Regionalized Input-Output Modeling to Assess the Impacts of Energy Transition Investments on the Local Economy:
A Case Study of Schleswig-Holstein, Germany

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FCN | Future Energy Consumer Needs and Behavior

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Agenda

- Introduction and Motivation
  - Why Schleswig-Holstein?
  - Why I/O modelling?
- Related Literature
- Methodology
  - Input-Output Models
  - Regionalization Techniques
- Data
- Results
  - Further work in progress
- Discussion

Introduction and Motivation I

ENERGIEKOSMOS ENSURE

KOPERNIKUS ENSURE PROJEKTE Die Zukunft unserer Energie

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

Exploring Germany’s electric grid infrastructure needs until 2050

Technology	Society	Economy	Ecology

Schleswig-Holstein:

Germany‘s northernmost federal state and “Modellregion” (‘model region’)

- well-developed wind power generation
- extensive grid infrastructure
- representative social and demographic structure

Introduction and Motivation II

Exploring Germany's electric grid infrastructure needs until 2050

Technology	Society	**Economy**	Ecology

Input/Output Modeling

- macroeconomic concept
- modeling the interdependence in production
  - network of exchanges between sectors

Research Question

What effects do investments in energy assets and grid infrastructure have on the regional economy (in the short-term)?

Related Literature I

I/O models and energy

Madlener and Schreiner (2021), *Energy Policy*: National I/O analysis of grid investments

Madlener and Koller (2007), *Energy Policy*: Regional I/O study on heating systems

DIW Berlin (2020), *DIW-Expertisen*: Regional I/O study on onshore wind energy in Schleswig-Holstein

Kronenberg et al. (2018), *report*: I/O-based scenario analysis for sustainable development in NRW, Germany

Lehr et al. (2018), *report*: I/O-based analysis of employment effects

I/O models and regionalization

Klijs et al. (2016), *Impact Assessment in Tourism Economics*: Comparison of commonly used regionalization methods

Flegg et al. (1995, 2000), *Regional Studies*: Development of the FLQ-methods for regionalization

Flegg and Tohmo (2008, 2019), *Papers in Regional Science*: Empirical evaluation of the FLQ method

Többen and Kronenberg (2015), *Economic Systems Research*: Development of the CHAR-method

Pratt (2015), *Annals of Tourism Research*: Regionalized I/O analysis on tourism

Energy and (regional) economy

Chang et al. (2019), *Global Energy Interconnection*: Investment optimization model for the entire grid

De Oliveira-De Jesus and Henggeler Antunes (2018), *Sustainable Energy*: welfare optimization model for grid investments

Wolak (2015), *Energy Policy*: Competitiveness benefits to consumers from grid expansion

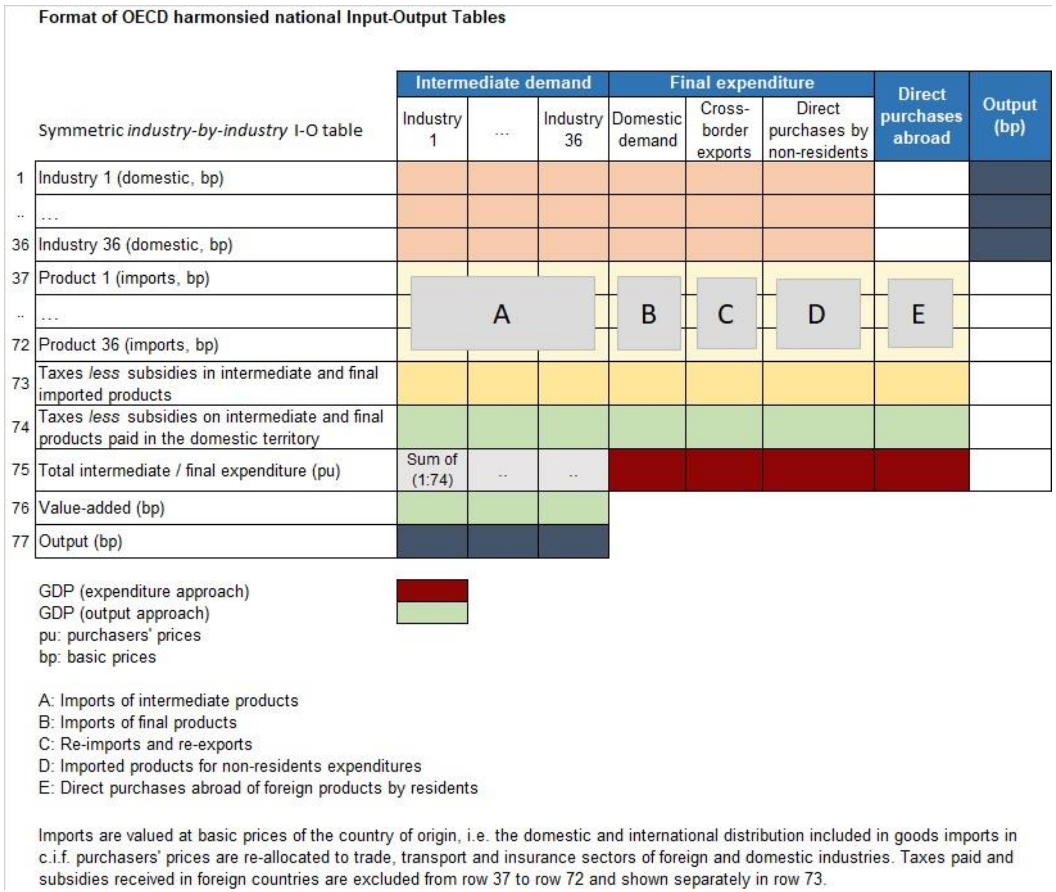
Missing Piece:

regional I/O studies for energy infrastructure

Methodology I:
Intptut/Output Modeling I: I/O Tables

I/O Models

Based on I/O-Tables, I/O models describe the structure of an economy



Format of OECD harmonsied national Input-Output Tables

	Symmetric *industry-by-industry* I-O table	Intermediate demand			Final expenditure			Direct purchases abroad	Output (bp)
		Industry 1	...	Industry 36	Domestic demand	Cross-border exports	Direct purchases by non-residents		
1	Industry 1 (domestic, bp)								
..	...								
36	Industry 36 (domestic, bp)								
37	Product 1 (imports, bp)	A			B	C	D	E	
..	...								
72	Product 36 (imports, bp)								
73	Taxes *less* subsidies in intermediate and final imported products								
74	Taxes *less* subsidies on intermediate and final products paid in the domestic territory								
75	Total intermediate / final expenditure (pu)	Sum of (1:74)	..	..					
76	Value-added (bp)								
77	Output (bp)								

GDP (expenditure approach)
GDP (output approach)
pu: purchasers' prices
bp: basic prices

A: Imports of intermediate products
B: Imports of final products
C: Re-imports and re-exports
D: Imported products for non-residents expenditures
E: Direct purchases abroad of foreign products by residents

Imports are valued at basic prices of the country of origin, i.e. the domestic and international distribution included in goods imports in c.i.f. purchasers' prices are re-allocated to trade, transport and insurance sectors of foreign and domestic industries. Taxes paid and subsidies received in foreign countries are excluded from row 37 to row 72 and shown separately in row 73.

I/O Table:

- national statistical office
- time-lag
- production by sector
  - intermediate use
  - final consumption

Image:
https://www.oecd.org/sti/ind/input-outputtables.htm

Methodology I:
Intput/Output Modeling II: A brief overview

$$X_i = \sum_{j=1}^{N} X_{ij} + F_i \qquad i = 1, \dots, N$$

Total production = sum of intermediate and final use

$$X_{ij} = a_{ij} X_j \quad \rightarrow \quad a_{ij} = \frac{X_{ij}}{X_j} := const$$

Assumption: constant technology in the short-run

$$X_i = \sum_{j=1}^{N} a_{ij} X_j + F_i, \qquad i = 1, \dots, N$$

Substitution

$$\begin{pmatrix} X_1 \\ X_2 \\ X_3 \\ X_{\dots} \\ X_n \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & \dots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \dots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \dots & a_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & a_{n3} & \dots & a_{nn} \end{pmatrix} \cdot \begin{pmatrix} X_1 \\ X_2 \\ X_3 \\ X_{\dots} \\ X_n \end{pmatrix} + \begin{pmatrix} F_1 \\ F_2 \\ F_3 \\ F_{\dots} \\ F_n \end{pmatrix}$$

Obtaining a system of linear equations

$$\boldsymbol{X} = \boldsymbol{A}\boldsymbol{X} + \boldsymbol{F}$$

Methodology I:
Intput/Output Modeling II: A brief overview

$$\boldsymbol{X} = \boldsymbol{AX} + \boldsymbol{F}$$

$$(I - A)X = F$$

Production by sector as a function of demand

$$X = (I - A)^{-1} \cdot F$$

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

$$X = L \cdot F$$

L is the Leontief-inverse matrix

(in honor of Wassily Leontief)

- describes output multipliers

Challenge:

Estimating **L** (or **A**) for a single region without survey data

Assumption: linear relationship with national coefficients

$$a_{ij}^{ir} = t_{ij}^{ir} \cdot a_{ij}^{n}$$

Methodology II: Regionalization
Simple-Location Quotient

Location Quotient | $a_{ij}^{ir} = t_{ij}^{ir} \cdot a_{ij}^{n}$ | national I/O table

Data: regional production

Assumptions:

1. The bigger/smaller the (relative) size of sector
   - The bigger/smaller the likelihood of supplying goods
2. Regional relative supply cannot exceed national supply

$$t_i^{ir} = SLQ_i = \frac{\left(\frac{x_i^r}{x^r}\right)}{\left(\frac{x_i^n}{x^n}\right)}$$

$$a_{ij}^{r} = \begin{cases} SLQ_i \cdot a_{ij}^{n} & \forall\, SLQ_i^r < 1 \\ a_{ij}^{n} & \forall\, SLQ_i^r \geq 1 \end{cases}$$

Limitations:

No Cross-Hauling

No measure of import-propensity

Methodology II: Regionalization
Flegg Location Quotient

Location Quotient | $a_{ij}^{ir} = t_{ij}^{ir} \cdot a_{ij}^{n}$ | national I/O table

Data: regional production

Assumptions:

1. The bigger/smaller the (relative) size of sector and the smaller/bigger the (relative) size of the receiving sector
   - The bigger/smaller the likelihood of supplying goods
2. Regional relative supply cannot exceed national supply

Estimation of δ by region size

Rule of Thumb:

$\delta = 0.25$

$$t_i^{ir} = FLQ_{ij} = \left[\log_2\left(1 + \frac{x^r}{x^n}\right)\right]^{\delta} \left(\frac{SLQ_j}{SLQ_j}\right) \quad \forall\, i \neq j$$

$$t_i^{ir} = FLQ_{ij} = \left[\log_2\left(1 + \frac{x^r}{x^n}\right)\right]^{\delta} SLQ_i \quad \forall\, i = j$$

$$a_{ij}^{r} = \begin{cases} FLQ_{ij} \cdot a_{ij}^{n} & \forall\, FLQ_i^r < 1 \\ a_{ij}^{n} & \forall\, FLQ_i^r \geq 1 \end{cases}$$

Limitations:

Strong assumptions on cross-hauling

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Methodology III:
Cross-Hauling Adjusted Method – CHARM

Cross-Hauling

- Simultaneous importing and exporting of goods in the same sector
- Leads to an overestimation of regional multipliers

Scaling of national I/O table with regional employment data

$$z_{ij}^{r} = \left(\frac{l_j^r}{l_j^n}\right) \cdot z_{ij}^{n}$$

$$w_{ij}^{r} = \left(\frac{l_j^r}{l_j^n}\right) \cdot w_{ij}^{n}$$

$$d_i^r = \left(\frac{BIP^r}{BIP^n}\right) \cdot d_i^n$$

Estimation of cross – hauling based on production and consumption by sector

➢ Measure of intra-sector heterogeneity

$$v = e_i + m_i = |b_i| + h_i \cdot (x + z + d)$$

Assumption

National heterogeneity estimates regional heterogeneity

$$h_i = h_i^r = h_i^n = \frac{v_i^n - |b_i^n|}{x_i^n + z_i^n + d_i^n}$$

enables estimation of regional im- and exports

Data

Macroeconomic Survey – Data:

National I/O Table:
- High resolution
- Time-lagged
  - 2017 version

Regional Economic Data:
- Much lower resolution
- Inconsistent classifications
- Incomplete w.r.t. trade, employment

Harmonization and Reclassification necessary

DESTATIS Statistisches Bundesamt

Statistisches Amt für Hamburg und Schleswig-Holstein

Der Norden zählt

Project – specific investment data:

Collected investment data from various reports and projects
- Few available on disaggregated level
- Classification of components according to producing sector
- Discounting future expenditures (if applicable)
  - Calculatory interest rate according to NEP

Construction of F – vector for projects:

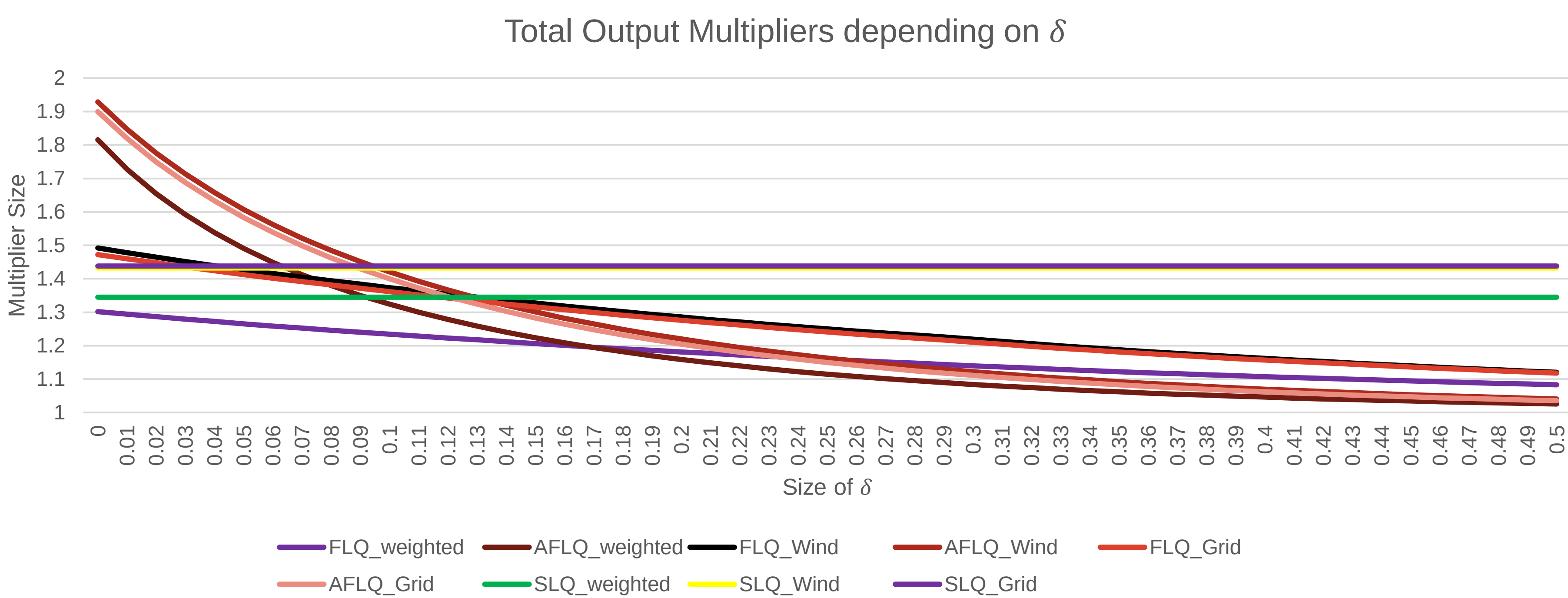
Normalization of Investment Costs to “representative” €uro
- Calculation of project share per sector
- F-vector sums to 1

Results:
Comparison of total output multiplier effects

	SLQ	FLQ _0.05	FLQ _0.25	FLQ _0.3	AFLQ _0.05	AFLQ _0.25	AFLQ _0.3	National
Grid Asset	1.44	1.41	1.24	1.21	1.58	1.15	1.11	1.82
Wind Asset	1.43	1.42	1.24	1.22	1.60	1.16	1.12	1.85
average multiplier	1.35	1.29	1.18	1.16	1.52	1.10	1.07	1.65
weighted average multiplier	1.34	1.27	1.16	1.14	1.49	1.11	1.08	1.71

- Regional Multipliers are smaller than national multipliers
  - ➢ About 25% - 30% of induced effects stay local!
- Energy Assets have an above-average multiplier effect
  - ➢ Consistent across all regionalization methods and national benchmark

Results:
Comparison of total output multiplier effects – role of δ



- SLQ gives highest estimates for reasonable values of δ (as expected)
  - Expected to overestimate
    - Can exclude $\delta < 0.15$
- AFLQ and FLQ estimates decrease in δ (as expected)
- AFLQ and FLQ estimates are in same ballpark
  - very close estimates for reasonable values of δ (i.e. $\delta > 0.15$)

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Results:
Further Work (in progress)

Previous work and reference:

Schreiner, L., & Madlener, R. (2021). A pathway to green growth? Macroeconomic impacts of power grid infrastructure investments in Germany. *Energy Policy*

Now: From national analysis to regional analysis

- Regionalization of **employment** multipliers
  - in progress
- Inclusion of **operation phase**
  - data on operation expenditures
  - discounting to today
    - necessary for static I/O model
  - in progress
- Regionalization of **fiscal** multipliers
- Estimation of optimal
  - in progress

- Expansion to **partially closed IOM**
  - in progress
  - difficulty: locally available wage and expenditure data
- **Displacement effects** for grid infrastructure
  - applicable to grid assets
  - not applicable to privately owned generation assets
  - need to recoup costs for infrastructure via grid-fees
    - not applicable, as expenses are recouped by grid fees on national level

Ongoing Research - Forthcoming FCN Working Paper

Croé, L., Madlener R. (2021). *Regionalized Input-Output Modeling to Assess the Impacts of Energy Transition Investments on the Local Economy: A Case Study of Schleswig Holstein*, FCN Working Paper Series, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University (in prep.)

Discussion

Limitations:

- no **empirical (survey-) data** to corroborate regional estimates
  - ➢ limited by regionally available data
- single projects highly dependent on individual characteristics
- short-run
  - ➢ no change in technologies
  - ➢ no operation (yet)
- **changing structure of economy** not considered

Policy Implications:

- effects on local economy **small, but noticeable**
- advertisement on local effects could ameliorate regional opposition to infrastructure projects
  - ➢ estimation of employment and (local) fiscal multiplier!
- energy assets create **above average local economic effects**
  - ➢ presumably even bigger when operation is considered

Further avenues of research:

- corroboration of method in **regions with available survey data**
- **dynamic I/O modelling**
  - ➢ inclusion of changing structure of economy
  - ➢ **structural change analysis**
- expansion to projects which require more local labor
  - ➢ e.g. solar roof installations, local microgrids
- estimation of **optimal, i.e. error-minimizing,** δ

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Thank you very much for your kind attention!

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