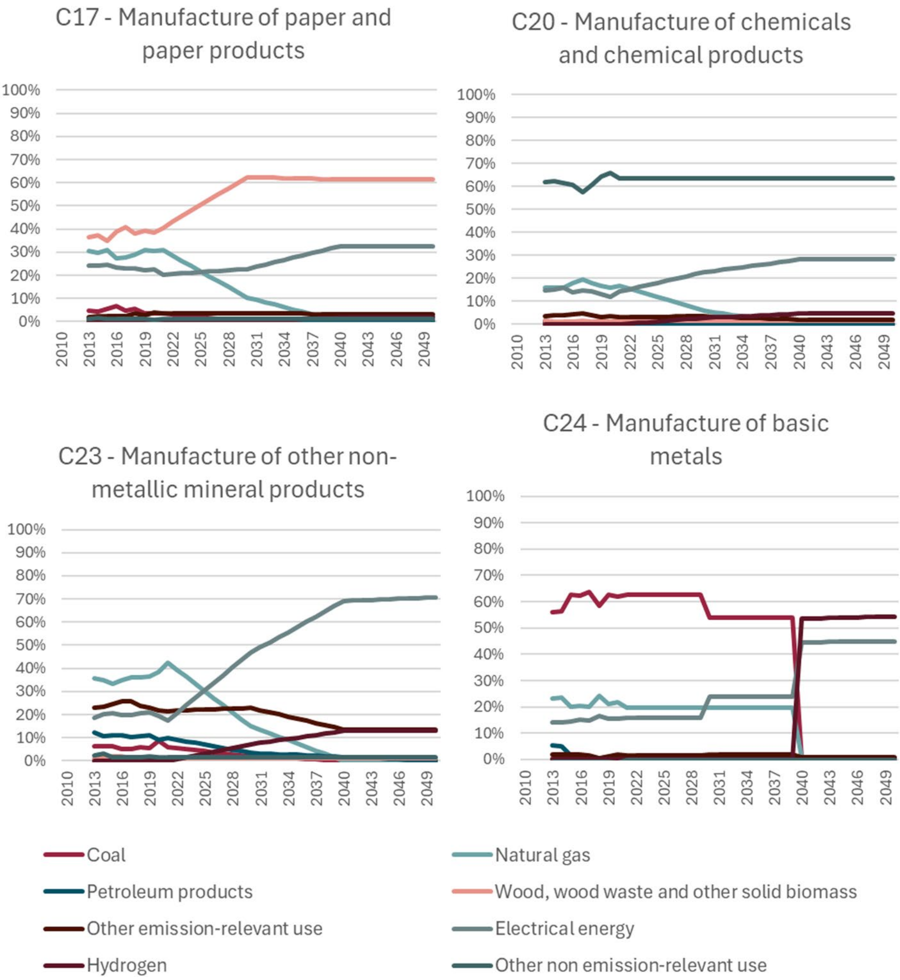

Fig. 1 Assumed transition in four energy-intensive sectors. *Source*: Own illustration

replaced primarily by electricity and partly by biomass, with hydrogen accounting for only a very small share. Regarding the speed of the transition and the shares of the individual renewables, it was assumed that they are largely analogue in all non-energy-intensive sectors except for wood due to a lack of more precise data. These assumptions result in the unit energy cost curves shown in Fig. 2 on the left-hand side for the energy-intensive sectors and on the right-hand side for the other sectors. To illustrate the non-energy-intensive sectors, representative sectors were selected whose development is largely analogous to the sectors not shown. Only wood products show a different trend due to the different assumptions regarding the energy mix.

Finally, it must be emphasised that the unit energy cost developments described here are based on many assumptions and should therefore be viewed more as a possible scenario based on the Environment Agency Austria's transition scenario and not as an exact forecast. For example, the relative importance of the various energy

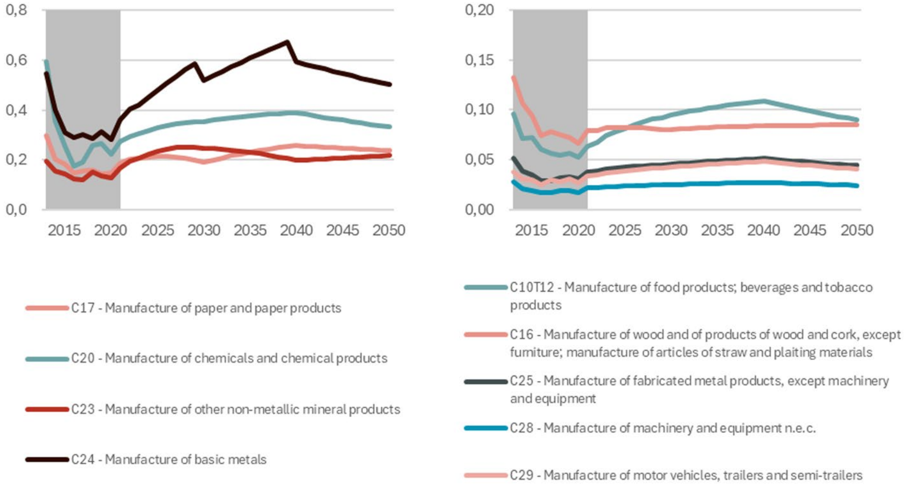

Fig. 2 Assumed development of unit energy costs in energy-intensive (left) and representative non-energy-intensive (right) sectors. *Source*: Own illustration

sources in the individual sectors in the future can only be estimated to a limited extent, and a different trend of electricity prices alone could lead to significant differences in cost trends in many sectors. Also, the spike of energy prices in 2022 and 2023 has not been modelled in the unit energy cost developments, as this is not really connected to the transition scenario and complicates the estimation of long-term effects.

5.2 Simulation results

The export models of the manufacturing sectors were used together with the assumptions on the development of unit energy costs described in the previous section to estimate how the shifts in energy prices and energy sources in the transition scenario KN40 could affect sectoral exports up to 2050. In addition to unit energy costs, the models include material and unit labour costs as well as an indicator for global trade in goods. Assumptions must therefore also be made for the development of these determinants up to 2050. It should also be noted that the simulations must begin in 2022 due to the availability of data in the FIGARO tables on which the model estimations are based. For the development of the exogenous variables, the actual data was used for the years 2022 and 2023 where available, for example for global trade. It should also be noted that the model comprises 17 sectors in the manufacturing industry for seven countries (Austria, Germany, Italy, France, Spain, USA, China). It is also important to emphasise that no econometrically estimated model can be used for forecasts over a period of almost 30 years. We therefore deliberately refrain from presenting the specific values of exports in euro, instead focussing on the differences between two scenarios.

First, a **baseline scenario** is created in which all unit costs (energy, labour and material unit costs) remain constant in all countries in all sectors over the entire period.

Second, a **transition scenario** was developed which assumes increasing energy costs in the EU due to climate change efforts, but also in the rest of the world energy costs rise, albeit only half as much as in the EU. In this scenario, unit energy costs therefore also rise in the USA and China, for example because of investment in lower-emission technologies or as a result of prices on emissions.

Specifically, the following assumptions were made:

- Global trade in all scenarios: 2022 + 3.1%, 2023 − 0.8%, 2024 + 2.5%, 2025 + 2.2%, 2026 + 0.8%, from 2026: +2.5% per year. The actual development was used for 2022 to 2024, the forecasts from the IHS summer forecast from June 2025 (Bonin et al. 2025) for 2025 and 2026, followed by a growth rate that due to the trade conflicts is somewhat below the average growth rate of global trade in goods since 2009, for the period from 2027 onwards.
- Real unit labour costs and real material costs in all scenarios: unit labour and material costs remain unchanged in all countries and in all sectors until 2050 compared to 2022.
- Unit energy costs in European countries in the baseline scenario: in the baseline scenario, unit energy costs in Europe also remain unchanged in all sectors until 2050 compared to 2022.
- Unit energy costs in the European countries in the transition scenario: unit energy costs in the transition scenario towards climate neutrality in Austria and the other EU countries develop as described in the previous section.
- Unit energy costs in the USA and in China: These remain unchanged in the baseline scenario until 2050 compared to 2022. In the transition scenario, unit energy costs in the USA and in China rise half as much as in the EU countries.

Using these assumptions, the two scenarios were created for the period 2023–2050. Stochastic simulations were carried out to take account of the uncertainty in estimating the model parameters. Stochastic simulations consider the fact that the model parameters cannot be calculated exactly in an econometric estimation but rather represent the mean value of a probability distribution. The more uncertain the estimation is, the greater the range of possible values for the coefficients around this mean value. Stochastic simulations use "draws" of the parameter values from the probability distribution. In this specific case, 5000 model runs were created. In addition to the mean value for the endogenous variables, i.e. for the exports of the sectors, the simulations also produce upper and lower limits resulting from the standard errors around the estimated model parameters. The simulations were defined in such a way that the actual value lies within the range with a probability of 68%. The results are shown in Table 6. The table shows the percentage deviations in Austria's sectoral exports in the transition scenario compared to the baseline scenario for the years 2030, 2040 and 2050. The table shows the deviation of exports in the transition scenario from the baseline in which unit energy costs are assumed to remain constant in all countries and sectors. The results shown in the first line for the entire manufacturing industry are calculated by adding up the exports in the sectors listed below. The unit costs (for energy, wages and material) are included in the models as a ratio of the costs in the country under consideration to the costs in all countries. Therefore, if unit

Table 6 Percentage deviations of exports in the transition scenario compared to the baseline scenario. *Source*: Own calculations

C Total manufacturing	2030			2040			2050		
	Lower limit	Centre	Upper limit	Lower limit	Centre	Upper limit	Lower limit	Centre	Upper limit
	−1.7	−0.3	0.0	−2.1	−0.4	0.0	−1.0	−0.2	0.0
C10–C12 - Food, beverages, tobacco	−0.3	−0.2	−0.2	−0.4	−0.3	−0.2	−0.2	−0.2	−0.2
C13–C15 - Textiles, clothing, leather	−1.7	−0.2	0.0	−2.1	−0.3	0.0	−1.3	−0.2	0.0
C16 - Wood, wood products	0.0	0.0	0.0	−0.2	0.0	0.0	−0.2	−0.1	0.0
C17 - Paper and paper products	−0.1	0.0	0.0	−1.3	−0.4	−0.1	−1.0	−0.3	−0.1
C18 Printing	−0.3	0.0	0.0	−0.4	−0.1	0.0	−0.2	0.0	0.0
C20 - Chemical products	−1.4	−0.3	0.0	−1.9	−0.5	−0.1	−1.0	−0.3	0.0
C21 - Pharmaceuticals	−2.0	−0.5	−0.1	−4.7	−0.7	−0.1	−1.8	−0.5	−0.1
C22 - Rubber and plastic goods	−2.8	−0.4	0.0	−3.7	−0.7	0.0	−1.8	−0.3	0.0
C23 - Other non-metallic products	−5.4	−0.6	0.0	−1.6	−0.3	0.0	−3.1	−0.4	0.0
C24 - Basic metals	−1.6	−0.4	−0.1	−2.1	−0.6	−0.1	−1.4	−0.4	−0.1
C25 - Fabricated metal products	−0.5	−0.4	−0.3	−0.7	−0.6	−0.4	−0.4	−0.3	−0.2
C26 - Computers, electronic products	−2.5	−0.2	0.0	−3.5	−0.5	0.0	−0.9	−0.1	0.0
C27 - Electrical equipment	−0.2	−0.1	0.0	−0.4	−0.1	0.0	−0.2	0.0	0.0
C28 - Machinery & equipment n.e.c.	−1.8	−0.4	0.0	−2.7	−0.6	0.0	−1.5	−0.3	0.0
C29 - Motor vehicles and parts	−2.0	−0.4	0.0	−3.1	−0.7	0.0	−1.7	−0.4	0.0
C30 - Other transport equipm.	−0.3	0.0	0.0	−0.4	−0.1	0.0	−0.2	0.0	0.0
C31–C32 - Furniture and other goods	−2.9	−0.2	0.0	−3.3	−0.4	0.0	−1.4	−0.2	0.0

costs increase equally in all countries, the relative costs for each country remain unchanged, and in such a case there would be no differences between the scenarios.

The effects of rising unit energy costs on exports are caused by two factors: firstly, the extent of the unit energy cost increase, and secondly, the response of exports in the sector concerned to changes in unit energy costs. The coefficient that measures this, the so-called elasticity, is very low in the sectors C18 (printing) and C30 (other transport equipment), for example, so that exports in these sectors hardly differ between the scenarios. At the other end of the elasticity spectrum are the sectors C26 (computer, electronic, optical products) and C24 (basic metals), whose exports are particularly sensitive to unit energy costs based on the FIGARO data for the period 2010 to 2022. For the sectors C18 and C30, it should be added that the coefficient that measures the influence of unit energy costs on exports is not statistically significant. This also applies to the sectors C25 (fabricated metal products) and C10–12 (food, beverages, and tobacco). This results in a high estimation uncertainty, which is reflected in the large ranges between the lower and upper limits shown in the table.

In the **transition scenario**, in which it is assumed that unit energy costs in the USA and China rise half as much as in the EU, the average deviation in exports in the entire manufacturing sector amounts to 0.3% in 2030, 0.4% in 2040 and 0.2% in 2050, respectively. All in all, the simulation results show that increased climate protection efforts, which lead to rising energy costs in the EU, impair the competitiveness of the domestic industry. However, according to the results presented here, a de-industrialisation of Europe is not to be feared. Some particularly energy-intensive sectors of the economy will come under greater pressure, others less so. The more countries pursue climate protection and are confronted with higher energy prices, the more neutral this is regarding the relative competitive position of individual economies.

When interpreting the results, it must be borne in mind that these are not forecasts but scenario analyses. The results are subject to a high degree of uncertainty for several reasons. Firstly, it should be noted that the data availability of the FIGARO tables implies that the estimation period of twelve years is relatively short for econometric estimates. Conversely, the simulation period is very long with almost 30 years. Within the already short support period, unit energy costs (and to a lesser extent unit labour costs and unit material costs) in individual sectors have fluctuated greatly from year to year, which increases the uncertainty of the model estimates. It must also be emphasised that the paths of the unit energy costs depend heavily on the assumptions regarding the prices for CO_2 and the energy sources as well as regarding the energy mix and total energy use in the individual sectors. The uncertainty in the estimates is expressed on the one hand in the fact that in four sectors the influence of unit energy costs on exports is not statistically significant. Secondly, the estimation uncertainty in some sectors leads to large ranges in the simulation results, represented in the table by the lower and upper limits.

It should also be noted that higher energy prices throughout the EU do not necessarily have the same impact on exports in every member state. Although wholesale prices for energy sources and electricity are similar in the EU member states, customer prices (for private households and industry) are different. In addition, there are second-round effects on inflation and therefore on competitiveness within the EU due to different regulations regarding indexation. Due to these limitations, the results should not be regarded as numerical forecasts of the effects of ambitious climate protection efforts in the EU. Rather, they provide an indication of which areas of the manufacturing industry are likely to be less affected and which areas are likely to be more affected based on previous data and experience. For example, the simulation results indicate that, under the assumptions made here, wood and wood products (C16), the printing industry (C18), the manufacture of electrical equipment (C27), and the manufacture of other transport equipment (C30) are likely to experience only small decreases in exports (compared to a baseline scenario of constant unit energy costs) as a result of rising unit energy costs. Stronger negative effects are expected in the manufacture of pharmaceutical products (C21), manufacture of rubber and plastic products (C22), manufacture of computers and electronic products (C26), manufacture of machinery and equipment (C28), and manufacture of motor vehicles and parts (C29). The latter two belong to the most important exporting industries in Austria.

6 Summary and conclusion

Austria committed itself to become climate neutral by 2040. In this paper, we present investment requirements to achieve this goal in different climate neutrality scenarios developed by the Environment Agency Austria. One important instrument to achieve net zero emissions is an increasing emission price, together with a stable and strict climate mitigation policy framework. These emission prices may raise the operation costs of Austrian companies. We estimate the paths of operating costs for the Austrian manufacturing sector and its sub-sectors, based on projections for the CO_2 price, the prices of fossil fuels, and for the change in energy sources used in the different industries, e.g. the substitution of oil and gas with renewable energy sources and electricity. Then we estimate by how much the rise in energy costs impacts on the competitiveness of Austrian companies, measured via changes in exports of the manufacturing sector. To do so, we estimated panel models for 17 sub-sectors of the manufacturing industry. The panel consists of seven countries: Austria, its four most important European trading partners and competitors, as well as the USA and China. The estimations and simulations until 2050 show that fears of a European de-industrialisation are exaggerated, but some energy-intensive industries come under pressure, in particular if other important countries like the USA und China are not confronted with rising energy costs. These results are valid for the energy price paths assumed in the transition scenario towards climate neutrality. However, sudden and sharp increases of energy prices have the potential to impair on the competitiveness of the affected economies. To protect the European industry from competition from countries with less strict environmental policies, a well-functioning Carbon Border Adjustment Mechanism will be essential. It has to be made clear that the simulations presented in this paper are not projections but only scenario analyses. The paths of energy costs in the different sectors depend strongly on a large number of assumptions regarding the prices of fossil fuels and of CO_2 emissions, as well as on technological changes and shifts in energy sources used in the production process. Furthermore, the short availability of data for the estimation of econometric models, in combination with a long simulation horizon calls for great caution when interpreting the quantitative results. However, the qualitative interpretations and the statements about the order of magnitude of the simulation results remain valid.

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Data availability The data and model files used for the publication are available upon request from the corresponding author.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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