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Authors’ addresses:

Daniel Höwer
RWTH Aachen University
Templergraben 55
52056 Aachen, Germany
E-Mail: Daniel.Hoewer@rwth-aachen.de

Christian A. Oberst
German Economic Institute (IW)
Konrad-Adenauer-Ufer 21
50668 Cologne, Germany
E-Mail: oberst@iwkoeln.de

Reinhard Madlener
Institute for Future Energy Consumer Needs and Behavior (FCN)
School of Business and Economics / E.ON Energy Research Center
RWTH Aachen University
Mathieustrasse 10
52074 Aachen, Germany
E-Mail: RMadlener@eonerc.rwth-aachen.de

Publisher: Prof. Dr. Reinhard Madlener
Chair of Energy Economics and Management
Director, Institute for Future Energy Consumer Needs and Behavior (FCN)
E.ON Energy Research Center (E.ON ERC)
RWTH Aachen University
Mathieustrasse 10, 52074 Aachen, Germany
Phone: +49 (0) 241-80 49820
Fax: +49 (0) 241-80 49829
Web: www.fcn.eonerc.rwth-aachen.de
E-mail: post_fcn@eonerc.rwth-aachen.de
Regionalization Heuristic to Map Spatial Heterogeneity of Macroeconomic Impacts: The Case of the Green Energy Transition in NRW

Daniel Höwer¹, Christian A. Oberst²,* and Reinhard Madlener³

¹ RWTH Aachen University, Templergraben 55, 52056 Aachen, Germany, e-mail: Daniel.Hoewer@rwth-aachen.de
² German Economic Institute (IW), Konrad-Adenauer-Ufer 21, 50668 Cologne, Germany, e-mail: oberst@iwkoeln.de
³ Institute for Future Energy Consumer Needs and Behavior (FCN), School of Business and Economics / E.ON Energy Research Center, RWTH Aachen University, Mathieustrasse 10, 52074 Aachen, Germany, e-mail: RMadlener@eonerc.rwth-aachen.de

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Abstract

We discuss a vector-based regionalization heuristic to map the spatial variation of macroeconomic effects. Empirical regional studies of energy markets are often unfeasible due to a lack of data, particularly on demand and distribution infrastructure. The proposed heuristic is useful to model effects with high spatial heterogeneity and small overall net impact. As an illustration without loss of generality, we apply the heuristic to results from an input-output analysis on value creation effects by the energy transition in manufacturing sectors in the German federal state of North Rhine-Westphalia. The heuristic is applicable for regionalizing other macro-results, for example, from survey and other energy modeling studies.

JEL Classification Nos.: R12, R15, R58, P48, Q43

* Corresponding author.
1. Introduction

Economic analysis must be undertaken at the spatial level at which the market operates. According to Cournot’s market definition: “A market for a good is the area within which the price for a good tends to uniformity, allowance being made for transportation costs” (Jones 2002, quoted from Stigler and Sherwin, 1985). The analysis of macroeconomic trends and effects solely on a macroeconomic economy-wide level neglects regional heterogeneity. For area-based impact evaluations of various policy measures, from tax reforms over infrastructure investments, to energy and environmental policies, a disaggregated data analysis is often needed to provide accurate and consistent results (including the measurement of true spillover effects between markets).

Regionalization is the approach of delineating an economy-wide level – such as the world, country, state or other area of interest – into subregions. Differences between these subregions can be used as data laboratories to examine macroeconomic theory and policy (cf. Carlino and DeFina, 2006). There are manifold reasons to be interested in identifying the spatial variation in the geographical distribution of outcomes, benefits and burdens of public policies; for example, it becomes possible to identify regions with favorable and unfavorable conditions (e.g. to introduce technological innovations such as photovoltaic systems or electric cars as well as implications of federal taxes and subsidies on regional value creation and employment). Regional and local information, in turn, provides important insights for regional policies and regional patterns of public acceptance for policies imposed at the superordinate institutional levels. However, relevant observation data for bottom-up approaches are often not available on a disaggregated subregional level (e.g. regional economic linkages such as intermediate input conditions, inflation rates or electricity demand), or only available with a severe time delay (e.g. sectorial employment data). Alternative information based on survey data, for example on the willingness to pay for renewable energies and public preferences on energy supplier (see Bergman et al., 2008; Amador et al., 2013), usually do not have the sample size to obtain significant results on a disaggregated regional level. The aim of this paper is to introduce a simple regionalization heuristic and a consistent mathematical framework that enables the modeling of
economic effects on different spatial scales separately from the net macroeconomic impact.

The development of analytical techniques that provide a better understanding of the regional development and allow the (regional) decomposition of macroeconomic effects has a long tradition in regional economics. A particularly popular method is the shift-share approach, see Dunn (1960) and Stevens and Moore (1980), or Blien and Wolf (2002) for an econometric analogue. The motivation behind the developed regionalization heuristic introduced in this paper is similar to that of shift-share analysis, i.e. regarding the lack of spatially disaggregated data and keeping the modeling approach simple to enable a quick understanding of key assumptions and serve the short-term information needs of public policy. A unique motivation in this paper is to find a technique that is particularly useful for the investigation of macroeconomic effects with high spatial heterogeneity but small overall impact of the explained development.

The premise of the regionalization heuristic proposed in this paper (similarly to the shift-share approach) is that the macroeconomic impact can be split into multiple effects, and that for each of the effects a suitable regionalization vector can be established that is based on available statistical data. In shift-share methods there is generally a share term that indicates a common development of regions (e.g. structural effects), whereas a shift term, as the name implies, describes how one region is different from the others (often referred to as local factor). The shift term (local factor) includes all effects that act in a particular region, making differentiation between contributors of the shift term difficult (Rusche and Oberst, 2010). The regionalization heuristic introduced in section 2 relates to the structural factor of a shift-share analysis and to the logic of modeling a hypothetical regional development according to each region’s economic structure.

Utility companies, regulators and policy makers could employ the heuristic in order to model spatial variations across regions or regional distribution system operators (DSO), the latter seems particularly useful for Germany with its high number of DSO. Further, it can be applied to regionalize results based on surveys that did not explicitly consider regional aspects. As an illustration, we apply the regionalization heuristic in order to map the spatial variation in estimated value-creation impacts of the green energy transition for three branches of the
manufacturing sector: machinery, chemicals, and fabricated metals in Germany’s most populous federal state of North Rhine-Westphalia (NRW). This state is particularly affected by structural change in the energy sector. While Többen (2017) shows that the expansion of renewable energies has an overall positive value added effect for NRW, particularly with the production of new renewable energy supply installations, the state benefits less from it than other German states. This is mostly due to the NRW tradition of being an industrial economy with energy generation largely based on fossil fuels. Therefore, NRW is particularly affected by negative (contractive) value added effects in the context of the energy transition by eliminating investments in conventional energy generation structures. The discussion on applying proportional regionalization vectors to the example of industrial value creation is of general interest for regional top-down modeling approaches with value creation as a dependent variable.

The economic impact of the green energy transition (”Energiewende”) on industrial value creation in NRW is an ideal example of macroeconomic effects with high spatial heterogeneity and small overall impact. While the process of the green energy transition process and corresponding policy measures (e.g. the German Renewable Energies Act, in German: “Erneuerbare-Energien-Gesetz” EEG, 2000) certainly impact the development of value added and employment, income distribution and other important technological and economic developments (e.g. digitalization) and conditions (e.g. competitiveness). Its impact on the economy is, in comparison to other factors (e.g. external economic developments, income tax regime, etc.), typically relatively small. An extensive amount of research has been undertaken on the green energy transition effects at the federal or state level (e.g. “regional” net impacts and social distribution effects, as in Többen, 2017), or the labor market implications of large investments into renewable energy as in Lehr et al., 2012), while regional studies on a smaller scale than the federal states usually comprise case studies for selected areas (e.g. Sunak and Madlener, 2016). The spatial dimension of the impacts of the energy transition has received much less attention. Notable exceptions are Broekel and Alfken (2015) on the impact of wind turbines on tourism demand, or Growitsch et al. (2015) on regional distribution effects of the German Renewable Energies Act.

Our application example is based on results from an input-output analysis by Többen and
Kuckshinrichs (2016) on value creation effects arising from the construction and maintenance of plants for the production of renewable energy. Results are shown for three different spatial levels (subregions): 18 functional labor market regions in NRW (as in Eckey et al., 2006), 16 functional commuting clusters by Oberst (2011), and 53 administrative districts (NUTS-3) as the base level of regional data and control level. It is important to note that the sole use of administrative regions neglects the systematic interdependency between those districts and is an arbitrary delineation regarding market behavior. In the regional science literature, it is argued that both the economy-wide level and systematic interdependent districts are inadequate study areas for regional evaluations, as they neglect or distort the observation of the behavior of the population (Casado-Diaz, 2000, Oberst and Oelgemöller 2013). The comparative analysis across different subregion definitions links this paper to another thematic part of the regional science literature – the Modifiable Areal Unit Problem (Gehlke and Biehl, 1934, and Openshaw 1984) and associated aggregation and disaggregating procedures (Simpson, 1951).

The paper proceeds as follows. Section 2 discusses the regionalization heuristic in general terms. Section 3 reports on an illustrative example application on mapping spatial variation in value-creation impacts of the green energy transition in NRW, using results from an input-output analysis by Többen and Kuckshinrichs (2016). Section 4 concludes and presents the main recommendations on how to best make use of the heuristic proposed.

2. General regionalization heuristic

2.1. Total and relevant macroeconomic net effects

The derivation of the procedure is kept deliberately general at first. It is assumed that the macroeconomic effects (e.g. induced by the green energy transition) can be decomposed into a number of different effects \( N_t \) (e.g. value added effects in different industry branches, n.b. \( N_t \) is only the number of effects, not the parameter recording them) which account for the total macroeconomic net impact \( I_t \) on the macroeconomic economy-wide level (index \( t \) indicates total quantities). The regionalization heuristic is carried out for one specific time period (e.g. the year 2011). At this point, there is no distinction between various kinds of economic effects (e.g. direct
vs. indirect value added effects or employment effects in operating and production sectors).† Any decomposition that subdivides a macroeconomic impact into a number of effects is admissible. It then follows that

\[ I_t = \sum_{i=1}^{N} \kappa^i, \]

where \( \kappa^i \) is the economic contribution of the \( i \)-th effect (e.g. value added effects in the machinery branch \( i = 1 \)) and \( N \) is the number of effects. For any given additive decomposition, it is possible to identify a set of individual effects \( N_e \) that sums up the relevant impact, or considered impact, of \( I_t \) by accounting for a given percentage \( p_e \) of the total macroeconomic impact \( I_t \). In the case where the most relevant effects by size are to be considered, the \( i \)-th effects are to be ordered by magnitude,

\[ \kappa^i / \kappa^{i+1} > 1. \]

Using (2), the argument can be written as

\[ p_e = \frac{\sum_{i \in N_e} \kappa^i}{\sum_{i=1}^{N} \kappa^i} = \frac{I_e}{I_t}, \]

where \( I_e \) is the relevant part of the total macroeconomic net impact \( I_t \). It is implied that eq. (3) is calculated for positive and negative effects separately.‡ The net relevance of the \( i \)-th effect is defined as

\[ \rho^i = \kappa^i / I_t. \]

In (3) it was established that if \( p_e \) percent of the impact need to be captured it is sufficient to only take \( i \) effects, element in \( N_e \), into account and discard the other effects. It then follows that according to (4) there is a critical significance level \( \rho_{N_e} \), which defines whether an effect is relevant or not. An effect is relevant if

\[ \rho^i \geq \rho_{N_e}. \]

† In the case of an input-output table the index \( i \) in \( \kappa^i \) would indicate the \( i \)-th sector (e.g. \( i = 1 \) Agriculture, Hunting, Forestry and Fishing, \( i = 2 \) Mining and Quarrying, etc.), as the input-output table is organized in sectors.

‡ Note that eqs. (1) to (3) do not need absolute value bars since all the relations are formulated in fractions, which cancel out the respective signs.
According to this line of argumentation, only effects of relevance $\rho > \rho^{N_e}$ need to be added up in order to capture at least $p_e$ percent of the total net impact. Then, the relevant macroeconomic net impact can be measured as

$$I_e = \sum_{i=1}^{N_e} \kappa^i. \quad (6)$$

In practice, this could be applied by summing up all effects (e.g. in an input-output table) and taking the largest effects until the sum of those effects accounts for $p_e$ percent of the sum. As previously indicated, this procedure has to be carried out twice, i.e. for positive and negative effects separately.

2.2. Regionalization vectors

The typical assessment of macroeconomic net impacts, as discussed in section 2.1, or usually most macroeconomic evaluations, does not consider spatial variation in the net impact or its determinants $k^i$. However, it is possible that even if the net contribution ($\kappa^i$) to the whole economy is zero, its positive and negative regional impacts are relevant. The possible implications are demonstrated in figure 1, for the case where some quantity $\kappa^i$, e.g. an external effect like a public good (or public bad), or some effect introduced by legislation, follows a checkerboard-like spatial distribution.

![Figure 1: Exemplary spatial distribution of some quantity $\kappa$ across a domain of $N_e = 4n^2$ regions](image)
In order to be able to model regional variations of macroeconomic impacts in a top-down approach, we introduce the regionalization vectors \( \mathbf{r}^i \), with \( \mathbf{r}^i \in \mathbb{R}^{N_r \times 1} \), where \( N_r \) is the number of subregions. Generally, the \( \mathbf{r}^i \) have to fulfill the condition

\[
\kappa^i = \sum_{j=1}^{N_r} r^i_j,
\]

(7)

where \( r^i_j \) is the contribution of the \( i \)-th effect in region \( j \) (i.e. \( i \in N_e, j \in N_r \)). It is noteworthy that \( r^i_j \) denotes the absolute values and not the regional shares of an effect \( \kappa^i \). A regionalization matrix \( \mathbf{R} \) can be formed by combining all \( \mathbf{r}^i \), which can be written in vector-matrix notation as

\[
\mathbf{R} = [\mathbf{r}^1, \mathbf{r}^2, \ldots, \mathbf{r}^{N_e}],
\]

(8)

or in more comprehensive notation as

\[
\mathbf{R} = \begin{pmatrix}
R_{1,1} & R_{1,2} & \cdots & R_{1,N_e} \\
\vdots & \vdots & \ddots & \vdots \\
R_{N_r,1} & R_{N_r,2} & \cdots & R_{N_r,N_e}
\end{pmatrix} = \begin{pmatrix}
r_1^1 & r_1^2 & \cdots & r_1^{N_e} \\
\vdots & \vdots & \ddots & \vdots \\
r_{N_r}^1 & r_{N_r}^2 & \cdots & r_{N_r}^{N_e}
\end{pmatrix}.
\]

(9)

If, for instance, a subsidy were to be distributed, \( R_{i,j} \) would be expressed in monetary units (absolute values, not regional shares). However, virtually anything can be regionalized in this general notation, so that the units of \( R_{i,j} \) depend on the context. Using the case of value added effects of a public regulation on a specific branch, \( \kappa^i \), with a spatial distribution across a domain of \( 4n^2 \) regions, where \( n \) is any integer number greater than 1, as shown in Figure 1, the effect is modeled as

\[
\sum_{j=1}^{4n} r^i_j = 2n^2(-1) + 2n^2(1) = 0.
\]

(10)

In the example, the net contribution of the \( i \)-th effect vanishes, as expected. However, the local variance \( Var(\mathbf{r}^i) \), defined as

\[
Var(\mathbf{r}^i) = \frac{1}{4n^2} \sum_{j=1}^{4n} (r^i_j)^2 = \frac{1}{4n^2} 2n^2(-1)^2 + 2n^2(1)^2,
\]

is clearly greater than zero. This simple example demonstrates how aggregation can obscure regional impacts of macroeconomic effects. The aim of the generalized heuristic is to illustrate this aggregation effect with new metrics, so that it can provide first insights on (possible) regional patterns of investigated macroeconomic effects.

It is useful to identify the column sums of \( \mathbf{R} \) as the \( \kappa^i \) according to (6) and the row sums as the
total impact on the $j$-th region $\lambda_j$, i.e.

$$
\lambda_j = \sum_{j=1}^{N_e} R_{i,j},
$$

(12)

where the column sum $\kappa^i$ is the net effect $i$ and the row sum $\lambda_j$ is the impact on region $j$ (cf. Table 1).

Table 1: Column and row sum of $R$

<table>
<thead>
<tr>
<th>$\sum$</th>
<th>$N_e$ economic effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\kappa^1$</td>
</tr>
<tr>
<td>$\lambda_1$</td>
<td>$R_{1,1}$</td>
</tr>
<tr>
<td>$\lambda_2$</td>
<td>$R_{2,1}$</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>$\lambda_{N_r}$</td>
<td>$R_{N_r,1}$</td>
</tr>
</tbody>
</table>

Note that not all entries of $\mathbf{r}^i$ have to have the same sign as $\kappa^i$, i.e. positive and negative values may cancel each other out. A noteworthy consequence is that

$$
\kappa^i = 0 \Rightarrow \|\mathbf{r}^i\| = 0,
$$

(13)

where $\|\mathbf{r}\|$ denotes the $L^2$ norm of the argument, cf. (23). From (13) it directly follows that focusing on the previously identified net effects does not guarantee that all locally important effects are included (e.g. taking the net effects from a macroeconomic input-output analysis is not a sufficient identification criterion). A more reliable criterion to identify regional net effects uses the spatial heterogeneity, which is

$$
\|\mathbf{r}^i\| \gg 1.
$$

(14)

To show this, $\mathbf{r}^i$ is split into a mean value and a variance term, i.e.

$$
\mathbf{r}^i = \bar{\mathbf{r}}^i + \tilde{\mathbf{r}}^i,
$$

(15)

where $\bar{\mathbf{r}}^i$ is a vector of length $N_r$ with all entries equal to the mean part of $\mathbf{r}^i$, i.e.

$$
\bar{\mathbf{r}}^i = \frac{1}{N_r} \sum_{j=1}^{N_r} R_{i,j}.
$$

(16)

Subsequently,
Note that $\tilde{r}^i$, on the one hand, is a vector (denoted by bold non-capitalized letters), whereas $\bar{r}^i$, on the other hand, is a scalar that denotes the mean operation being applied to the vector. It can be shown that this expression is closely related to the sample variance and standard deviation $\sigma$ used in statistics. Recall that for a general and complete set of sample points $X$ with $N_x$ elements

$$Var(X) = \frac{1}{N_x} \sum_{i=1}^{N_x} (X_i - \bar{X})^2$$ \hspace{1cm} (18)

and

$$\sigma(X) = \sqrt{\frac{1}{N_x} \sum_{i=1}^{N_x} (X_i - \bar{X})^2},$$ \hspace{1cm} (19)

where again

$$\bar{X} = \frac{1}{N_x} \sum_{i=1}^{N_x} X_i.$$ \hspace{1cm} (20)

Notice that the variance and standard deviation definitions for a complete set were used.\(^6\)

Expression (16) is now compared to

$$\frac{1}{\sqrt{N_r}} \|\tilde{r}^i\| = \frac{1}{\sqrt{N_r}} \|r^i - \bar{r}^i\| = \sqrt{\frac{1}{N_r} \sum_{i=1}^{N_r} (r^i_j - \bar{r}^i)^2}$$ \hspace{1cm} (21)

with

$$Var(\tilde{r}^i) = 0$$ \hspace{1cm} (22)

which means that $\tilde{r}^i$ is just a location parameter for the variance and subsequently

$$\sigma(\tilde{r}^i) = \sigma(r) = \frac{1}{\sqrt{N_r}} \|\tilde{r}^i\|$$ \hspace{1cm} (23)

This proves that even when $\tilde{r}^i = 0$, i.e. there is no mean component, as for instance in Figure 1, $\|r^i\|$ is still not 0 if there is a variation in contributions and the magnitude of $\|r^i\|$ is proportional to its standard deviation. Therefore, this approach solves the problem described in Figure 1. The

---

\(^6\) By default, Matlab and many other software packages use the variance and standard deviation definitions for $N_x$ observations of a random variable. In this case the appropriate prefactor is $\frac{1}{N_x-1}$. However, for the complete set investigated in this paper $\frac{1}{\sqrt{N_r}}$ is the correct prefactor. The built-in standard definitions of many statistical programs for the variance and standard deviation will therefore produce some deviation from the results of this paper, and the expression should be evaluated directly from eqs. (17) and (18).
relevant impact can be described as

\[ I_e = \sum_{i=1}^{N_e} \sum_{j=1}^{N_r} r_j^i. \]  \hfill (24)

Note that generally \( N_e^* \neq N_e \), since a different measure of significance is introduced. Based on the relationships derived in this section, \( N_e^* \) is defined through \( p_e^* \) as

\[ p_e^* \leq \frac{\sum_{i=1}^{N_e^*} ||r_i||}{\sum_{i=1}^{N_e^*} ||r_i||}. \]  \hfill (25)

Equation (23) can also be written symbolically as

\[ I_e = \sum_{j=1}^{N_r} r_j^1 + \sum_{j=1}^{N_r} r_j^2 + \cdots + \sum_{j=1}^{N_r} r_j^{N_e}. \]  \hfill (26a)

which emphasizes the nature of eq. (27). In eq. (25), the \( r_i^j \) contain the regional distribution of each individual effect. Furthermore, it is possible to redefine \( l_i^j \) such that

\[ I_e = \kappa^1 l_1 + \kappa^2 l_2 + \cdots + \kappa^{N_e} l_{N_e} \]  \hfill (26b)

\[ I_e = r_1 + r_2 + \cdots + r_{N_e}. \]  \hfill (26c)

The \( l_i^j \) can be calculated from

\[ l_i^j = \frac{1}{\sum_{j=1}^{N_r} r_j^i} = \frac{1}{\kappa^i} r_i^j, \]  \hfill (29)

and \( l_i^j \) are thus completely decoupled from the magnitude of the effect. This makes them particularly useful as they can be used to regionalize any effect. Furthermore, the standard
deviation of all effects with the same regionalization scheme can directly be calculated from

\[ \sigma(r^i) = \kappa^i \sigma(l^i). \]  

(30)

Equation (31) is useful for discussing the contribution of net magnitude-related (\(\kappa^i\)) and distribution-related (\(\sigma(l^i)\)) variation. Furthermore, if the \(l^i\) or \(\sigma(l^i)\) of an effect are known, then the detailed regional implications of another effect that is distributed in the same way can be discussed without any further calculations beyond (30).

2.3. Discussion on applying proportional regionalization vectors: the example of industrial value creation

Equations (7)-(24) hold true for all regionalization vectors \(r^i\), but they are not sufficient to unambiguously define the regional impacts. If net macroeconomic impacts from an input-output table are to be regionalized through the regionalization vector concept, a sector-specific distribution scheme is an obvious choice. Still, the procedure discussed in this section is not limited to input data from input-output analysis. In order to make the argument more tangible, the value added from an input-output table is considered in this section without loss of generality.

It can be argued that the value added of a sector is distributed the same way as the employees are. This argument implicitly assumes that the employees within a sector have the same value added in a regional-average sense. So if, for instance, there are two regions with chemical plants it would be assumed that both plants have the same average value added per employee. The employees within the plant might contribute different amounts of value added. However, if one of the plants had a considerably lower average value added per employee, it would likely not be competitive with the other plant because wages would need to differ as well (which in most cases would be impeded by labor market inflexibilities, e.g. master contracts negotiated by employers and trade unions, minimum wages, etc.). If information on asymmetric productivity patterns is available, it could be used to construct bi-variate regionalization vectors.

The proportional regionalization vector for industrial value creation is assumed to be not much less robust than using reported value added data on a subregional level, as companies may report at different locations than the location of the true economic activity. The proportional
regionalization vectors are assumed to be accurate for branches that largely apply uniform wage agreements and have typically high plant sizes, as the value added per employee is assumed here to be less volatile. Once it has been established that the value added should be distributed proportionally to the number of employees in a specific sector (or branch) it is possible to write

\[ r_j^i = k^i \frac{e_j^i}{e_t^i}, \]  

(31)

where \( e_j^i \) is the number of employees in sector \( i \) registered in region \( j \) and \( e_t^i \) is the total number of employees in sector \( i \) across all considered subregions, i.e.

\[ e_t^i = \sum_{j=1}^{N_r} e_j^i, \]  

(32)

where condition (28) is satisfied by

\[ l_j^i = \frac{e_j^i}{e_t^i}, \]  

(33)

since in combination with (30) it holds that

\[ \sum_{j=1}^{N_r} \frac{e_j^i}{e_t^i} = \frac{\sum_{j=1}^{N_r} e_j^i}{e_t^i} = 1. \]  

(34)

In this section, as before, each sector is considered to account for a specific contribution to the net impact, i.e. the total impact is subdivided into effects which correspond to sectors. Therefore, when making this particular choice, sector and effect can be used interchangeably. This argument can be made for any sector and is convenient since the sectoral delineation chosen in input-output tables usually matches the sectoral delineation of the statistical agencies. It is expected that this argument is a particularly good approximation for industrial sectors like chemistry, machinery, metal production etc. since wage unity is assumed to be strong in these sectors in NRW, and which coincidentally also turn out to be the relevant ones. In the case of value added it is plausible to construct \( \hat{r}_j^i \) by normalizing over the number of employees across branches in a sector. If, for instance, the manufacturing industry is considered, the appropriate normalization unit would be the number of employees in the manufacturing sector.
\[ \hat{r}_j^i = \kappa^i \frac{e_j^i}{\epsilon^i \epsilon_j^{manu}}, \]

where \( \epsilon_j^{manu} \) is the number of employees in manufacturing in region \( j \).

3. Application for mapping spatial variation in industrial value-creation impacts of the green energy transition on the manufacturing sector in NRW

3.1 Sectoral choice and operationalization

In the application, we investigate the value added effects of the green energy transition on the manufacturing sector in NRW. For this purpose, we take macroeconomic net effects calculated by Többen and Kuckshinrichs (2016) with an input-output analysis for the year 2011 for the construction and maintenance of plants for the production of renewable energy (see also Többen, 2017). The energy transition requires the construction and maintenance of facilities and equipment related to renewable energy power generation, such as wind turbines, solar photovoltaic panels, and biogas plants. For the influence of each \( \kappa^i \) a suitable regionalization vector can be constructed. The available input-output tables are on a value added per branch basis. For regionalization purposes it is assumed that the value added is distributed in a uniform manner over all employees in a given branch. Therefore, a region will benefit from investments in renewable energies proportionally to the number of employees in the respective branches in this region. Previously, we argued from the point of view that the added value in a regional-average sense has to be similar across regions in order to ensure competitiveness.

We focus in our application on three branches of the manufacturing sector: machinery, chemicals, and fabricated metal. These industries have in common that they are highly relevant for the NRW economy, are strongly affected by the energy transition due to their relatively high energy intensity and costs, and provide potential for cross-industrial collaborations (see Kobiela and Vallentin, 2016). The spatial concentration in NRW of these sectors ranges from “highly concentrated” (chemicals) to “widely dispersed” (machinery). This selection on substantive grounds replaces the identification of relevant macroeconomic effects (section 2.1). In the long term, more relevant maintenance of renewable energy plants, these three branches of the manufacturing sector account for 61% of the value added effect of the energy transition,
compared to 50% in the rest of Germany, and 52% of construction. According to table 2, \( k^{mach} \) is 117 million Euros, \( k^{chem} \) is 95 million Euros and \( k^{met} \) is 248 million Euros. The macroeconomic net impact by the energy transition on NRW, is according to Többen and Kuckshinrichs (2016), 460 million Euros, which is about 53% of the total impact on the manufacturing sector in total in NRW, and 28% of the impact on the whole economy of NRW.

Table 2: Value added effect of the operation and construction of renewable energies (Energy Transition)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Value added effect of the Energy Transition in 2011, in million Euros</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operation</td>
</tr>
<tr>
<td></td>
<td>NRW</td>
</tr>
<tr>
<td>Chemicals and Chemical Products</td>
<td>14</td>
</tr>
<tr>
<td>Fabricated Metals</td>
<td>23</td>
</tr>
<tr>
<td>Machinery, Nec</td>
<td>29</td>
</tr>
<tr>
<td>Considered impact</td>
<td>66</td>
</tr>
<tr>
<td>Other manufacturing branches</td>
<td>42</td>
</tr>
<tr>
<td>Other sectors</td>
<td>197</td>
</tr>
<tr>
<td>Captured impact on manufacturing</td>
<td>61%</td>
</tr>
<tr>
<td>Captured impact all sectors</td>
<td>28%</td>
</tr>
</tbody>
</table>

Source: Based on data from Többen and Kuckshinrichs (2016)

In this context, (32) can be specified for the machinery branch as

\[
r_j^{mach} = \frac{e_j^{mach}}{e_t^{mach}} k^{mach}, \tag{36}
\]

for the chemicals branch as

\[
r_j^{chem} = \frac{e_j^{chem}}{e_t^{chem}} k^{chem}, \tag{37}
\]

and for the fabricated metals branch as

\[
r_j^{met} = \frac{e_j^{met}}{e_t^{met}} k^{met}. \tag{38}
\]

where \( e_i \) is the overall number of employees in branch \( i \) and \( e_j^l \) is the number of employees in
As an example, assume a development process that causes an effect of additional value creation related to the machinery branch by one million Euros. In the whole economy, there are 5,000 persons employed in the machinery branch, of which 90 are located in the considered region \( j \). Without any other information, an approximate estimation is that the region profits with 18,000 Euros in terms of value added.

The normalized vectors following (37) can be written for the machinery branch as

\[
\hat{r}_{\text{mach}, \ j} = \frac{e_{j}^{\text{mach}}}{\varepsilon_{\text{t}} \varepsilon_{j}^{\text{manu}} k^{\text{mach}}},
\]

(39)

for the chemical branch as

\[
\hat{r}_{\text{chem}, \ j} = \frac{e_{j}^{\text{chem}}}{\varepsilon_{\text{t}} \varepsilon_{j}^{\text{manu}} k^{\text{chem}}},
\]

(40)

and for the fabricated metal branch as

\[
\hat{r}_{\text{met}, \ j} = \frac{e_{j}^{\text{met}}}{\varepsilon_{\text{t}} \varepsilon_{j}^{\text{manu}} k^{\text{met}}},
\]

(41)

In eqs. (41–43), \( \varepsilon_{j}^{\text{manu}} \) is the total number of employees in the manufacturing sector in a given region, i.e. the same number in all three cases. Since regional input-output tables are per definition subdivided into branches, the construction of the regionalization vectors from branch employment data is straightforward. The regionalization vector obtained can be used to regionalize all state-level quantities that are expected to be distributed over the state in a similar manner to the workforce in the machinery and equipment branch. Furthermore, this approach can be used with the corresponding appropriate employment distributions for all effects that arise from the bi-regional input-output analysis by Többen and Kuckshinrichs (2016).

In the following, we map the value added effects on the machinery branch, the chemicals branch, and the fabricated metals branch. For each case, we provide figures in which the regionalized net effect in absolute values (\( r^{i} \)) and in relative values (\( \hat{r}^{i} \)) are compared. First, the level of 53 districts (municipalities) serves as a baseline; second, 18 functional labor market regions in NRW (as in Eckey et al., 2006), and, third, 16 clusters of districts based on commuting patterns delineated by Oberst (2011) are used.
3.2. Modeling and mapping spatial variation of value added effects of the machinery branch

The machinery branch in NRW as of 2011 is comprised of 1 383 businesses with a total of 198 710 employees. This makes machinery the biggest branch in the manufacturing sector in NRW. The total value added in NRW due to the construction and maintenance in this branch $\kappa^{mach}$ was 117 million Euros in 2011. In figure 2, the regionalized net effects on the machinery branch in absolute values ($r^{mach}$) and in relative values ($\hat{r}^{mach}$) are mapped. On the district level, the highest estimated individual effect for the machinery branch in absolute and normalized (relative) terms occurs on the rural (large area) district of Warendorf in the north of the state, where over a third of the 26 502 employees in the manufacturing sector – i.e. 9 843 – work in the machinery branch. The machinery businesses in Warendorf account for 51 of the 206 registered businesses in the manufacturing sector. In comparison, the total effect in the neighboring district on the eastern side, Gütersloh, is almost as high as in Warendorf, i.e. 6 171 million Euros compared to 6 085 million Euros; however, there are 49 952 employees in the manufacturing branch in Gütersloh. Therefore, the relative effect $r^{mach}_{Gütersloh}$ is only 111.26 Euros per employee in the manufacturing branch, whereas $r^{mach}_{Warendorf} = 219.29$ Euros per employee in Warendorf. This illustrates the desired effect of the normalization of $r^i$ to $\hat{r}^i$, and highlights the relative importance of macroeconomic impacts on regions.

The functional subdivision of NRW by Eckey et al. (2006) and Oberst (2011), both based on commuting patterns rather than reflecting administrative boundaries, shows a more balanced situation regarding the value added effect in absolute and normalized values of the machinery branch across regions. In absolute terms, the highest impact is shown for the cluster in the northwest, mainly overlaying a region called Ostwestfalen-Lippe, and the centered cluster consisting of the cities of Dortmund and Hagen and surrounding districts. The latter cluster is usually considered to be an industrial region. In relative importance, the highest estimated impact is shown for the cluster in the center-north, overlaying with a region called Münsterland, which includes the district of Warendorf. We conclude that from the growth impulse in the machinery branch stemming from the energy transition process mainly the region of Münsterland (north) is profiting. The least benefits are expected in the regions of Euskirchen (south-west) and the
middle-/northern Ruhr area (Essen, Bottrop, Gelsenkirchen, Recklinghausen).


![Figure 2: Regionalized value creation effect of the machinery branch](image)

Value creation effect in **relative values** in Euros per employee (NRW average = 102 Euros per employee). Districts – left plot, Eckey et al. (2006) – center plot, Oberst (2011) – right plot.  W Warendorf, MS Münsterland, EU Euskirchen, M-Ruhr Middle Ruhr Area

3.3. **Modeling and mapping spatial variation of value creation effects of the chemicals branch**

The chemicals branch is investigated analogously to the machinery branch. The plots for the regionalized macroeconomic net effects for the chemicals branch are shown in Figure 3. In the normalized case the standard deviation ratio is consistent. However, the $\sigma(l_{chem})$ values are at a relatively high level, about one order of magnitude higher than the $\sigma(l_{mach})$ values. The highest nominal values unsurprisingly occur in Leverkusen (9:104 million Euros) and Düsseldorf (8:422 million Euros). In 13 of the 53 districts, there are no employees registered in the chemicals branch at all. Note that while Düsseldorf has the second-highest nominal value and hence is clearly notable in the figure with the absolute values, it fades in the normalized figure with the relative
values. This is a desirable effect. The goal of the normalization is to highlight the relative importance of a given branch for a region and the chemicals branch is more relevant for Leverkusen's economy than it is for Düsseldorf's. This can be explained without detailed regional knowledge, namely by the very high heterogeneity in the chemicals industry. There are only 404 registered businesses, and the plant size is higher with an average of 221.6 employees per plant compared to the machinery branch. The functional delineations are helpful for identifying locations that profit indirectly through their commuters from value creation effects in the chemicals branch (even if there are no chemical industries located in their own districts). We can conclude with regard to the growth impulse within the chemicals branch arising from the energy transition process, mainly the Rhineland regions of Cologne-Bonn (incl. Leverkusen) and Düsseldorf are the main beneficiaries. Few or no benefits are to be expected in the western half of the state.


Figure 3: Regionalized macroeconomic net effects for the chemicals branch
3.4. Modeling and mapping spatial variation of value creation effects of the metals branch

The same analysis is conducted for the value added effects in the fabricated metals branch (see Fig. 4). The macroeconomic net effect of the fabricated metals branch is about twice as high as that of the previous two effects, which is reflected in relatively high nominal values. High contributions in nominal and normalized terms are identified in the south and central area, with a notably high nominal and normalized contribution in the district Märkischer Kreis. This district accounts for 38.366 million Euros. However, the highest normalized value added occurs in Solingen with 694 Euros per employee in the manufacturing sector. We conclude that owing to the growth impulse within the metals branch caused by the energy transition process, mainly the region of the eastern and south-eastern Ruhr area are profiting (incl. districts of Dortmund, Hagen und surroundings, Siegerland, and Bergisches Land).


In **relative values** in Euros per employee (NRW total = 210 Euros per employee). Districts – left plot, Eckey et al. (2006) – center plot, Oberst (2011) – right plot. MK Märkischer Kreis, S Solingen, SI Siegerland

**Figure 4:** Regionalized macroeconomic net effects for the metal branch
4. Summary and conclusion

A regionalization procedure based on the proposed regionalization vector concept has been developed in order to regionalize macroeconomic impacts. The regionalization procedure has been applied to results of a recent input-output analysis in the German green energy transition context on the district and functional region level. The construction of the regionalization vectors is based on available statistical data. The developed procedure yielded several new metrics which can be used to assess regional heterogeneities in a variety of contexts. The new metrics illustrate the potential variance across regions and enable the discussion of economic effects separately from the net macroeconomic impact in a standardized mathematically well-defined framework.

Furthermore, each regionalization vector can be used to regionalize a certain class of effects. Therefore, once a regionalization vector is established it can easily be transferred to another problem which contains effects of the same class. This framework is particularly useful to regionalize aggregated results with high regional heterogeneity and small overall impact - defined as the sum of all regional effects - are to be discussed since these effects are not well-suited for standard regression techniques. The heuristic could also be applied in order to regionalize results from survey data. This might be used to validate the presented value added calculations. The regionalization of the value added from input-output tables is subject to considerable uncertainty, as the input-output tables are already based on assumptions and the regionalization introduces yet more assumptions. It was argued that for the considered sectors the assumptions under which the value added regionalization vectors were constructed - i.e. sector-wise regional average-sense constant value added per employee (proportional distribution) - should be valid. It is recommended to investigate to what degree the assumptions hold for the considered sectors and to what degree they can be extended to other sectors. In any case, the heuristic illustrated heterogeneity of regional impacts and the results’ sensitivity to the chosen spatial resolution.
Acknowledgement

This study was conducted within the project “Energy Transition in North Rhine-Westphalia – Transforming Industrial Infrastructures”, funded by Stiftung Mercator, Essen, Germany, as part of the Virtual Institute (VI) “Transformation – Energy Transition North Rhine-Westphalia” (http://www.vi-transformation.de/en/). We are grateful to Annedore Kanngießer, Daniel Vallentin, Georg Kobiela, Hendrik Schmitz, Johannes Többen and Torsten Müller for their useful comments and suggestions. The usual disclaimer applies.

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