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Renewable energies and their impact on local value added and employment

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Abstract

Background: Beyond the motivation to reduce the environmental impact of energy production, the economic rationale is a key incentive for local communities to become involved in renewable energy (RE). Substituting imported fossil fuels or final energy with RE sources creates opportunities at the local level to establish steps of the RE value chain, resulting in value added and employment in the respective region's RE sector.

Methods: The model approach is described and applied to the example of onshore wind energy. Subsequently, the implementation of the model for an average model municipality is explained, which then serves as the basis for calculating the model results. The model was designed for the specific conditions in Germany but the approach can be transferred to other countries.

Results: A total of 9.3 million euros of municipal value added and 166 jobs could have been generated in the RE sector in the average model municipality in Germany in 2011. The value chain stage of systems manufacture contributed the largest share, but in total, the continuous effects, i.e., the effects generated by operation and maintenance (O&M) and in the system operator stage, were greater.

Conclusions: The model introduced in this paper allows for a detailed analysis of the extent and distribution of RE value-added and employment effects at the local level. The results show that the use of RE has significant potential to create value added and employment throughout Germany's RE sector, even in regions without manufacturing industries. Knowledge of these effects can be an important input to local decision-making processes, increase acceptance, and enhance motivation to further expand decentralized RE generation.

Keywords: Local value added; Renewable energy; Regional development; Sustainable energy supply

Background

In the context of the transition from fossil fuel-based systems to renewable energy (RE) systems, municipalities play an important role. Municipalities are a driving force behind the expansion of RE and can benefit at the same time. Many municipalities and districts are pursuing ambitious climate-protection objectives that even exceed targets set at the national level. Along with increased awareness of the need for climate-protection measures, the main reasons for municipality involvement are the regional economic effects associated with the use of RE sources [1]. Gradually replacing previously imported fossil fuels and final energy with local energy sources leads to a series of value chain steps occurring within the municipality itself due to the decentralized structure of RE; the result can be a positive impact on local value added and employment in the region's RE sector. However, there is a knowledge gap concerning how exactly the municipalities profit from the use of RE. In this paper, a methodical approach to quantifying the value added and employment resulting from the use of RE at the municipal level is presented.

The link between the expansion of RE and the resulting economic benefits has been discussed in numerous studies with different geographical focuses (generally the national level, sometimes the regional level), and they do not include an assessment of value added. Breitschopf et al. [2] provide a comprehensive overview of the existing literature on the employment impacts of RE. They distinguish between methods that consider only the positive effects of RE (gross studies) and methods that also measure negative impacts (net studies). The authors

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present six methodical approaches and conclude that the gross input–output modeling approach is most suitable for analyses at the national level, due to its universal approach, which allows for very detailed technology and country-specific adjustments if data are available. A generally more accurate approach would be the macroeconomic modeling approach, which takes into account detailed information on specific technologies and countries and enables conclusions on questions concerning time horizon, regional levels, economic dimensions, and impact indicators. An important statement is that the quality of input data is most crucial for all methods mentioned. The various types of profits and costs at the national level in Germany were analyzed in Breitschopf et al. [3,4]; the latter includes the results of Lehr et al. [5] regarding employment effects. Lehr et al. [5] apply an input–output model designed to link economic and environmental aspects. Their input data are based on a survey of relevant companies in the RE sector that covers the direct economic effects of investment and operating activities. The information collected is used as input data for the input–output model to calculate additional indirect effects. Like every other input–output model, it is not transferable to the municipal level because of a lack of regional economic statistics. In Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) [6], a method to quantify local value added was developed; however, it does not cover the entire value chain, but only the operation phase.

In Coon et al. [7], an input–output model established for the state of North Dakota (USA) is used to determine the regional economic effects of the enhanced expansion of RE facilities in the recent years, namely, wind turbines and ethanol plants. In this economic study, direct and indirect first-round effects are collected by means of a survey of the relevant regional companies. The empirical data are then used as input data for the regional input–output model to determine additional indirect second-round effects. The model solely considers economic integration within the state in question. The results include one-time effects caused by construction activities and also annual effects of ethanol production and wind turbine operation; however, the authors do not explicitly report value-added effects, but rather a limited set of economic figures. Employee income and regional fiscal revenue are components of regional value added in accordance with the addition method used in the model developed by the Institute for Ecological Economy Research (IÖW) and henceforth referred to as the 'IÖW model'. Without further calculations, however, it is not possible to establish the third component of the regional value added, as business volume and overall economic activity do not directly correlate with business profits; thus, the results of this study do not represent a complete analysis of value added. In general, though, the model is suitable for the analysis of value-added effects in the RE sector and is almost the same as that applied by Lehr et al. [5], although it does not cover substitution or crowding out of other economic activities. As this regional input–output model was developed by the authors through multiple studies, the transferability to other regions is relatively restricted, as well as limited by the considerable effort required to develop a regional input–output table.

Another study that relies on an input–output model was published by the Spanish Renewable Energy Association (APPA) [8]. The authors determine the various economic, social, and environmental effects of RE at the national level in Spain, explicitly including value-added and employment effects. Their input data are drawn from financial statements and questionnaires in order to illustrate a specific economic sector for RE activities and to calculate the contribution of RE to national gross domestic product (GDP). The questionnaires also provide information about the provisioning structure of the sector in order to determine the results of spin-off effects in the rest of the economy through the application of the input–output model; these effects are comparable to the indirect effects presented by Lehr et al. [5] and Coon et al. [7]. The study also presents results for the economic effects of RE at the national level and is not transferable to the regional level, where the expansion of RE in Germany is being driven forward most. Furthermore, it is not clear whether the effects that have been calculated only include those generated by investment activities or whether plant operation activities are also being considered; the latter are important for already installed capacity and will become more important in future years. The subtraction method, calculating value added as the difference between revenues and expenditures, does not provide information about the distribution of overall effects across the various value-added components.

Hence, until recently, a transferable method providing a detailed analysis of the extent as well as the distribution of local value added and employment has been lacking. Given the varying potentials that each specific RE technology offers for generating local value added, the knowledge gap becomes even greater, a fact that is all the more surprising when one considers that the positive impact of RE on economic development is a central motive for local actors with respect to the expansion of RE in many communities [1]. Accordingly, the demand for such information and knowledge is great.

It was against this background that the IÖW developed a model to quantify the value-added and gross employment effects generated by RE on a local scale.[a] Thus, a transferable method is available that makes it possible to quantify the economic effects for an average municipality, as well as selectively for the most typical decentralized RE technologies along the value chain. The model and the underlying methodology will be presented and discussed in this article. By way of illustration, the method will then be implemented for a model municipality, in order to demonstrate the potential value-added and employment effects achieved in an average municipality in Germany in 2011 by using RE. It must be noted that this approach does not provide actual data relating to regional value-added effects like empirical data from the national accounts, but rather an estimate within the scope of the model to close the gap in the national accounts regarding the renewable energy branch.

Methods

Quantifying municipal value-added and employment effects

The IÖW model presently includes a wide range of RE technology value chains, representing a broad portfolio of distributed power and heat-generating facilities, the supply of biofuels for transport, wood fuels for power and heat generation, and local district heating networks fed by RE. Thus, essentially all technologies and plant sizes in the areas of electrical power and heat generation, as well as wood and biofuels, that would be applicable to an average German municipality are analyzed. Special RE cases such as large-scale hydropower, offshore wind energy, and deep geothermal, which, due to their site requirements, are found in only a few municipalities, are not currently included in the model.[b] The model was designed for the specific conditions in Germany and contains country-specific input data such as profitability and productivity figures for companies, wage levels, and the modeling of the German tax system. Nevertheless, the approach can be transferred to other countries if country-specific data are available and the tax methodology is adapted.

The primary basis for assessing value added in the model is an analysis of the specific turnovers relating to installed capacity[c] along the RE technology value chain. The analysis is restricted to turnovers directly relevant to RE (i.e., the components and services necessary to produce, install, and operate the RE technology). The value chains are broken down uniformly into four stages, reflecting the various phases of the life cycle of an RE facility, and thus provide for comparability across all technologies. The stages *systems manufacture* and *planning and installation* account for one-time impacts, arising before a facility is placed into operation. The stages *operation and maintenance (O&M)* and *system operator*, on the other hand, include annually re-occurring effects that continue throughout the entire operational lifespan of a facility. Research and development and dismantling are further stages, but they are not explicitly analyzed here, since their impact at the regional level is minor compared to the other stages. Nevertheless, their contribution to regional employment and value creation is included in the turnover approach.

The four stages of the value chain are in turn subdivided into various value chain steps, depending on the specific technologies involved. Systems manufacture includes the manufacture and production of the various components; O&M covers items such as maintenance and fuel costs; the system operator stage includes energy generation profits and their associated tax revenues.

For each of the value chain steps, the cost structures of investments in the specific technologies and system operations turnover are identified. Allocating the individual cost items to a step of the value chain makes it possible to determine the turnover for each of these steps. In the literature, the cost structures are generally stated relative to investment costs and, in part, relative to ancillary investment costs. Such a percentage-basis approach makes it possible to apply the cost structures to the specific investment costs, which are drawn from the current literature (market analyses, evaluation reports, etc.). In addition to these direct costs and revenues that arise through investments in the specific stages of the value chain, further operational revenues are generated. In contrast to (one-time) investment costs, these costs are incurred annually during the operational lifespan of a facility. During operation, a need for replacement parts arises, which generates an additional component demand that must be accounted for in the systems manufacture stage of the value chain.

The model follows the income approach to calculate value added. Model results correspond to the net value added provided by national accounts, i.e., gross value added minus depreciation. First, company profits and salaries created in the RE value chains are estimated, followed by an assessment of taxes paid by enterprises and employees. Thus, value added is decomposed into three components. Added together, these yield a total municipal value-added impact (see Figure 1). Specifically, the three components are

1. After-tax profits of the participating enterprises
2. Net incomes of the employees involved
3. Taxes paid on business profits and on adjusted gross employee income.

With respect to taxes, it is possible to distinguish between municipal, state, and federal tax revenues. In the regional value-added analysis, taxes at the municipal level are significant; these consist primarily of trade tax and the municipal share of income taxes. The first two value-added components, profits and incomes, provide indirect benefits to the local municipality by increasing purchasing power and investment capital. Local tax

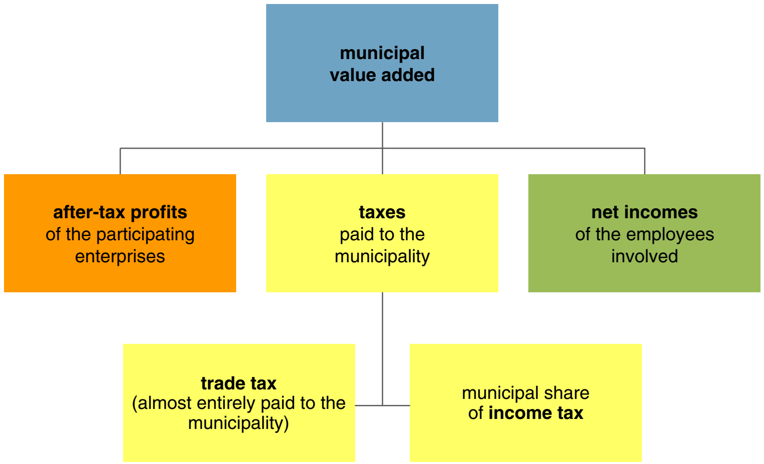

Figure 1 **Components of municipal value added.**

revenues, on the other hand, flow directly into the municipal treasury.

Profits

To determine profits at each step of the value chain, the operating profit margin is utilized, which compares the annual profit (before taxes) of an enterprise to the turnover achieved in the same period. In this case, before-tax results were used for the calculation. The profit-turnover ratio is drawn from statistics compiled by Germany's central bank, the Deutsche Bundesbank [9], which extrapolates figures based on data from the annual financial statements of German companies for the years 1997 to 2009. These pooled data include results from approximately 140,000 financial statements per year of non-financial enterprises, including both incorporated and non-incorporated companies. The classification of enterprises according to business activity in the Deutsche Bundesbank study is based on the German Classification of Economic Activities (WZ-2003) from the Federal Statistical Office. Because the various REs are not specifically itemized here, comparable branches for each value chain step were consulted. The average profit-turnover ratios of the various branches were used to establish a mean value for the years 2000 to 2009. In two cases, a different method had to be applied. For the assessment of the profits in the system operator stage, before-tax earnings were calculated with the help of average return on equity for each of the corresponding RE technologies; this information was drawn from the Renewable Energy Sources Act (EEG) Progress Report [10]. The profits earned in connection with the provision of wood fuels were calculated from turnover minus cost of provision.

Employment and income effects

Income effects as a function of turnover are determined for each of the value chain steps; in addition to the data on income, this method also provides results on employment effects. Initially, the employment effect is calculated as the number of persons employed. The Federal Statistical Office publishes figures on employment numbers and turnover according to business branches following its own German Classification of Economic Activities (WZ-2008); these figures, broken down by branch, are allocated to the corresponding steps of the value chain. Thus, an indication of jobs per euro of turnover can be determined, which, when multiplied by turnover per kilowatt (kW) of installed capacity, yields a figure for the number of employees per kW. Wages and salaries in euros per kW are determined on the basis of average gross annual income in the business branch of the corresponding value chain step, as determined from Federal Statistical Office sources.

An exception is the calculation of management salaries for the system operator stage. Here, typical specific management compensation figures on a per kW basis were drawn from an analysis performed as part of the IÖW project EXPEED [11]. The number of employees per kW is then determined as the quotient of the specific income and a typical gross monthly income for the corresponding Federal Statistical Office occupational category. In the case of the provision of wood fuels, the employment and income effects are determined on the basis of the specific working-time requirement for each of the value chain steps.

Taxes

Calculation of the tax load of an enterprise is dependent on its corporate structure. The enterprises generating value added are therefore subdivided into incorporated and non-incorporated companies in order to account for differences in tax treatment. The calculation of net income is derived from gross annual incomes of the occupational categories in the value chain stages under consideration, taking into account the current tax environment as well as social security contributions.

The municipalities profit in the value-added process in two ways. First, enterprise profits are subject to trade tax (*Gewerbesteuer*), which is paid almost entirely to the municipality. Only a tax levy has to be paid to the federal government and the states. Second, the municipalities receive a share of the taxes paid on wages and income, profiting from the additional income taxes paid by participants in a business partnership as well as from the payroll taxes of employees in the firms.

Exemplification: the wind energy value chain

The following paragraph illustrates the methodology, using the example of the onshore wind energy value chain, and demonstrates technology-specific model results per kW of installed capacity. The German wind energy industry is well positioned internationally and accordingly enjoys a substantial level of exports; furthermore, the installation of wind energy plants in Germany itself generates substantial value added. Wind energy, like photovoltaics and biomass, plays an important role in job creation in the RE sector [12]. Not only the producers of wind energy plants, but also plenty of component suppliers contribute to this development. In the IÖW model, the effects per kW of the specific value chain steps for wind energy plants are quantified as described. As base data for the model, it is necessary to establish the specific investment costs of a reference plant. In this case, a plant with a capacity of 2 megawatts (MW) was chosen, representing the current state of technology in the sector. The specific investment costs are drawn from [10] and are divided into investment costs for the wind power turbine and ancillary investment costs. These cost components are further broken down by position for the various steps of the value chain. The investment costs are split into separate components, for example, tower, generator, and rotor blades. The ancillary investment costs include items such as planning, installation, the foundation, grid access and connection, and ecological compensatory measures, which can be enforced by the authority to make up for the ecological damage caused by the installation of the wind energy plant (see Table 1). Alongside the one-time costs incurred in the installation phase of the plant, there are ongoing operating costs that have to be paid continuously during the operation phase. These are likewise further subdivided into the various components, e.g., service and maintenance, insurance, and electricity costs.

Table 1 Stages and steps of the wind energy value chain

Value chain stage	Value chain step
Systems manufacture	e.g., tower, generator, rotor blade
Planning and installation	e.g., grid connection, foundation
Operation and maintenance	e.g., service and maintenance, insurance, lease
System operator	Profits and associated taxes

The value-added components are calculated for each cost position as described above. Figure 2 shows the municipal value added of wind energy plants per kW broken down by stage of the value chain and component of value added. Figure 3 shows the effects over a period of 20 years, the duration of remuneration according to the German Renewable Energy Sources Act (EEG).

Method implementation for an average model municipality in Germany

The model outputs the specific value-added and employment effects in euros per kW of installed capacity (or per square meter of collector surface area) and employees per kW of installed capacity, respectively. On this basis, the effects can be quantified for various geographical reference areas (municipality, region, state, and country). To illustrate the effects of value added and employment in a typical municipality, the model was implemented for a model municipality in Germany. This municipality features 75,000 inhabitants, an installed generating capacity of the various RE technologies in accordance with the German average of installed capacity per capita, as well as an average manufacturing capacity in 2011, the year in question.

The basis for estimating the effects deriving from manufacturing, as well as planning and installation of new investments, was the addition to installed capacity in Germany in 2011. Import and export of components and technologies are taken into consideration by using export quotas drawn from Lehr et al. [5]. To estimate value added and employment generated by the operation of the RE facilities, installed capacity in 2011 is relevant (installed capacity at the end of 2010 plus half of the capacity newly installed in 2011). Diverging from this methodology, the effects generated by biomass supply are based on consumption figures from 2011. After calculating the model results for Germany, the specific values per resident in Germany were derived and then multiplied by the number of residents in the model municipality.

Real municipalities do not necessarily cover the entire spectrum of RE, nor are local companies always fully engaged in all stages and steps of the value chain. In a study of an actual municipality, the model has to be adjusted to regional characteristics. Therefore, the model must be adjusted according to the actual industry and service structure of the respective region. This issue is addressed by collecting empirical data from

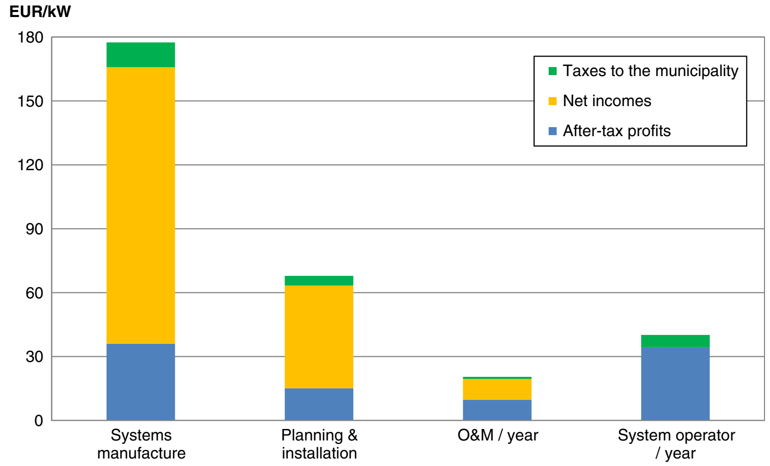

Figure 2 Municipal value added of wind energy plants (onshore), singular and annual effects in 2011.

local companies and by gaining insight from local branch-specific experts.

Results

A total of 9.3 million euros of municipal value added was generated within the RE sector in the modeled average municipality in Germany in 2011. Figure 4 shows the model results for the various RE technologies. The most important contribution, roughly 3.9 million euros, was generated by solar power. This can be explained by the enormous number of newly installed solar systems in 2011, which generated comparatively large effects in the value chain stages of systems manufacture and planning and installation (see Figure 5). More than half of the value added in this industry consists of employee wages, followed by company profits. Wind energy accounts for almost 25% of total value added in the municipality, or 2.2 million euros. In this case, about 70% of the value added was effects generated in the stages O&M and system operator (see Figure 5). Since the operation of wind energy plants is not as labor-intensive as the production of components, company profits contribute the largest portion. Of the total municipal value added, 4.4 million euros resulted from the after-tax profits of the participating enterprises and 4.1 million euros from the net incomes of the employees involved. The municipal share of the taxes paid on business profits and on adjusted gross employee income was 0.8 million euros. Approximately 166 workers in our average municipality were employed in the RE sector in 2011.

In Figure 5, the results for the four stages of the value chain are depicted. It can be seen that the systems manufacture stage contributed the largest share to the total municipal value added in 2011. But in total, the continuous effects, i.e., the effects generated by O&M and the system operator stage, were larger than the one-

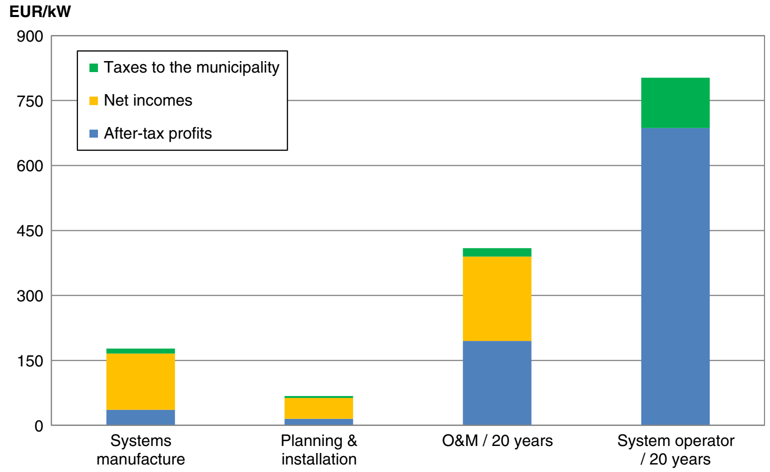

Figure 3 Municipal value added of wind energy plants (onshore) over a period of 20 years.

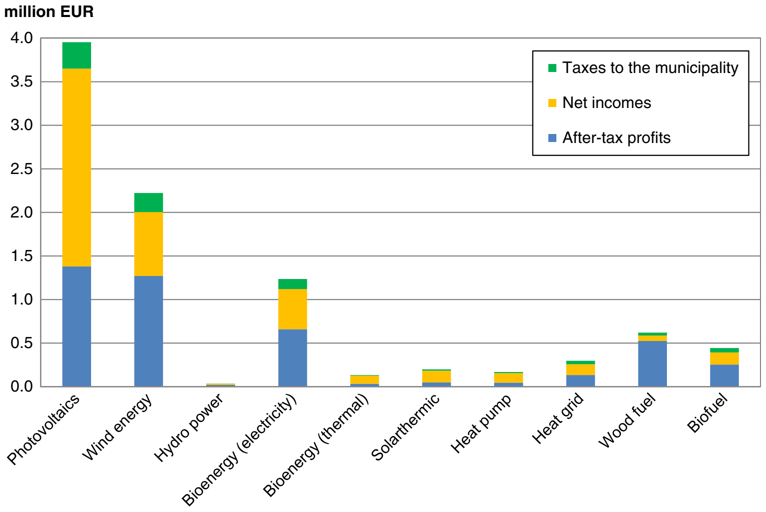

Figure 4 **Municipal value added in the average municipality, differentiated by RE technology.**

time impacts of systems manufacture and planning and installation. Moreover, the magnitude of the continuous effects will go on to increase annually, as long as renewable energy expansion continues. This means that, although systems manufacture is certainly very important with respect to the value added by RE, the continuous effects are significant as well.

Discussion

The model results for the average municipality in 2011 show that the use of RE technologies can make an important contribution to municipal value added and local employment. The extent of the impact on the local economy in the average municipality varies depending on the RE technology in question in the model, as can be seen in Figure 4. There are several reasons for this. First, the effects depend on absolute installed capacity and biomass consumption in the municipality. At the same time, differences regarding the cost structures of investments in the specific technologies and the different feed-in tariffs under the German Renewable Energy Sources Act (EEG), as well as the specific employment intensities and the varying profitability of companies all lead to technology-specific profiles with regard to capacity-specific value-added and employment effects. Therefore, the regional technology mix also determines the municipal value added. As explained earlier, in most municipalities in Germany, not all of the stages and steps of the value chain will be present. This is especially true of the systems manufacture stage, since the location of large production facilities is limited to a small number of communities. However, since the companies along

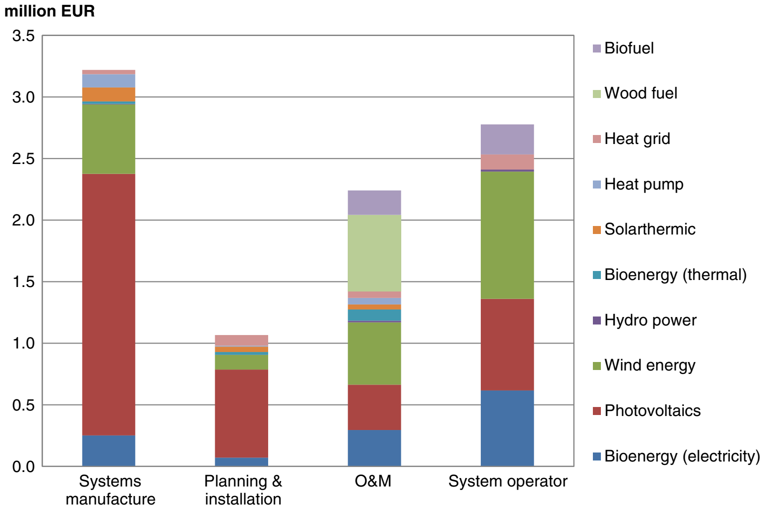

Figure 5 **Municipal value added in the average municipality, differentiated by stage of the value chain.**

the value chains and the investors are not necessarily located in the same region where the RE plants have been installed, this also applies for the three other stages of the value chain. It is important to understand that municipal value added is primarily generated by the companies that, among other things, plan and install the RE plants and operate the facilities. For example, a municipality with a wind farm within the municipal boundaries but no local companies or investors will only profit from part of the trade tax and the lease income. The largest share of the value-added effects will flow off to other regions. When looking at a specific region, only those steps of the value chain that are empirically observable or assumed to be taken by regional companies will be (proportionally) taken into account. Naturally, the municipality derives the greatest benefit if all of the value chain steps of a specific RE technology take place within the region. But, as the results for the model municipality show, significant effects can also be generated even when this is not the case, e.g., when there is no local production but a high level of installed RE capacity - on condition that a reasonable number of participating companies and investors are located within the region, and vice versa. This is good news for municipalities in regions with a lack of industrial manufacturing.

Using the method presented here, the direct effects generated by the use of RE systems can be quantified. The model, however, is not constructed to determine indirect effects generated by upstream value chain stages. A possible inclusion of these indirect effects, e.g., by coupling this model with other methods, such as input–output, might result in higher municipal value-added and employment effects. In order to compare the results with other studies, it is thus necessary to verify which type of effects is considered - only direct effects or also indirect effects - and how these are differentiated. It is also not possible to use the method presented here to quantify impacts on the local economy that result from the substitution or crowding out of economic activities (e.g., conventional energy generation) caused by the use of RE. Assessing these effects is a complex task and requires further research. Lehr et al. [5] have quantified net employment effects for various expansion scenarios at the national level; these demonstrate that the net effects are still positive overall. However, the distribution of the effects can be very heterogeneous, and this can mean that the balance is negative in some communities, whereas positive net effects are generated in other communities. Moreover, the methodology presented here focuses on monetary valuation and thus only represents one aspect of the assessment of sustainable business practices, as ecological and societal aspects are not considered here. Nonetheless, the economic effect of value added is an important criterion that can contribute an element of impartial objectivity.

As the description and implementation of the model above show, the IÖW model was especially designed to determine value-added effects of RE at the regional level. The bottom-up approach allows for the adjustment of different key figures relating to the examined region. Top-down approaches, such as the method used by Lehr et al. [5] and APPA [8], break down information generated on national level and do not use distinct regional data to analyze regional effects. This is a significant advantage of the IÖW model, since it allows the generation of more region-specific results. Another aspect that characterizes the IÖW model is the distinction of different value chain stages and single value chain steps to distinguish between one-time and continuous effects, and also between the different stake holders participating in the expansion of RE. Therefore, the IÖW model points out more than just employment effects as is the case in Lehr et al. [5], or value-added effects only relating to the O&M stage of the value chain, as calculated in BBSR [6]. The more detailed design thus allows taking a closer look at regional economic indicators such as community tax revenues or the flow of energy generation profits across municipal borders. Consequently, the bottom-up approach used in the IÖW model with its distinction between 30 RE technologies and capacity increments as well as the differentiation of single value chain steps is a good tool to quantify value added and employment for different regional levels. For the determination of effects at national level, the research question is - amongst other factors - determinative for the choice of model listed in the ‘Background’ section.

Conclusions

Knowledge of value added as well as employment generated in connection with RE technologies at the local and regional level is becoming increasingly important. The model developed by the IÖW can be used to quantify the technology-specific effects of value added and employment in the RE sector for various geographical units. The modular structure of the model, furthermore, allows the effects to be calculated for every step along the value chain as well as for each individual value-added component. Given knowledge of the locally installed RE capacity and the local RE companies along the value chain, it is possible to implement the model for various geographical areas. The potential for transferability is thus an important feature of this method. However, the model can only be used to calculate direct effects associated with the use of RE. As a consequence, the method presented here cannot be used to assess the effects generated on upstream value chain stages or the effects that occur due to the substitution or crowding out of economic activities as a consequence of RE expansion.

The model implementation for an average municipality in Germany in 2011 has shown systems manufacture, planning and installation, and also facilities operation to be sources of important value-added effects at the local level that can contribute considerably to employment in the municipality's RE sector. The production of plants and components accounts for about one third of the total municipal value added and is thus an important factor for German manufacturing industries. With the exception of systems manufacture, the majority of the value chain stages are widely distributed throughout the country, including rural areas, due to the decentralized nature of RE.[d] Thus, the use of RE has significant potential to create value-added and employment effects throughout Germany, as opposed to the limited number of locations that tends to be the case with energy production based on fossil fuels.

Furthermore, the analysis of value added and employment resulting from the deployment of RE in a specific municipality or region goes beyond the mere quantification of these regional economic effects. For instance, it can shed light on gaps in a specific value-added chain, i.e., those steps not yet addressed by companies or investors located within the region in question. In addition, collecting the input data necessary for implementing the model in a specific municipality or region (installed capacity, companies along the value chain, etc.) can facilitate targeted cluster management of the RE sub-sectors, as it focuses on the various enterprises and investors along the value chain. Moreover, quantifying the effects that can be generated by the use of RE sources in specific municipalities or regions makes it possible to compare the results with value-added and employment data from other sectors of the economy. As was pointed out in the 'Background' section, many local actors anticipate regional economic effects in connection with the expansion of RE but, in the majority of cases, do not know the magnitude of the effects in their municipality. Comparing the results with value-added and employment in other sectors can thus indicate the current economic relevance of the RE sector in the municipality. The assessment of local value-added and employment effects can thus be an important factor for local acceptance of RE technologies and the further expansion of RE in a region. In conclusion, knowledge about the opportunities as well as the success factors for expanding RE in a region can help communities benefit from a restructuring of the energy system towards a decentralized energy supply.

Endnotes

[a] Meanwhile, the model has been extended to the quantification of effects at the state and federal levels.

[b] In a current research project, these RE technologies are being added to the model.

[c] The reference value for solar thermal systems is installed collector surface; for wood and biofuels, it is the amount produced.

[d] Depending on the RE technology, there are exceptions, such as the planning and installation of wind energy plants, which is mainly done by a small number of larger service providers in Germany.

Abbreviations

IÖW: Institute for ecological economy research (IÖW); kW: kilowatt; MW: Megawatt; O&M: Operation and maintenance; RE: Renewable energy.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors made a significant contribution to the design and the further development of the model, focusing on different RE technologies. All authors drafted a part of the manuscript. All authors read and approved the final manuscript.

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