Regional policy analysis in Germany

Michael Hübler[*] Marius Braun[†] Nils Keimes [‡]

May 2024

Abstract

This article discusses improvements of regional (within-country) policy analyses focusing on Germany. Policy results from the literature and own model simulations of the current EU climate policy with carbon border adjustments highlight significant differences in policy results across EU countries and German regions. Whether carbon border adjustments have a significant average effect on the entire EU is questionable. Because official and constructed regional German data sets are incomplete or not publicly available and compilation methods are not standardized, the public provision of a harmonized, comprehensive, up-to-date data set, at least with federal state level resolution, is advisable.

JEL classifications: C68; F18; Q52; Q54; R50

Keywords: regional data; input-output data; climate policy; carbon border adjustments; CBAM; Germany

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[*] Corresponding author, email: michael.huebler@agrar.uni-giessen.de, phone: +49-641-99-37052, fax: +49-641-99-37059; Agricultural, Food and Environmental Policy, Institute for Agricultural Policy and Market Research, Center for International Development and Environmental Research (ZEU), Justus Liebig University Giessen, Senckenbergstr. 3, 35390 Gießen, Germany.

[†] Faculty of Business Studies and Economics, Justus Liebig University Giessen, Germany.

[‡] Faculty of Business Studies and Economics, Justus Liebig University Giessen, Germany.

1 Introduction

Input-output tables are an important basis for model-based assessments of climate, trade or other economic policies and economic shocks, such as energy or food price changes. While national input-output tables are widely available, within-country data (regional input-output tables, RIOTs, and multi-regional input-output, MRIO, tables) are scarce, especially for countries encompassing relatively small areas, particularly, Germany. Within-country disaggregation of data and models is more elaborated for countries covering large areas, structured in federal states or provinces, i.e., the United States, China and India (see, for example, Caliendo et al. 2018; Zhang et al. 2020; Leimbach et al. 2024). In Europe, within-country data are available for the United Kingdom, Belgium and Spain, which have been applied to assess regional carbon footprints (Lenzen et al. 2010; Towa et al. 2022) and the impact of trade relationships on water resources (Cazcarro et al. 2013).

Within-country data are necessary to assess regional policy effects within countries in a reliable way. This relevance stems from the differential economic impacts of policies or shocks across regions due to differences in the economic importance of active sectors, their interconnections and their contribution to the overall output of a region. Future impacts of climate change, such as floods, and the policy reaction to them are a concrete example for socially and politically highly relevant regional aspects.[1] Besides adaptation to climate change, mitigation of greenhouse gas emissions, especially the transformation of the energy system with the expansion of renewable energies, is a major challenge with regional potentials and obstacles and will be in the spotlight of this article.

Whereas German regions with strong dependence on fossil fuel-based sectors (such as coal in Lusatia) are presumably negatively affected by stricter climate/energy policy regimes and may therefore receive adequate financial support, other regions are more robust to stricter climate/energy policy settings or even benefit from them. Besides Schleswig-Holstein (Bröcker et al. 2016), Lower Saxony is a prominent expected beneficiary (cf. Pothen and Hübler 2018; Pothen and Hübler 2021) among the German federal states. Therefore, the regional focus of our policy simulations is on Lower Saxony. Although wind power plants are common across Germany, the northern federal states exhibit a relatively large on-shore and off-shore wind power potential and a high economic dependency on the wind power industry compared to the rest of Germany.[2] Thus, climate policies striving for an increasing share of renewable energies will presumably result in (negative or positive) region-dependent welfare effects (leaving aside reduced climate change damages) that we explore.

Against this background, we review the regional economics literature focusing on Germany to clarify the availability of regional data and their use in policy analysis. Furthermore, we evaluate the regional effects of the current European climate policy. Different to the literature that mostly uses input-output methods or

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[1] See, for example, Adeel et al. (2020) regarding regional effects of floods in the United States, Canada and Mexico.

[2] Similarly, southern federal states have a relatively large solar power potential.

common computable general equilibrium (CGE) models, we deploy a global CGE model with an advanced trade module (Eaton and Kortum 2002; Caliendo et al. 2018) to identify regional differences of policy impacts. Based on that, we derive research priorities and data requirements. The obtained insights can be relevant for modelers, data providers, funders and policy makers. Although the focus is on climate policy and federal states of Germany, the priorities and challenges identified in this article apply more generally to regional impacts of policies or shocks and other countries in Europe or elsewhere.

As a contribution to the economic policy modeling literature, we simulate the *regional* effects of the current European Union's (EU's) Carbon Border Adjustment Mechanism (CBAM) in Germany based on the EU Emissions Trading Scheme (ETS). Hübler et al. (2024) study the effects of the EU ETS, CBAM and so-called "climate clubs" on German household income groups at the German-wide level. They find significant differences between the policy effects, e.g., a positive effect on poor household but a negative effect on rich households. Other studies find regional differences of climate and trade policy on German regions (Pothen and Hübler 2018; Hübler and Herdecke 2020; Pothen and Hübler 2021). However, they do not study the effects of CBAM. The model-based literature on carbon border adjustment policies (see, for example, the model comparison summarized by Böhringer et al. 2012) has so far, to the best of our knowledge, not examined *regional* policy effects within countries.

Overall, our literature review and policy analysis reveal significant, policy-relevant regional differences of economic effects. For instance, according to our policy simulations, the effect of the EU ETS on the North of Germany is positive (due to its large wind power potential) whereas the effect on the Rest of Germany is negative (note that benefits of reduced climate change impacts are not modeled in this cost effectiveness analysis). CBAM has small positive effects on both regions but the effect is considerably larger in the North than in the Rest of Germany. An effect of CBAM on the entire EU is hardly visible. Consequently, regional policy advice based on results from more aggregate regions (here, Germany or the EU) can be misleading.

By contrast, our review of available data from Germany reveals a lack of regional data from Germany. While RIOTs of some German federal states and one MRIO table (Többen 2017a; Többen 2017b) covering all federal states have been constructed and compiled by researchers, publicly available, official, up-to-date data (from statistical offices) are largely missing. Consequently, we identify and discuss priorities of future research and data requirements aiming at the provision of a unified, official, publicly available country-wide regional data set of Germany.

The article proceeds as follows. Section 2 explores the availability of regional input-output data from Germany. Section 3 reviews the literature on regional policy effects in Germany.Section 4 provides a model-based regional policy analysis of the current EU ETS and CBAM policies focusing on Northern Germany. Section 5 discusses research challenges, research priorities and data requirements. Section 6 concludes.

2 Availability of regional input-output data from Germany

This section summarizes the availability of regional data at the German federal state level. The latest input-output table of a German federal state officially provided by a statistical agency appears to be available for Baden-Wuerttemberg in the year 1990 (Pothen and Hübler 2018). Although approaches for developing time series data of subnational input-output tables have been developed (Wang et al. 2017), which attempt to provide a more continuous spatial and temporal coverage of input-output tables at the subnational level, regional input-output data remain scant. Therefore, researchers have constructed/compiled more recent input-output tables of further German federal states.

At the time of writing, such compiled regional input-output tables (RIOTs) are available for eight of the 16 federal states (see Table 1). Schulte in den Bäumen et al. (2015) use regionally disaggregated German data; a corresponding input-output table is, however, not publicly available. The state with the most RIOTs is Baden-Wuerttemberg, for which we found three RIOTs since 2010 (Heindl and Voigt 2012; Haigner et al. 2015; Koch et al. 2019). The majority of RIOTs are not publicly available. Furthermore, the level of sectoral disaggregation of RIOTs varies considerably, ranging from 12 sectors (Prognos 2007; Prognos 2009) to 72 sectors (Heindl and Voigt 2012).

Regarding regionalization, the literature generally relies on non-survey methods, with two common approaches being the Commodity Balance (CB) approach (also known as Supply-Demand Pool, SDP, approach) and the Location Quotient (LQ) approach. The CB method presupposes that regional intermediary transactions, along with interregional trade, can be inferred from national data by assessing the balance between regional supply and demand (Jin 1991). The LQ method, together with the more recent FLQ method developed by Flegg and Webber (2000) and Flegg and Tohmo (2013), estimates regional multipliers using national and regional employment data in order to derive regional input-output coefficients (Flegg et al. 1995). However, as pointed out by Tohmo (2004) and Kronenberg (2009), both methods tend to produce tables that are systematically biased, primarily because they do not account for cross-hauling, i.e., intra-industry trade (the simultaneous exporting and importing of the same type of product). Most recent contributions therefore apply the Cross-Hauling Adjusted Regionalization Method (CHARM) developed by Kronenberg (2009) which addresses this shortcoming of the traditional approaches. In addition, some authors (e.g., Koch et al. 2019) adopt a hybrid approach that includes the use of original federal state-specific data, which allows for a more precise accounting of regional economic activity.

As shown in Table 2, data sources for this approach include the Scientific Use Files of the Household Budget Survey ("Einkommens- und Verbrauchsstichprobe", EVS, microeconomic household survey data from "Forschungsdatenzentren", FDZ 2024) provided by the Research Data Centre (RDC) of the German Statistical

Office, the German Statistical Office (“Statistisches Bundesamt”, Destatis 2022, macroeconomic German-wide non-survey data), the Regional Accounts of the Federal States (“Volkswirtschaftliche Gesamtrechnung der Länder”, VGRdL 2022b, macroeconomic non-survey data from the German federal states) as well as labor market statistics provided by the Federal Employment Agency (“Bundesagentur für Arbeit”, BfA 2022).

State	Author(s)	Year	Num. of sectors	Method	Publicly available
Baden-Wuerttemberg	Haigner et al. (2015)	2010	51	CHARM	no
Baden-Wuerttemberg	Heindl and Voigt (2012)	2006	72	CB/SDP	yes
Baden-Wuerttemberg	Koch et al. (2019)	2014	38	CHARM	no
Hamburg	Prognos (2009)	2005	12	?	no
Hamburg	Kronenberg (2011)	2003	71	CHARM	no
Hessen	Penzkofer (2002)	1995	?	?	no
Hessen	Koschel et al. (2006)	2000	18	LQ	no
Lower Saxony	Schröder (2012)	2007	71	CHARM	yes
Lower Saxony	Stöver (2018)	2013	20	CHARM	yes
Mecklenburg-Western Pomerania	Kronenberg (2010)	2003	16	CHARM	yes
North Rhine-Westphalia	Kronenberg and Többen (2011)	2007	59	CHARM	yes
North Rhine-Westphalia	Prognos (2007)	2000	12	?	no
Saxony	Lehr et al. (2013)	2006	16	CHARM	no
Thuringia	Dettmer and Sauer (2014)	2010	73	FLQ	no
All German federal states	Többen (2017a) and Többen (2017b)	2011	41	CHARM	no

Table 1: Regional input-output tables for German federal states (based on Kronenberg and Wolter 2017, and an own survey of the literature). CHARM: Cross-Hauling Adjusted Regionalization Method, CB: commodity balance, SDP: supply-demand pool, LQ: location quotient, FLQ: flegg location quotient.

In addition, there are two notable contributions to the literature not included in Table 1. First, Schröder and Zimmermann (2014) describe the construction of a RIOT for the Baltic Sea region. However, they do not produce a complete RIOT but provide regional output multipliers for different regionalization methods. Second, using shipment data, Krebs (2020) constructs an interregional input-output table (IRIOT) containing 402 German counties, 26 foreign trading partners and 17 sectors. The IRIOT itself is not publicly available; however, the code necessary to construct the table is available upon request.

A more comprehensive approach is provided by Többen (2017a). Based on a modified version of the CHARM method developed in Többen and Kronenberg (2015), he creates a multi-regional input-output (MRIO) table for the year 2011 covering all 16 German federal states. For this purpose, a set of single regional tables is created, which are subsequently interconnected through estimates of interregional trade (for a more detailed description of the construction of the MRIO, see Többen 2017b). The modified CHARM method addresses two major limitations of the original approach: First, the original approach implicitly assumed cross-hauling in interregional trade to be zero. Second, due to structural differences between the regional and national economies, estimates of interregional trade flows potentially violated accounting balances. This MRIO is, however, not publicly available.

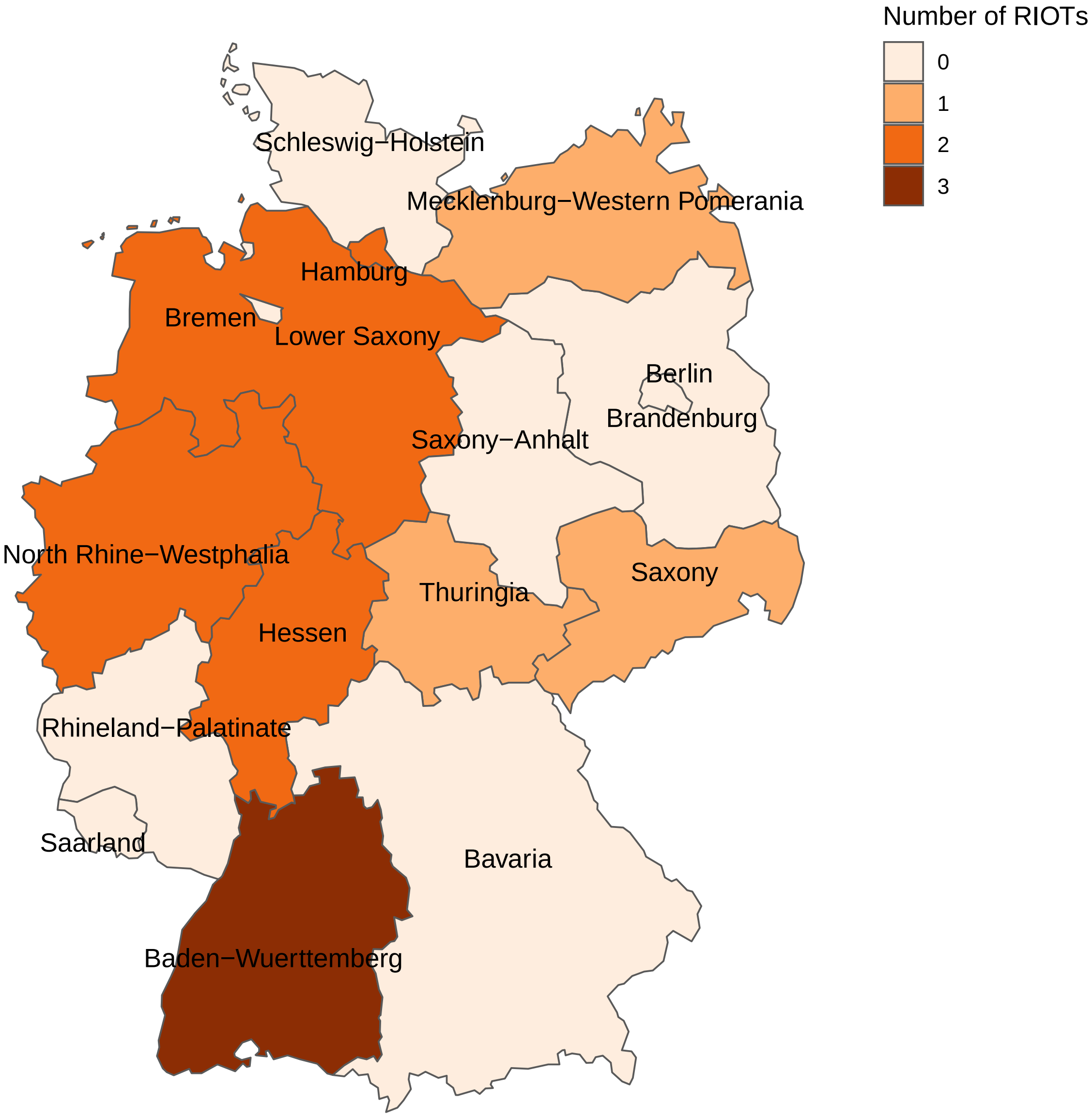

Figure 1: Availability of regional input-output tables (RIOTs) of single German federal states.

Variable	Data source	Provider	Publication frequency	Publicly available
Intermediate demand	NIOT	Destatis	annual	yes
Private consumption	EVS	Destatis	quinquennial	no
Government final consumption expenditure	VGRdL	Federal states	annual	yes
Gross fixed capital formation	VGRdL	Federal states	annual	yes
Change in inventories	NIOT	Destatis	annual	yes
Exports and imports	CHARM/NIOT	-	-	-
Compensation of employees	VGRdL	Federal states	annual	yes
Employment by sectors	Labor data	BfA	monthly	yes

Table 2: Data sources for the construction of regional input-output tables (based on Stöver 2018; Koch et al. 2019). NIOT: national input-output table, Destatis: German Statistical Office, EVS: Household Budget Survey, VGRdL: Regional Accounts of the Federal States, CHARM: cross-hauling adjusted regionalization method, BfA: Federal Employment Agency.

As illustrated in Figure 1, the availability of RIOTs differs at the German federal state level. While Baden-Wuerttemberg, Hamburg, Hessen, North Rhine-Westphalia and Lower Saxony provide multiple RIOTs, there is a discrepancy in the availability (number) of RIOTs between the eastern and western federal states.

3 Literature on regional policy effects in Germany

In the previous section, we have identified a lack of RIOTs from Germany. Correspondingly, only a relatively small number of studies attempt to quantify regional policy impacts in Germany. Focusing on the German energy transition, our literature survey has identified only a few CGE models analyzing subnational climate policy effects in Germany.

Due to the German coal phase-out, North Rhine-Westphalia is a hot spot area regarding socio-economic repercussions (for related policy recommendations, see Göke et al. 2018; Kittel et al. 2020). Therefore, González-Eguino et al. (2012) use a CGE model to investigate the effects of climate policy in North Rhine-Westphalia. The author, however, do not explicitly model CO_2 pricing or renewable energy subsidies. Instead, they assume a 15% relocation of the iron and steel sector away from North Rhine-Westphalia. The authors find that this relocation results in a decrease in regional GDP of 0.37% and a reduction in regional CO_2 emissions of approximately 2%.

Pothen and Hübler (2018) study the impacts of CO_2 pricing and renewable energy subsidies in Lower Saxony using a new quantitative trade model, i.e., a global CGE model including an elaborated trade module, with renewable energies in the electricity sector (see Section 4.1). In summary, they identify significant differences in the economic effects between Lower Saxony and the Rest of Germany induced by climate and/or trade policy. They estimate that CO_2 pricing via the EU Emissions Trading System (ETS) results in a minor welfare loss of 0.04% and a reduction in CO_2 emissions of 26.54% in Lower Saxony. The welfare loss increases to 0.27% in Lower Saxony when the ETS is accompanied by renewable energy subsidies, while the small welfare loss in the Rest of Germany is hardly affected (0.06%–0.08%). A scenario with carbon pricing but without import tariffs or export subsidies results in a welfare gain of 0.40% in Lower Saxony compared with 0.18% in the Rest of Germany.

Pothen and Hübler (2021) calibrate the model introduced by Pothen and Hübler (2018) dynamically to future development scenarios until the year 2050. Their results confirm significant regional differences between Northwest Germany and the Rest of Germany caused by climate policy. They estimate, for instance, a welfare loss of 0.11% in Northwest Germany compared with 0.59% in the Rest of Germany in a future development scenario (FDS3) with EU climate policy in 2040.

Hübler and Herdecke (2020) study the economic effects of US import tariffs against China and, as a reaction, increased Chinese import tariffs. They evaluate the model of Pothen and Hübler (2018) and another global CGE model for comparison. They find overall very small welfare effects on Germany. Nonetheless, depending on the targeted goods/sectors and magnitudes of the imposed tariffs, regional differences of policy effects are visible and can have opposite signs; for example, a 0.008% gain in Lower Saxony but a 0.004% loss in the Rest of Germany. Again, these policy modeling results indicate that regional disaggregation matters.

Several scholars carry out input-output analyses to estimate regional production and employment effects of climate policy in Germany. These studies show considerable variation in the choice of relevant economic variables and the magnitudes of the related estimated effects. Schröder (2010), for instance, investigates the production and employment effects of wind energy deployment in the Hanover region. Using a RIOT for the year 2009, he finds that wind energy use has very small regional effects on value added and employment. In his study, the construction of wind power plants is associated with additional value added of 1.6 million Euros and employment of 29 person-working hours in 2009, respectively, while the operation of wind power plants is associated with additional value added of 2.3 million Euros and additional employment of 34 person-working years. Likewise, Schröder (2012) estimates that offshore wind energy use is associated with an increase in Lower Saxony's total production value of 0.007% and additional employment of 159 person-working hours.

Heindl and Voigt (2012) conduct an input-output analysis of the turnover and employment effects of the German Renewable Energy Sources Act (EEG) in Baden-Wuerttemberg. They find that the net turnover and employment effects are highly dependent on whether investments in renewable energies are funded internally or externally via exports. With internal funding, the authors estimate net turnover and employment effects of approximately 2.4 billion Euros and –34,000 jobs until 2020, respectively, whereas investments from external funding are associated with turnover and employment effects of approximately 6.5 billion Euros and +24,000 jobs, respectively.

Bröcker et al. (2016) carry out an input-output analysis of the regional impacts of offshore wind energy expansion in Northern Germany on value added and employment. Assuming an additional offshore wind energy capacity of 15 gigawatts until 2030, the authors project an additional annual production value of 688 million Euros in 2029 and additional employment of 9,093 persons in Northern Germany.

Kronenberg et al. (2018) study the economic impacts of increased investments in energy efficiency in North Rhine-Westphalia using a bi-regional input-output table (the two regions considered being North Rhine-Westphalia and the rest of Germany). They consider a target scenario, in which the investment ratio is increased to 18% of the regional GDP and a baseline scenario without this increase. Compared to the baseline scenario, the target scenario results in a-.3 percentage point increase in the growth rate of gross value added and an additional employment of about 98,000 people.

Többen (2017a) develops an MRIO table of all 16 German federal states to analyze the regional and distributional effects of the EEG. He finds that most federal states benefit from an extended operation of renewable energies in terms of value added, particularly those states with large capacities for renewable energy generation. In addition, North Rhine-Westphalia and Baden-Wuerttemberg in particular benefit from the production of renewable energy power plant owing to their status as suppliers of intermediate products. Regarding distributional effects, the EEG has a negative impact on disposable income, which is primarily due to increased consumer prices, which puts an additional burden primarily on low-income households.

4 Simulation of regional climate policy effects in Germany

This section presents an exemplary regional policy analysis of Germany. It provides an overview of the model and its regional disaggregation, it defines climate policy scenarios and discusses the simulation results.

4.1 Overview of the model

In our policy analysis, we apply the global new quantitative trade model by Pothen and Hübler (2018) with an updated calibration to Global Trade Analysis Project (GTAP) version 10 data with the base year 2014.[3] The trade module follows the Ricardian new trade theory of Eaton and Kortum (2002). Within Germany, it goes beyond GTAP by explicitly representing the federal state Lower Saxony separated from the Rest of Germany (for an overview of the regional disaggregation, see Section 4.2; for details, see Pothen and Hübler 2018). Additionally, it goes beyond GTAP by disaggregating the power sector of the regions Lower Saxony

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[3] `https://www.gtap.agecon.purdue.edu/`.

(LSX), Rest of Germany (ROG), France (FRA), United Kingdom (GBR) and Italy (ITA) representing the following energy sources/technologies: coal, oil, gas, nuclear, hydro, wind, solar, geothermal and biomass.

Sector	Description
AGRI	Agriculture
COAL	Coal
CRUD	Crude oil
NGAS	Natural gas
PETR	Refined petroleum
FOOD	Food production
MINE	Mining
PAPR	Paper and pulp
CHEM	Chemicals, rubber and plastic
NMMS	Mineral products nec.
IRST	Iron and steel
NFMS	Non-ferrous metals
MANU	Manufacturing
ELEC	Electricity
TRNS	Transport
CONS	Construction
SERV	Services
INVS	Investment

Table 3: Sectors (goods and services) of Pothen and Hübler (2018).

The deployed aggregation of the global data set GTAP features 18 production sectors (various goods, services and investment, see Table 3) in each of the 19 model countries/regions (see Table 4).[4] Production (output) is sold domestically or exported. Investments are not traded but added to the domestic capital stock. Each model country/region features a representative consumer who absorbs domestic production and imports. Her expenditures are financed via income from providing the production factors labor, capital and natural resources and from receiving net transfers (tax revenues minus subsidies) in a lump-sum way. The production factors are internationally immobile. They enter the production sectors as inputs together with intermediate goods inputs that can be produced domestically or imported.

Production, consumption and trade are represented by constant elasticity of substitution functions. The reaction of trade flows to changes in tariffs or trade costs is based on a structural estimation of the parameter values of the trade module including iceberg trade costs and gravity model parameters, such as a common border, common language or free trade agreement (see Pothen and Hübler 2018). The GTAP data incorporate existing taxes/tariffs and subsidies. Hence, the model represents a sub-optimal second-best world.

The solution of the resulting set of optimality conditions yields a market equilibrium of all goods and factor markets in all countries under perfect competition without modeling externalities.

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[4] *EU27* (European Union) and *WRLD* (World) aggregate the results of the included countries but do not appear in the model.

4.2 Regional disaggregation of the model

For the following policy analysis, the data underlying the model have been updated to GTAP 10. Within Germany, the model calibration separates Lower Saxony (LSX) from the Rest of Germany (ROG). To this end, following the literature summarized in Sections 2 and 3, Pothen and Hübler (2018) derive a regional disaggregation procedure which is detailed in Appendix E of their article.

First, using consumption/investment data from VGRdL (2022b) and assuming that consumer preferences are identical across German federal states, Lower Saxony's consumption and investment shares are calculated and applied to the GTAP data.

Second, using employment and energy data from BfA (2016a), BfA (2016b), LAE (2016a), LAE (2016b), and WVEE (2012), Lower Saxony's sectoral gross output shares are calculated.

Third, assuming that the pattern of intermediate goods inputs in production is the same across German federal states, Lower Saxony's input shares are computed.

Fourth, the Cross-Hauling Adjusted Regionalization Method (CHARM, Kronenberg 2009), extended by Többen and Kronenberg (2015), is applied to approximate trade flows between Lower Saxony and the Rest of Germany as well as other countries and world regions.

4.3 Definition of the policy scenarios

For our exemplary regional policy analysis of German, we define two policy scenarios.

First, to set the emissions target of the European Emissions Trading System (EU ETS), we follow the current greenhouse gas emissions target for the year 2030 envisaged by the European Commission (Climate Action) and translate it into a 44% reduction of CO_2 emissions vis-à-vis 2014, which is within the scope of the model's capability to reduce emissions based on the benchmark data of the year 2014.[5] We denote this policy scenario by EUETS.

Second, the novelty of our analysis is the examination of regional effects induced by the Carbon Border Adjustment Mechanism (CBAM) announced by the European Commission (Taxation and Customs Union).[6]

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[5] "Our ambition for 2030: Under the European Climate Law, EU Member States will work collectively to become climate neutral by 2050. As a first milestone, the EU is aiming to reduce net emissions by at least 55% by 2030 compared to 1990. The revised EU ETS will contribute to delivering this target. To achieve the necessary emission reductions cost-effectively, the EU ETS has been strengthened, and its scope expanded to maritime transport. Altogether, the cap is tightened to bring emissions down by 62% by 2030 compared to 2005 levels," `https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/our-ambition-2030_en` (accessed 03/2024).

[6] "CBAM: The EU's Carbon Border Adjustment Mechanism (CBAM) is the EU's tool to put a fair price on the carbon emitted during the production of carbon intensive goods that are entering the EU, and to encourage cleaner industrial production in non-EU countries. By confirming that a price has been paid for the embedded carbon emissions generated in the production of certain goods imported into the EU, the CBAM will ensure the carbon price of imports is equivalent to the carbon price of domestic production, and that the EU's climate objectives are not undermined. The CBAM is designed to be compatible with WTO-rules. CBAM will apply in its definitive regime from 2026, while the current transitional phase lasts between 2023 and 2026. This gradual introduction of the CBAM is aligned with the phase-out of the allocation of free allowances under the EU Emissions Trading System (ETS) to support the decarbonisation of EU industry," `https:`

This policy aims at levelling the carbon playing field between producers within the EU subject to EU carbon pricing and those producing outside the EU without or with lower carbon pricing and exporting into the EU. In this way, fairer competition and reduced carbon leakage[7] shall be achieved. The carbon contents of products imported into the EU are taken from Hübler et al. (2024) and priced at US-\$240 per ton of CO_2 derived from the general equilibrium model solution. We denote this policy scenario by CBAM.

4.4 Results of the policy scenario simulations

Table 4 reports the policy scenario simulation results focusing on the welfare effects of each policy scenario relative to the benchmark calibration without these policies. Figure 2 summarizes and illustrates the policy effects on Lower Saxony and the Rest of Germany.

Region	Description	EUETS	CBAM	CBAM –EUETS
LSX	**Lower Saxony**	**0.17**	**0.42**	**0.25**
ROG	**Rest of Germany**	**–0.19**	**–0.05**	**0.14**
FRA	France	0.10	0.19	0.08
GBR	United Kingdom	–0.21	–0.18	0.04
ITA	Italy	–0.23	–0.22	0.01
EUR	Rest of EU-27	–0.56	–0.69	–0.12
ROE	Rest of ETS (non-EU)	0.02	0.13	0.12
$EU27$	EU-27 (aggregate result)	–0.30	–0.31	0.00
FSU	Former Soviet Union	0.06	–0.14	–0.20
BRA	Brazil	0.00	–0.01	–0.01
CAN	Canada	0.02	–0.03	–0.05
USA	United States of America	–0.01	–0.02	–0.01
MEX	Mexico	0.01	–0.03	–0.04
CHN	China	0.00	0.00	0.00
IND	India	–0.01	–0.03	–0.02
JPN	Japan	0.01	0.02	0.02
KOR	South Korea	0.00	0.04	0.04
ROA	Rest of Asia	–0.03	–0.07	–0.04
OCE	Australia & Oceania	–0.05	–0.07	–0.02
ROW	Rest of the World	0.02	–0.12	–0.14
$WRLD$	World (aggregate result)	–0.08	–0.10	–0.02

Table 4: Policy effects of the European Emissions Trading System (EUETS) and the European Carbon Border Adjustment Mechanism (CBAM) on the model regions. The reported welfare effects are measured as relative changes between the scenario EUETS or CBAM compared with the no policy benchmark scenario referring to the year 2014 (GTAP 10). CBAM–EUETS reports the difference between CBAM and EUETS in percentage points.

`//taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en` (accessed 03/2024).

[7] Theoretically, emissions reductions in the EU can partly be compensated by emissions increases abroad via reductions of fossil fuel prices on international markets, relocation of EU producers to abroad or climate policy relaxation abroad.

Welfare effects of EUETS:

The CO_2 price in the EU ETS reaches approximately US-\$190 per ton of CO_2. The renewable energy share in power generation (ELEC) increases to almost 46% compared with 30% in the benchmark in Lower Saxony (LSX) and to 42% compared with almost 21% in the benchmark in the Rest of Germany (ROG). While all resulting welfare losses are smaller than 0.6%, all welfare gains are smaller than 0.2%.

Lower Saxony (LSX, 0.17%) and France (FRA, 0.10%) benefit most from the EU ETS due to their large wind or nuclear potential, respectively. The Rest of Germany (ROG), the United Kingdom (GBR) and Italy (ITA) become worse off (by 0.19%, 0.21% and 0.23%, respectively). The remaining EU ETS countries that are not EU members (ROE) benefit slightly (0.02%). The remaining EU countries that are EU members (EUR) lose significantly (by 0.56%): while the model features renewable energies explicitly in the separate EU countries (LSX, ROG, FRA, GBR and ITA), this feature is not available in the aggregate EU ETS regions (EUR and ROE), which renders decarbonization more difficult and costly. The aggregate EU ($EU27$) region suffers a moderate welfare loss (by 0.30%).

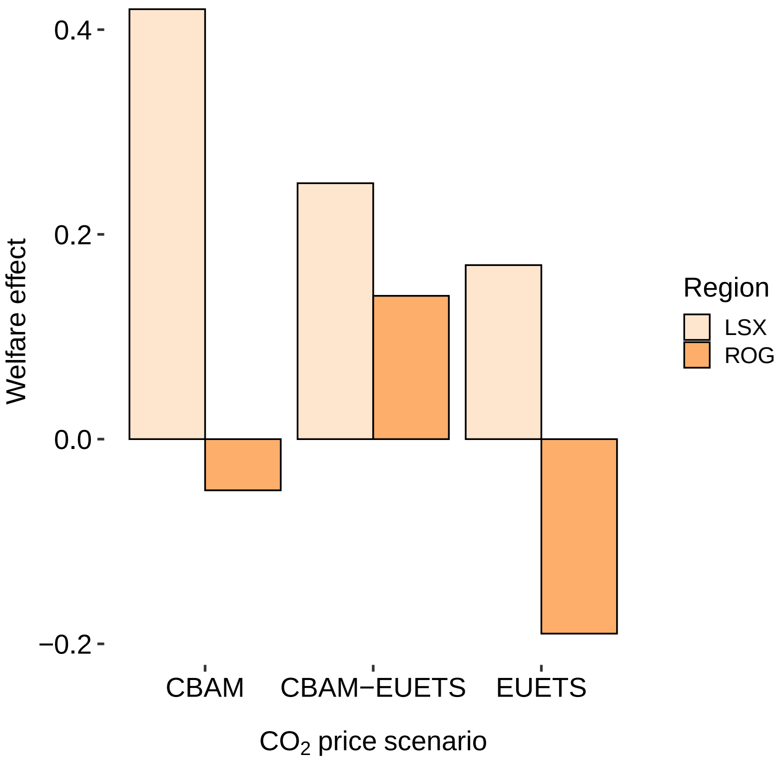

Figure 2: Policy effects of the European Emissions Trading System (EUETS) and the European Carbon Border Adjustment Mechanism (CBAM) on Lower Saxony (LSX) and the Rest of Germany (ROG). The welfare effects are measured as relative changes between the scenario EUETS or CBAM compared with the no policy benchmark scenario. CBAM–EUETS illustrates the difference between CBAM and EUETS in percentage points.

The former Soviet Union (FSU) countries benefit slightly from the EU ETS (by 0.06%); although fossil fuel imports into the EU are hindered, carbon-intensive production may be relocated from the EU to neighbor countries, such as FSU. Effects on the Rest of the World (ROW, a 0.02% gain) and the entire world ($WRLD$, a 0.08% loss) are small. Similar to the entire EU, the entire World loses due to carbon pricing because the benefits of less CO_2 in the atmosphere and hence reduced climate change are not taken into account and carbon pricing creates an economic distortion (inefficiency). The large open economies USA and India (IND, both a 0.01% loss), Japan (JPN), Mexico (MEX, both a 0.01% gain) and Canada (CAN, a 0.02% gain) are affected to a minor extent, while Korea (KOR), China (CHN) and Brazil (BRA) are insignificantly affected.

Overall, the EU ETS has smaller effects than in the study by Hübler et al. (2024), because the model examined here provides more flexibility to reduce CO_2 emissions, especially to decarbonize power supply in the EU countries where energy sources/technologies are modelled explicitly. Particularly, France (FRA) benefits from its large nuclear power potential. The policy effect on the Rest of the EU-27 (EUR), however, is very similar in both models (approximately, –0.5%) despite different climate policy targets (a 10% reduction in 2014 in Hübler et al. 2024). The EU policy spillovers on other countries/regions in the world are also smaller in this study than in Hübler et al. (2024) which indicates that the trade module of the model deployed here provides more flexibility as well. The qualitative pattern of the policy spillovers on other countries/regions in the world also differs from the results of Hübler et al. (2024).

In summary the EU ETS results presented in Table 4 and illustrated in Figure 2 underline that regional disaggregation matters: the climate policy effects of the EU ETS on Lower Saxony and the Rest of Germany have similar magnitudes but opposite signs. Lower Saxony benefits from climate policy with emissions trading due to its large wind power potential. Further disaggregation of the Rest of Germany, e.g., in south, east and west, could reveal further differences between regions regarding their potential to expand renewable energies and hence to reduce emissions with relatively low marginal abatement costs. Furthermore, the policy effects differ significantly across European countries/regions.

Welfare effects of CBAM:

In this policy scenario, the CO_2 price reaches approximately US-$240 per ton of CO_2. The renewable energy share in power generation (ELEC) increases to more than 47% compared with 46% under EUETS in Lower Saxony (LSX) and to 46% compared with almost 42% under EUETS in the Rest of Germany (ROG). All resulting welfare losses are smaller than 0.7%, while welfare gains are smaller than 0.5%. We are particularly interested in the differences in the welfare effects of CBAM (EU ETS plus import tariffs) compared with those of the EU ETS alone (see above) as displayed in the right column of Table 4 in percentage points.

CBAM intensifies the EU ETS effects and creates typical trade policy effects. The EU is hardly affected (tiny negative effect) by CBAM compared with EU ETS whereas the entire World ($WRLD$) slightly loses (by 0.02 percentage points) compared with the EU ETS. The Rest of the World (ROW) significantly loses (by 0.14 percentage points) due to CBAM.

France (FRA), the United Kingdom (GBR) and Italy (ITA) benefit from CBAM (by 0.08, 0.04 and 0.01 percentage points, respectively). While the Rest of the EU (EUR) becomes worse off (by 0.12 percentage points), the Rest of the EU ETS (ROE) becomes equally better off (also by 0.12 percentage points). The entire EU ($EU27$) is not significantly affected by CBAM compared with EUETS. Notably, CBAM significantly reduces the EU ETS-induced loss of the Rest of Germany (ROG, 0.19%) by 0.14 percentage points (to 0.05%). Similarly, CBAM substantially increases the EU ETS-induced gain of Lower Saxony (LSX, 0.17%) by 0.25 percentage points (to 0.42%).

The Former Soviet Union (FSU) countries lose significantly due to CBAM (by 0.20 percentage points), because fossil fuel imports as well as imports of carbon-intensive goods into the EU are hindered. Japan (JPN) and Korea (KOR) gain slightly (by 0.02 and 0.04 percentage points) due to CBAM, while Canada (CAN) and Mexico (MEX) lose slightly (by 0.05 and 0.04 percentage points). Again, large open economies, such as China (CHN), the USA and India (IND) are affected to a minor extent (by 0.00, 0.01 and 0.02 percentage points, respectively).

The qualitative pattern of the policy spillovers of CBAM on other countries/regions in the world derived from the new quantitative trade model is very similar to the pattern found by Hübler et al. (2024) derived from an Armington trade model. Quantitatively, the magnitudes of the effects of CBAM compared with those of the EU ETS are also similar to those found by Hübler et al. (2024). One notable exception is the small welfare loss of the Rest of the EU due to CBAM displayed in Table 4 that contrasts with a small gain found by Hübler et al. (2024). Considering the entire EU-27 (*EU27*), according to Table 4, however, this negative effect is neutralized by the positive effects in the explicitly modeled EU countries such that an EU-wide effect of CBAM is hardly visible. This outcome highlights the relevance of modelling single countries within a larger political or geographic macro-region (here the EU) because the effects within a macro-region can be heterogeneous.

In summary, the CBAM results confirm that regional disaggregation matters: the positive regional effects of CBAM on Lower Saxony are substantially stronger than on the Rest of Germany. As before, the policy effects differ across European countries/regions.

5 Research priorities and data requirements

The insights from the literature review (in Section 3) and the policy modeling (in Section 4.1) highlight regional differences of policy effects within Germany. The overview of available data (in Section 2), however, reveals a discrepancy in the availability (and number) of RIOTs describing single federal states across the German federal states, especially between the eastern and western part of Germany. Notably, the existing regional data are in general not officially, comprehensively and publicly provided by statistical offices but have been constructed by researchers in need of regional data for their envisaged (policy) analysis. Several *priorities* of future research and data provision emerge from these considerations and results:

First, we have identified a lack of available RIOTs for several German federal states. Official data from statistical offices seem to be exceptional and outdated. This dearth of data is particularly prevailing in the eastern federal states. Considering the large differences in the economic importance of certain sectors across regions (e.g., mining in Lusatia or wind energy in Schleswig-Holstein), this discrepancy should be addressed by researchers in order to accurately quantify the regional impacts of climate policy measures. Consequently, the creation and provision of a standardized/harmonized German regional database, at least with federal state level resolution covering all federal states (i.e., a multi-regional input-output, MRIO, table following Többen 2017a; Többen 2017b), should be enhanced and established, supported by public funding. As long as such a comprehensive data set is not officially available, scholars can consecutively advance the creation of federal state RIOTs that can eventually be combined to a German-wide data set.

Second, at the time of writing only five of the 14 RIOTs identified in our review of the literature were publicly available. While this issue appears to be particularly prevalent in older publications, even in the most recent contributions included in our survey the constructed regional data sets are not openly accessible. Thus, future research or official statistical data provision should enable the public availability of up-to-date regional data to provide a openly accessible database for all interested researchers.

Third, while the need for nationwide data is not adequately met at the federal state level, further disaggregation of RIOTs within federal states to individual regions is required to narrow down specific policy effects. Evaluating such effects at a more granular level can be crucial for regions that are strongly affected by climate change impacts or climate/energy policy measures due to sensitive sectors located there. This includes regions whose production depends on energy- or greenhouse gas-intensive production sectors or production chains with resulting negative effects of carbon pricing and regions that strongly benefit from the subsidization of climate-friendly technologies or from financial compensation. One example for such a climate policy-sensitive region is Lusatia in the east of the federal state of Brandenburg (Seibert et al. 2018). Despite the relatively low population density, Lusatia is the second-largest lignite mining region in Germany.

Considering the relevance of lignite for power generation, the mining sector is of particular importance for the local economy. While in the short-run, lignite will continue to be used for power generation, Germany's energy policy includes a complete phase-out of coal for power generation by 2038 (Stürmlinger and Fuchs 2021), which will likely have important implications for Lusatian employment and purchasing power. Sgarciu et al. (2023), using a partial-equilibrium investment and dispatch model, project an annual loss of 900 jobs due to the coal phase-out plan in Lusatia. In addition, the authors find that increases in CO_2 prices may accelerate the phase-out of Lusatian lignite-fired power generation. However, their results likely underestimate the total employment impacts, as their model does not capture general equilibrium effects of the coal phase-out plan. Against this backdrop, the long-term goal should be the creation of a German-wide input-output table that distinguishes (policy-sensitive) regions within German federal states. In this regard, the available district level data provide a profound basis (see points eight and nine below, VGRdL 2022a).

Fourth, a particular challenge emerges because trade and factor mobility between regions within a country differ from international trade and factor mobility. They are not monitored and reported in official statistics like international trade, migration or capital movements either. A reasonable assumption could be perfect factor mobility across regions within the same country but no factor mobility across countries or world regions. Then, however, the definition of a model region based on a representative consumer with region-specific factor-endowments becomes a technical challenge. Consequently, imperfect factor mobility within a country could be a solution. Then, factor mobility across countries with a lower degree of mobility could be a logical next step, especially considering the increasing relevance of international migration for Germany, Europe and the World as well as the importance of foreign direct investment (FDI) and international financial flows (portfolio investments). These mechanisms, however, require a suitable and tractable theoretical foundation, model implementation as well as calibration data. Similarly, we need to find an adequate representation of within-country trade, especially regarding data assumptions, in contrast to the standard case of international trade, for which we have theories, model implementations and data. In the context of international trade and international investments, multinational enterprises and "global players" play a central role. Within a country, however, they reside within specific federal states or regions and there is likely regional concentration of producers and suppliers making use of supplier-customer relations within the supply chain, business relations, exchange of workers and ideas, i.e., knowledge spillovers, and so forth (the most prominent example is the Silicon Valley). Consequently, domestic, foreign or international policies affecting such multinational enterprises have strong effects on their regions of residence and smaller effects on other regions. A profound regional policy analysis in a globalized world would need to take this into account.

Fifth, related to that, the sectoral structures of federal states or regions (with a focus on agriculture, automotive etc.) can significantly differ. The sectoral structures, however, might not be perfectly represented by constructed data sets, and data on (sectoral) intermediate goods inputs can be missing. Furthermore, the available sectoral resolution can be insufficient. For the purpose of climate/energy policy analysis, Pothen and Hübler (2018) and Pothen and Hübler (2021), for example, combine the regional disaggregation with the disaggregation of the power sector distinguishing different energy sources/technologies. In Section 4, we follow this model setup. Depending on the policy question, such a sectoral disaggregation can also be relevant for other sectors. In the climate/energy policy context, the representation of specific energy-/CO_2-intensive industries (cf. Hübler and Löschel 2013), such as cement, possibly including process emissions, can be relevant (in combination with regional disaggregation). Other examples for sectors that are relevant for Germany, are the automotive industry and specific types of machinery or information and communication technologies.

Sixth, against this background, a major research priority is the establishment of a standardized/harmonized method for the construction of RIOTs or MRIO tables, especially when combining the developed RIOTs of single federal states to one German-wide data set (because different approaches to disaggregating the data might lead to misleading differences in the policy results). This includes the treatment of within-country versus cross-country trade of final and intermediate goods (and factor mobility). A promising method to harmonize the construction of RIOTs and MRIO tables is the CHARM approach by Kronenberg (2009) taking into account within-industry trade. To create a harmonized data set, more cooperation amongst researchers, coordination and (project) support from statistical offices or governments are needed.

Seventh, for climate and energy policy analysis, the transfer of electricity (and other types of energy carriers, such as gas or hydrogen) is of particular interest. Due to elaborated within-country grids, within-country energy exchange is presumably significantly larger than between countries. Improvements and extensions of power supply and energy storages that are necessary for renewable energy expansion, such as the North-South transmission line in Germany, need to be considered. In this regard, links to power grid models or their results and insights can be helpful, for example, considering decentralization of power supply, high-voltage grids, electricity-heat coupling, renewable energy fluctuations and storages (e.g., Böing et al. 2018). For this purpose, the design of a comprehensive nation-wide modeling framework, for instance, within an interdisciplinary project with combined capability in engineering and economics can be helpful (see, for example, the interdisciplinary NEDS – Nachhaltige Energieversorgung Niedersachsen – project on Northwest Germany; Blaufuß et al. 2019).

Eighth, macroeconomic data are provided by the Statistical Offices of the Federal States for the German federal states and even for administrative districts. The district level ("Kreisebene") data contain the gross domestic product, (sectoral) value added, (sectoral) employment and so forth (VGRdL 2022a). The federal state data contain the gross domestic product, employment, (labor) income, savings/investments, public and private consumption and so forth (VGRdL 2022b). However, they do not contain the detailed patterns of income sources and consumption expenditures on different goods/services that are required for regional analysis methods. In absence of these data, the standard assumption adopted in our analysis (in Section 4) is that the income and consumption patterns of the representative consumer of each federal state mimic those of the average nation-wide consumer. This assumption, however, neglects discrepancies in income and inequality within a country, here Germany, that are related to differences in income sources. Income sources are in turn related to region-specific (in-situ) natural resource endowments including fossil fuels. Climate/energy policy, however, significantly devaluates fossil fuels and thus has significant negative income effects on fossil fuel owners (cf. Hübler et al. 2024) which can be expected to show up as region-specific losses. Additionally, capital ownership may differ across regions. How far consumption patterns regionally differ within a country in a policy-relevant way depends on the policy under scrutiny and is left for future descriptive and analytical research.

Ninth, the distinction of household/consumer income groups is another important dimenstion of disaggregation. While disaggregated income groups have been implemented at the German-wide level (Hübler et al. 2024) and led to significant differences in policy effects across income groups, the investigation of inequality effects at the regional within-country level is missing. Because average income differs regionally, between rural and urban areas and particularly across federal states in Germany, regional differences in the inequality effects of policies can be expected. Therefore, the combination of regional data with household income group data can provide new insights. The required data are basically available within the German Household Budget Survey (EVS, FDZ 2024).

6 Conclusion

We have reviewed the literature on regional policy effects in Germany and carried out a new policy analysis of the European Carbon Border Adjustment Mechanism (CBAM) that is currently being implemented regarding its regional effects within Germany as a new aspect. The results from the literature and our own analysis highlight regional differences in policy effects. Our general equilibrium model-based policy simulations indicate small but opposite effects of the European Emissions Trading System (EU ETS) on Lower Saxony (positive effect) compared with the Rest of Germany (negative effect). CBAM has small positive effects on both regions, however, the magnitude is considerably larger in Lower Saxony than in the Rest of Germany. As expected, the entire EU is worse off due to the EU ETS, because benefits from reduced climate change are not modeled. Positive and negative policy effects of CBAM across EU members, however, nearly cancel each other out such that the effect of CBAM on the entire EU is negligible. These insights underline that region-wide (here, the EU) and country-wide (here, Germany) results can be misleading for giving reliable local (here, Lower Saxony) policy advice.

In contrast to these insights, our review of available regional data within Germany reveals a dearth of publicly available official and constructed data. Therefore, the overarching goal is the creation and provision of a comprehensive, standardized, *publicly available, Germany-wide* multi-regional input-output (MRIO) table as developed by Többen (2017a) and Többen (2017b). It shall cover all 16 federal states and is suitable for policy modelling (where Berlin, Hamburg and Bremen can be integrated in surrounding federal states). This comprehensive data set could be officially and publicly provided by the Germany-wide or federal state-specific statistical offices (such as Statistisches Bundesamt) in an easily accessible way (online access). Financing such data provision appears to be reasonable in the context of financing the German energy transition and climate/energy policy-related research. Meanwhile, scholars can consecutively advance the creation of RIOTs following harmonized standards so that the data can eventually be combined to a German-wide data set.

With such a database, researchers could verify how far the results found in the literature and in our own analysis are robust to the choice of the regional disaggregation procedure and the availability of accurate and comprehensive data. The results can also differ when more German regions (federal states) are modeled separately/explicitly, because the interactions across regions via interregional trade (compared to international trade) and interregional factor movements (labor mobility, i.e., migration, capital mobility, i.e., geographic flexibility of investments) are conceptually different within countries compared with the mechanisms across countries, for which established theories and (numerical) models exist. The more artificially constructed regional data are used, e.g., for several federal states and their interactions, the more sensitive the results will be towards differences in the disaggregation methods used, including necessary heuristics/approximations. In the climate/energy policy and energy transition context, interregional power grids and transmission lines (together with energy storages) create important interregional linkages and require an interdisciplinary economics-engineering approach (Böing et al. 2018; Göke et al. 2018; Blaufuß et al. 2019).

Considering that policies can have a restricted local/regional scope and country-wide policies can have extraordinary local/regional effects due to local/regional circumstances (e.g., the German coal phase-out and its effects on Lusatia and North Rhine-Westphalia), a more detailed geographic resolution of the provided data than the federal state level can be appropriate, at least for selected relevant areas that need to be identified by policymakers and researchers.

Policies often affect different sectors/industries to very different extents (see, e.g., Hübler and Löschel 2013). The sectoral structure varies significantly across (German) federal states that can be dominated by agriculture or specific industries, such as the automotive industry with car producers and suppliers of components. Therefore, a more precise and comprehensive regional representation of the output and input structures is required. Additionally, the combination of regional with further sectoral disaggregation can be advisable. Sectoral disaggregation of power supply implemented by Pothen and Hübler (2018) has been used in our model simulations. Hübler and Löschel (2013) provide a disaggregation of industry sectors separating energy-intensive segments. In this way, in the context of climate/energy policy also process emissions can be considered. This kind of sectoral disaggregation can be extended to further important German sectors, such as automotive, machinery, information and communication technologies, preferably at the regional level.

In this regard, multinational enterprises and "global players" play a crucial role in the determination of policy impacts, such as employment effects. They are not only affected by local policies but also by policies abroad or changes in international regulation or on international markets. Because such enterprises are located or concentrated in certain areas, the effects can be locally strong but average out at the country-wide level. Therefore, to identify these effects, regional disaggregation at the federal state level or better at a more granular level is required.

On the consumption side, regional data need to include detailed region-specific income source and consumption expenditure patterns of households/consumers instead of assuming that they are the same throughout the country. A related relevant dimension of disaggregation that can lead to significant differences of policy effects is the distinction of household/consumer income groups. So far, the distinction of income groups has been implemented at the German-wide level using official survey data (see Hübler et al. 2024; FDZ 2024). Because the distribution of income as well as land/resource ownership is regionally different, the combination of regional disaggregation with consumer disaggregation can provide new insights in regional inequality effects.

Against this background, we have identified a number of challenges summarized in the paragraphs above. If these challenges are successfully addressed, a reliable harmonized database for the analysis of regional policy effects in Germany can be established. We believe that the discussion of Germany provides insights that are relevant for other countries as well.

Acknowledgement

We gratefully acknowledge funding from the German Federal Ministry of Education and Research (BMBF) for the project "Mitigation Policies in a Globalized and Developing World: The Role of Structural Change and Distributional Effects" (ROCHADE, grant 01LA1828C). We thank Johannes Hampp for updating the model calibration and Malin Wiese for helpful comments.

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