Evaluation concept for „100% Renewable Energy“-projects

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***Abstract* — Many projects exist to advance the energy transition at the regional level. In this paper, 14 selected projects are dealt with. The projects can differ significantly in terms of goals, scope or approach. Therefore, the question of how these projects should be classified and which factors make such a project successful or less successful is to be answered here. As a method for this, an evaluation matrix is presented, which is based on 10 evaluation criteria with different weighting. This makes it possible to receive an overall score for each project that can be compared with those of the other projects. The evaluation procedure is explained for 5 out of the 14 project examples. Projects with particularly high scores include the energy self-sufficient village Feldheim and the Rhein-Hunsrück-Kreis. These and other high-scoring projects have in common that they benefit from high citizen initiative and participation. They also rely on a wide range of renewable energy technologies and are not dependent on just one or two. Therefore, high citizen initiative and participation and a broad technology portfolio are two particularly important and promising project characteristics. It has to be pointed out that especially the conversion of the transport sector to renewable energies causes difficulties. Here, suitable approaches are still lacking almost everywhere. Finally, attention is drawn to the strengths and weaknesses of the evaluation matrix.**

1 Introduction

Throughout Germany and internationally, there are many projects that deal with the implementation of a decentralized renewable energy supply. The evaluation and comparison of the projects described here as "100% renewable energy" is often difficult. Reasons for this can be, among others, the different goals, approaches or simply the project scopes. Because of those problems, a concept is presented here that offers the possibility to classify and evaluate "100% renewable energy" projects. The concept is based on an evaluation matrix. With the help of this matrix the projects are considered under different aspects respectively evaluation criteria. The aim of this concept is to find out which factors are decisive for the successful implementation of such "100% renewable energy" projects. In addition, conclusions are to be drawn about promising procedures for the realization of an energy supply with 100% renewable energies.

2 Project Examples

The development and application of the evaluation concept is based on a total of 22 national and international exemplary projects. This paper concentrates on 14 of these projects located in the German-speaking countries Germany, Austria and Switzerland. The focus of the "100% Renewable Energy" projects is on advancing the energy transition. The scope of the projects can range from that of a single house to that of an entire region. The concrete goals pursued by the individual projects can vary greatly in detail. In the best case, this is energy self-sufficiency in the electricity, heating and transport sectors. However, projects that for example specialize in only one of the three sectors are also considered. Fig. 1 shows the locations of the 14 projects in focus. The color coding indicates the project scope.

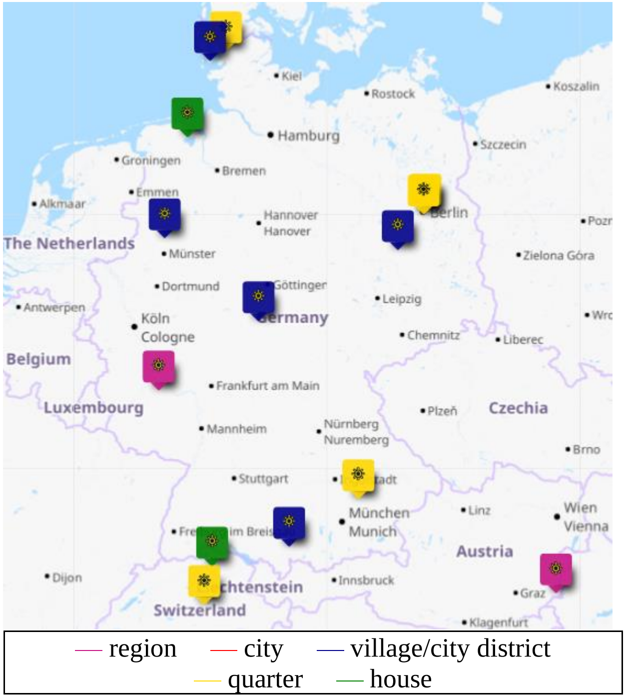

Figure 1: project locations and scopes [1]

3 EVALUATION CONCEPT

3.1 Evaluation methodology

The evaluation is carried out with an evaluation matrix. The matrix contains different evaluation criteria, each of which is assigned a weighting factor X. The weighting factor indicates the relevance of the respective evaluation criterion. The higher the weighting factor, the higher the relevance of the evaluation criterion.

Depending on how well a project performs regarding a specific evaluation criterion, a first score A between 1 and 5 is given. The first score is then multiplied by the weighting factor, resulting in the second score B. This process is then run through individually for all evaluation criteria. The scores B of all evaluation criteria are then added up. This gives each project an overall score C and allows it to be compared to other projects. Table 1 shows an example of the procedure for evaluating a project.

TABLE 1: EVALUATION METHODOLOGY

evaluation criteria	**weighting factor X**	**score A**	**score B**	**overall score C**
evaluation criterion 1	X_1	A_1	$\mathbf{B_1} = X_1 * A_1$	$\mathbf{C} = B_1 + B_2 + B_3$
evaluation criterion 2	X_2	A_2	$\mathbf{B_2} = X_2 * A_2$	
evaluation criterion 3	X_3	A_3	$\mathbf{B_3} = X_3 * A_3$	

3.2 Evaluation criteria

The ten evaluation criteria included in the evaluation matrix are described in detail below. Table 2 shows an overview of the ten evaluation criteria together with the associated weighting factors.

TABLE 2: OVERVIEW OF THE EVALUATION CRITERIA AND THEIR WEIGHTING FACTORS

evaluation criteria	**weighting factor X**
autarky rate – electricity	6
autarky rate – heat	7
autarky rate – transport	8
project scope	5
settlement density	2
settlement structure	2
technology portfolio	5
project progress	3
project ambitions	2
citizen participation	6

3.2.1 Autarky rates (self-sufficiency rates)

The autarky rates in the electricity, heat and transport sectors form the first three evaluation criteria. Autarky is the complete or partial self-sufficiency of a household, a municipality, a region or a state with goods and services [2]. In terms of energy supply this is the share of self-generated and used renewable energy out of the total energy consumption. The points are assigned by defining different areas of the autarky rate.

The higher the autarky rate, the higher the score:

- Autarky rate: 0 – 39% → score: 1 point
- Autarky rate: 40 – 59% → score: 2 points
- Autarky rate: 60 – 79% → score: 3 points
- Autarky rate: 80 – 99% → score: 4 points
- Autarky rate: 100% → score: 5 points

In a few cases, it is highlighted that 100% autarky has been achieved in reality and not only by calculation. In these cases, the criterion is given 6 points for. Autarky rates are the most important criteria in project evaluation. The status of a project can be determined by this, and in the end, it is the autarky rate against which the project must be measured. For example, an autarky rate of 100% in all three sectors would indicate a successfully completed project. The autarky rates are therefore given the highest weighting factors. Nonetheless, the weighting factors should also take into account the different complexity of autarky in the electricity, heat or transport sectors. Autarky in the electricity sector is relatively easy to achieve with PV and wind energy, so that a weighting factor of 6 is used for this criterion. A changeover in the heating sector is more difficult to implement, simply because of the effort involved in replacing almost all heating appliances or setting up a heating network. For this reason, the autarky rate for heat is weighted by a factor of 7. In most of the researched cases, the primary focus is on the electricity and heat sectors. Fully renewable transportation seems to be much more difficult to implement. "In addition to suitable charging infrastructure or car-sharing offers, every individual must be convinced to take advantage of these opportunities, which has not yet been the case." [3] as Guido Wallraven, project manager of the climate community Saerbeck, confirms in a conversation. For these reasons, the highest weighting factor of 8 in the evaluation matrix is used for the autarky rate in transport.

3.2.2 Project scope, settlement density & structure

Furthermore, the project scope is evaluated. Here, above all, the effort or the complexity is considered, which has the conversion to a renewable energy supply or its construction. The complete supply by means of renewable energies is comparatively easy to implement for a single house, while the effort increases with increasing project scope. The classification is therefore made in:

- House → score: 1 point
- Quarter → score: 2 points
- Village/city district → score: 3 points
- City (>10000 inhabitants) → score: 4 points
- Region → score: 5 points

But looking only at project scope would be insufficiently accurate. Project scope alone does not take into account the energy demand or the amount of space available to build up renewable energy generation plants.

These two points can differ significantly for two different sized cities or villages, for example, even though the same score is assigned for the project scope criterion. In order to be able to rank the projects even better in this respect, two further criteria are introduced.

On the one hand, the settlement density. If this is relatively low, it can be assumed that (free) space is available for renewable energy generation plants. Furthermore, the energy demand in densely populated areas is comparatively higher and therefore more difficult to cover by means of renewable energies.

On the other hand, the settlement structure. Here, a distinction must be made between, for example, rural/agricultural, industrial and residential areas. This aspect is considered separately from settlement density, although these are often related in terms of their influence on energy demand. Rural areas often have a lower energy demand, which may be due to a lower settlement density, while residential areas often require more energy, sometimes due to the higher settlement density. However, it is not uncommon for industries to locate on the periphery of cities and thus in less densely populated areas, which, however, greatly increases the energy demand of these and makes it more difficult to supply them completely using renewable energies.

Settlement density is difficult to divide into clearly defined areas, so it is estimated as low (1 point), medium (2 points), or high (3 points) based only on surrounding farmland and open space.

The settlement structure is similarly divided into rural or little industry (1 point) and large-scale town or much industry (3 points). If the settlement structure and thus the estimated energy demand lies somewhere in between, this is assessed with 2 points.

The project scope is weighted by a factor of 5. Settlement density and structure are each weighted by a factor of 2. The combination of these three criteria breaks down the scope of a project and its associated complexity precisely enough for the purposes of the evaluation matrix. The principle applies: the more complex, the higher the rating.

3.2.3 Technology portfolio

In addition, the technology portfolio of the projects is evaluated. This raises the question of how many different renewable energy technologies are used. If only one technology is used, the dependency on this technology is high and the flexibility is low. If autarky in the electricity sector is to be realized, for example, solely through PV technology, there is a risk of insufficient electricity supply during times when the sun is not shining. Without adding e.g. storages to the portfolio, dark lulls would be inevitable. Consequently, projects with a broad technology portfolio are given a higher score than those that rely on only one or two. However, the scope of the project must be considered in the evaluation. It is obvious that, for example, many more technologies can be used in regions than in a single house. The weighting factor for the technology portfolio is 5.

3.2.4 Project progress

Another evaluation criterion is the progress of the project. This examines which of the goals set at the beginning of the project have been achieved so far. The evaluation also includes whether there were any problems and how they were dealt with. For example, whether initial goals had to be scaled back again. In addition, the duration of the project should be taken into account, that means the time that has already passed since the start of the project. In the evaluation, an idea is only as good as its implementation. Projects that have already been successfully completed are therefore awarded 5 points, while those that are still in the planning phase or have even been abandoned are assessed accordingly with 1 point. In the weighting, a factor of 3 is selected for the project progress.

3.2.5 Project ambitions

The project ambitions are the evaluation criterion with the lowest weighting - weighting factor 2. This examines which concrete goals are to be achieved or have already been achieved. Or in other words how ambitious these goals are. For example, it is examined whether complete autarky is aimed for and in which sectors or whether the goals even go beyond complete autarky. Further aspects would be, for example, a commitment to environmental protection and nature conservation that goes beyond the conversion of the energy supply, or special public relations work by the project executers. This criterion can also be used, among other things, to determine whether the project is making a serious attempt to advance the energy transition or whether the project image is in the foreground, as it appears to be in the case of some individual projects.

3.2.6 Citizen participation

The last evaluation criterion to be mentioned is the citizen participation. This criterion examines the extent to which citizens are or were involved in the planning process. And whether citizens are or were able to engage themselves, participate in decision-making, or contribute financially. The weighting factor of 6 is relatively high. This is based on findings obtained from research, as well as discussions with Mr. Guido Wallraven [3], project manager of the climate community Saerbeck and Mr. Frank Michael Uhle [4], climate manager of the Rhein-Hunsrück-Kreis.

4 EVALUATION OF THE PROJECT EXAMPLES

In the following, the evaluation results of several exemplary projects are presented. For this purpose, the projects are first described more in-depth and a detailed insight into how the evaluations come about is given.

4.1 Energy self-sufficient village Feldheim

The energy self-sufficient village of Feldheim is a village with about 130 inhabitants in Brandenburg, Germany. The village includes 37 households, 3 farms, 2 commercial units and is located in a rural area. Thus, the project receives 3 points under the project scope criterion. Due to the low population and the rural structure, settlement density and structure are each awarded 1 point. [5]

The energy supply in Feldheim is based on the following renewable energy technologies [5]. These result in a score of 5 points for the technology portfolio criterion:

- Wind park Feldheim (55 wind turbines) – power: 123 MW
- Biogas plant – power: 526 kW_{el}; 560 kW_{th}
- Battery storage – capacity: 10.7 MWh
- Woodchip heating plant – power: 299 kW
- Solar park Selterhof – power: 2.25 MWp
    - Yield approx.: 2748 MWh/a
    - 9844 PV-modules distributed over 284 movers
    - For public grid feed only

Thus, 100% real autarky is achieved in the electricity and heat sectors, which results in ratings of 6 points for the criteria autarky rate electricity and autarky rate heat. Here, 6 points are awarded instead of 5 points since the energy demand can be covered at any time with the help of the battery storage and the base-load capable biogas plant as well as the woodchip heating plant. In the transport sector, no known efforts have been made so far, which is why the autarky rate for transport is assessed with 1 point. [5]

At the beginning, the project goals were complete self-sufficiency in electricity and heat supply, which has already been achieved. The transport sector played a subordinate role at that time. In the near future, however, a traffic concept is to be discussed with the district. In addition, the production of green hydrogen is planned [6]. The project progress is therefore rated with 4 points. For the criterion project ambitions, the energy self-sufficient village Feldheim also receives 4 points. In addition to the initial and future project goals, the village's public relations work is also a reason. For example, guided tours are offered, which promote a decentralized renewable energy supply and serve as inspiration for other communities [5].

For the evaluation criterion - citizen participation, the project receives 5 points. The project is based entirely on the initiative and commitment of the villagers. At the beginning of the project, they were convinced by Michael Raschemann who was student at the time, to go the renewable energy route. The village has separate distribution networks for electricity and heat, which, like the renewable energy generation plants, were partly co-financed by the residents. The electricity grid is owned by Energiequelle GmbH und Co. WP Feldheim 2006 KG, the company of first initiator Michael Raschemann. The local heating network is owned by Feldheim Energie GmbH & Co. KG, an association of the connected households, companies and the town. [5, 7]

The energy self-sufficient village Feldheim achieves an overall score of 180 points.

4.2 Energy self-sufficient apartment house Brütten

This project is located in Brütten, Switzerland [8]. 1 point is awarded for the project scope - house. Settlement density is also awarded 1 point. Due to the location within a village, it can be assumed that more space is available than in urban areas. The settlement structure is rated with 1 point for this project. The settlement structure within which the house is located has no influence on the energy demand of the house. However, it is simply assumed here that a simple residential house has a lower energy demand than, for example, a single industrial building.

The energy supply of the multi-family building is based on the following renewable energy technologies [8]. These result in a score of 5 points for the technology portfolio criterion:

- Solar PV on roof – power: 79.54 kWp
- Solar PV on facade – power: 46.96 kWp
- Short-term storage (up to 3 days): Lithium iron phosphate battery – capacity: 153 kWh
- Long-term hydrogen storage (seasonal) – capacity: 120 m³ – linked with electrolyzer and fuel cell
    - Electrolyzer – electric power: 14.5 kW (consumption); thermal power: 8 kW/35 °C; yield: 2 Nm³/h hydrogen (30 bar)
    - Fuel cell – electric power: 6.2 kW/ 5.6 kW (continuous power); thermal power: 5.5 kW (continuous power)/ 60 °C
- 2 x 125 m³ hot water storage tanks – max. usable temperature 65 °C – charge/discharge by means of heat exchanger
- Heat pump – max. 28 kW – heat sources: Earth probes, outside air, long-term thermal storage, waste heat from electrolysis and inverter.
- Waste heat of fuel cell

With the help of the technology portfolio, electricity and heating requirements in the house can be completely covered at any time. This means that the house is truly self-sufficient in both sectors, which results in 6 points each for the evaluation criteria autarky rate electricity and autarky rate heat. As a result, the house does not require a connection to either the electricity or the heating network. [8]

An electric car and a vehicle powered by biogas are available to residents. The electric car is charged with self-produced electricity from the PV system. The biogas is partly produced from kitchen waste. To what extent the offer is used by the residents is not known. However, the autarky rate transport, due to the existing opportunities for environmentally friendly transport, is rated at 3 points. The rating is not higher here since the demand of a multi-family building with only two vehicles probably cannot always be met. [8]

As the project has been successfully completed, the project progress is awarded 5 points. For the criterion project ambitions 3 points are awarded. The energy self-sufficient multi-family house is a project realized by the project sponsor Stiftung Umwelt Arena Schweiz. The Stiftung Umwelt Arena Schweiz wants to inform the population through its projects in the areas of sustainability and energy transition and motivate them to act. For example, guided tours of the energy self-sufficient apartment building in Brütten are also offered. However, due to the small scope of the project, no higher rating is given here. Citizen participation in the project was or is not present, therefore the criterion citizen participation is given a score of 1. [8]

The project achieves an overall score of 163 points.

4.3 The Eco-Energy-Land (the Güssing model)

The Eco-Energy-Land (EEL) is a region in the state of Burgenland in Austria in which the city of Güssing is located. The region is with about 18100 inhabitants, distributed over 19 municipalities, relatively sparsely populated and relatively structurally weak. Therefore, besides the project scope, which is evaluated with 5 points for a region, settlement density and structure are evaluated with one point each. [9]

Data on the following renewable energy generation plants in the project region are known [9]. These result in a score of 5 points for the technology portfolio criterion. The potential of wind power plants is low in the region, which is why 5 points are awarded despite the absence of this technology [10]:

- 3 hydropower plants – 0.24 MW; 960 MWh/a
- 76 PV-systems – 2.23 MW; 2453 MWh/a
- Waste biomass power plant – 1.3 MW; 6500 MWh/a
- 4 biogas power plants – 2.5 MW; 17500 MWh/a
- Battery storage – 25 kWh
- 3 Solar-thermal-system – 0.5 MW; 550 MWh/a
- Waste biomass power plant – 7 MW; 44800 MWh/a
- 4 biogas power plants – 1.5 MW; 10500 MWh/a
- Primary solid biofuels – 22 MW; 51000 MWh/a

Just under 25% of the region's energy demand for electricity and heat is covered by renewable energies. No detailed data is available for transport. Therefore, 1 point is awarded for each of the three evaluation criteria autarky rate electricity, heat and transport. [9]

In the past, the region of Güssing mainly relied on the energetic use of wood biomass, as this resource is widely available. The aim was to boost the region's economy and increase regional value creation, as the region was one of the poorest in Austria at the beginning of the 1990s. This was noticeable in the form of a high unemployment rate, emigration rate and capital outflow. However, this strategy was only temporarily successful. In the meantime, 98% of the heat demand and 150% of the electricity demand could be covered. As the national (and also the EU) strategy has moved away from the use of biomass for energy supply and state subsidies have thus been suspended, biomass use has been reduced again. The project was already further advanced in the past than at the present time, but then failed partly due to the wrong strategy. The current project status leads to a rating of 1 point for the evaluation criterion project progress. [9, 11, 12]

Today, efforts are being made to focus more on photovoltaics and biogas, as these technologies also have a relatively large potential in the EEL. The goal is to become independent of fossil energy imports and to obtain renewable energy from the regionally available resources [9]. In addition, the region wants to prepare for the coming consequences of climate change through adaptation measures [13]. This results in an evaluation of the project ambitions with the score 2.

The extent to which citizens can get involved in the planning or participate financially is hardly clear from the available sources. The project therefore receives 1 point for citizen participation.

The Eco-Energy-Land achieves a total score of 88 points.

4.4 Rhein-Hunsrück-Kreis

The Rhein-Hunsrück-Kreis is located in Rheinland-Pfalz, Germany and has around 103000 inhabitants. This community consists of 137 cities and communities of which 75% have under 500 inhabitants [14, 15]. Due to the predominantly rural settlement structure and the relatively low to moderate settlement density, these two criteria are each awarded 2 points.

The energy supply by means of renewable energies is primarily provided by wind and solar energy, as well as the use of biomass in CHP units for heat and power generation. Other technologies are also used sporadically, but these are not so important, which is why the technology portfolio of this project is rated with 4 points: [15]

- 276 wind turbines – power: 722 MW; 1200000000 kWh (2019)
- 5245 PV systems – power: 104 MW; 473 Mio kWh/a (2019)
- 18 biomass plants – power: 6.1 MW; approx. 32 Mio kWh/a (2019)
- Woodchip heating plant – saves 60000 l heating oil equivalent per year
- 17 local heat parties + waste biomass plant – save 2.7 Mio l oil equivalent per year

The goal is to have zero emission, including traffic and waste, and therefore becoming a reference region for sustainability. Considering the size of the community and the total number of inhabitants, this is a very ambitious goal, which requires a huge project scope. For this reason, this criterion as well as the project ambitions are rated with 5 points. As for today many subprojects has been successfully implemented and although the overarching goal has not been reached yet the circumstances for this are given and the Rhein-Hunsrück-Kreis is well on the way. Therefore, the project progress is rated with 4 points.

In regards of self-sufficiency in the electricity sector, at the end of 2018 the wind turbines generated electricity for more than 300000 households. In addition, it was investigated how many roof areas would be suitable for the installation of PV systems; from a total of approx. 80000 roof surfaces in the district 58600 are suitable. Here almost the entire electricity demand of the RHK that is 484 million kWh per year (2017) could be covered. At the end of 2019 the share of renewable electricity in the district was around 310% based on 2017 electricity consumption. [15]

A surplus of energy is deliberately generated so that rural areas function as "energy growers" for surrounding large cities. Surplus electricity is transported to the three surrounding electricity sinks by means of three distribution network levels, so that the "last kWh" is purchased no later than 60 km outside the district. [4] Smart operators are to be used to better exploit the potential of renewable energies locally and to balance grid loads. Following suggestions from citizens, more of these cells are to be used in the region in order to realize a swarm power storage system. The total budget for this so-called "energy honeycomb" of around €7 million is being borne by Innogy/Westnetz. The heart of the project is a large battery with 2.5 MW power and 4 MWh capacity, which was inaugurated in 2018. [15, 16] Due to these factors, not only real self-sufficiency, but moreover a surplus has been achieved, so that this criterion is evaluated with the maximum score of 6 points.

Heat is primarily generated using biomass, which feeds local heating networks that have recently been supplemented by solar thermal energy. According to Mr. Uhle the biomass power plants can remain completely switched off in the summer [4]. Unfortunately, no data or figures are available for this so the exact share of renewable heat remains uncertain; therefore self-sufficiency rate is given a score of 3, because it remains uncertain whether peak outputs can be met by waste, biomass and solar thermal or whether natural gas-fueled peaking boilers are nevertheless available, for example. It should be noted, however, that this evaluation is associated with a certain degree of uncertainty and the project could potentially be better in this area than presented here.

The mobility sector is still the biggest problem at the moment. According to Mr. Uhle, emissions have actually increased compared to the 1990s. Since there are a lot of "stationary vehicles", more car sharing concepts need to be developed in addition to more e-cars replacing classic combustion cars in general. In this context bidirectional charging has the potential to become a gigastorage system in which 30000 commuters with e-cars with e.g. 40 kWh batteries form a 1.2 GWh swarm power plant. Car owners set how much capacity they need, while the rest is made available to the swarm storage, for which the car owner receives financial compensation; however, this is only a concept so far. [4] Although this sector is still problematic, the problems are known and there are concepts and plans to solve them, so self-sufficiency in the transport sector is rated 2 points.

In terms of citizen participation 4 points are awarded, because although the participation is very high, the project is also carried by the district administration and DESIGNETZ whose interests do not necessarily have to coincide with those of the citizens and their needs. In general, the approach of this project is to solve energy problems regionally, then supraregionally, then nationally. [4, 14, 16] One key aspect is to convert energy import costs into regional jobs and value creation through energy efficiency and renewable energies. By seeing energy not just as something necessary, but as a resource that can be "harvested" and sold, it was possible to turn the challenge of the energy transition into a kind of business model from which those involved, in this case the residents of the district, benefit directly e.g., financially. [4, 15, 16] Local support programs such as free energy consultations, LED changeover days or subsidies for balcony installations can thus allow even low-income earners to participate in the energy transition. Moreover, there are further information events or discussion evenings, where concepts, plans or even problems are presented to the residents to discuss together, [4] and therefore strengthen the acceptance and citizen participation. For example, Mr. Uhle was involved in the founding of a voluntary e-mobility working circle in Koblenz. Here, only private persons are admitted, so that experiences are exchanged and discussed. This also gives previously only interested persons an honest insight into aspects such as operating costs, without having to worry that it is advertising or marketing. According to Mr. Uhle, this working circle is well accepted by the citizens and attended with interest, which can potentially significantly increase the acceptance and participation of the population. [4]

The project achieves an overall score of 172 points.

4.5 Pellworm

Pellworm is an isle-community with about 1250 inhabitants in Schleswig-Holstein, Germany. Due to the low population and the rural structure, settlement density and structure are each given 1 point for.

The energy supply in Pellworm is based on the following renewable energy technologies [17, 18]. These result in 3 points for the criterion technology portfolio:

- 12 wind turbines – power: 22.5 MW
- PV systems – power: 2.2 MW
- Biogas plant – approx. 4475 MWh_{el}/a
- 30 solar thermal systems – 174.2 MWh_{th}/a
- 35 heat pumps – 525 MWh_{th}/a
- Woodchip heating plant – 140 MWh_{th}/a
- biogas plant – 1700 MWh_{th}/a

The so-called Masterplan 2020 defined goals to reach until 2020. It contains for example increasing the renewable electricity production to 69.000 MWh/a, heat production to 4.300 MWh/a and reduce the energy demand in all areas by 30% and the use of oil by 50% [18, 19]. The developed island vision (Sustainable Pellworm 2027) consolidates the realization that every contemporary development has to be sustainable and the CO_2-neutral heat supply possibility of individual quarters and districts should be worked out. In this context, energy supply and mobility should be economical, safe, cooperative and sustainable. [18, 20] Although these goals sound good, they are formulated in a relatively vague manner and their implementation is questionable. This results in a rating of 2 points for the project ambitions.

Considering the previous criteria, the project scope is evaluated with 3 points. The self-sufficiency rates for the electricity, heat and transport sectors can only be roughly estimated. The available data on energy generation is incomplete in some cases, and consumption can only be derived from an energy concept from 2010 [18]. The electricity sector is therefore rated at 4 points and the heating sector at 3 points. CO_2 emissions in the transport sector are accounted for, but very few concrete solutions are presented, which is why the transport sector is awarded 1 point. [18, 21]

The project was mainly carried by E.on, whose interest may have been in testing technologies under real conditions, as some articles may suggest. [22, 23] Therefore it seems that there was not much room for citizens to contribute ideas, suggestions, or generally participate. Because of this the project is awarded with 1 point for the criterion of citizen participation.

According to the community website Pellworm is not only striving for climate neutrality, it is also well advanced in this direction and forms an energy sink to a large extend. [18, 19] Other sources state that the project has failed. The problem was that even if Pellworm produces more energy than demanded the storages are not big enough to guarantee a power supply at any time. The additional investment costs could not be covered by any of the worked out models and so self-sufficiency could not be achieved and E.on closed the project [22, 23]. Although some subprojects have already been implemented, the complete stop and thus failure of the project cannot be ignored, which is why the project progress is evaluated with only 1 point.

Since no data more recent than those already presented could be found, and the latest information comes from newspaper articles about the failure of the project, it can probably be said that Pellworm is a prime example of the biggest problems of the energy transition and shows the discrepancy between theoretical or balance sheet and real self-sufficiency (in the electricity sector).

The project achieves an overall score of 100 points.

5 Discussion and conclusions

Fig. 2 shows how many of the 14 projects considered fall into each evaluation range. If a project receives the maximum score A for each criterion, the maximum overall score C of 222 points is achieved. The minimum overall score C is 46 points if the minimum score A is awarded for each evaluation criterion. The range between minimum and maximum overall score can be divided into 4 evaluation ranges using the intervening scores A.

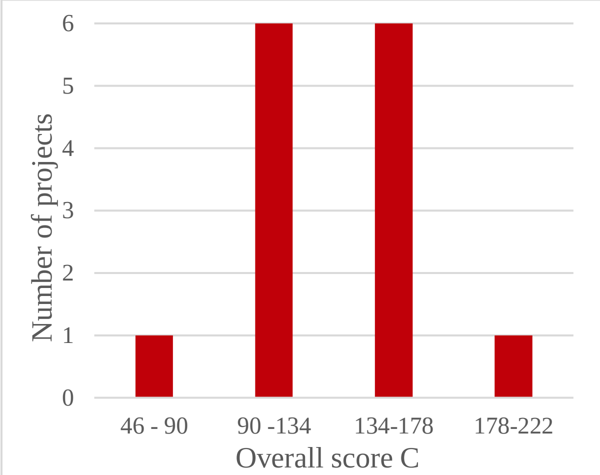

Figure 2: Distribution of the project examples across the evaluation ranges

It can be seen that 12 projects are in the medium evaluation ranges, while only 2 are in the poor or good evaluation range. The reason why the projects in the poor evaluation range are barely represented could be that they are still at the beginning or have at least partially failed. There is little documentation of such projects and little information about them on the Internet. On the other hand, there are many reports about successful projects and attention is drawn to them. Projects that are in the good evaluation range are also barely represented. One reason for this is often poor performance in the evaluation criterion autarky rate transport, which is weighted with the highest factor. No project receives more than 3 points for this criterion. It is particularly noticeable that large-scope projects (villages/city districts or regions) have little to show in this area. This underlines that the implementation of transport concepts based on renewable energies is challenging.

It is also noticeable that autarky in the heating sector is still much less common than in the electricity sector. Here, the situation is less problematic than in the transport sector, but it still seems easier to implement a renewable electricity supply than a renewable heat supply. These findings again confirm the choice of the weighting factors for the three autarky rates evaluation criteria rate.

Now the question arises, what are the other reasons for the success of the best rated projects. These projects include those described above: Energy self-sufficient village Feldheim and Rhein-Hunsrück-Kreis. On the one hand, it is remarkable that these projects are based on strong citizen initiative or at least participation. Thus, a high degree of participation and scope for action on the part of the citizens seems to be promising. It therefore makes sense to inform the people on site. To get them excited about the energy transition so that project executer and people on site can then act together instead of deciding over the heads of many uninvolved people. This is the role that the project executer must play.

In addition, a broad technology portfolio speaks in favor of the mentioned projects. The energy supply is based on various renewable energy technologies. This avoids dependence on just one technology. In the best case, the technology portfolio includes base-load capable renewable energy technologies as well as energy storage to ensure the best possible security of supply. Too much dependence on a single technology or energy source can have negative consequences, as can be seen in the project example Eco-Energy-Land (Güssing model), as well as too less storage as can be seen in the case of Pellworm.

However, it should be noted that reading the matrix can provide a general overview but does not go into more detail about particular aspects of a project, some of which may be critical to its success. Entering data into the matrix requires a detailed examination of the project in order to be able to make meaningful assessments that can be compared with other projects. The data required for this is often not or only partially publicly available, so that some criteria had to be evaluated on the basis of estimates; this reduces the accuracy of the evaluation.

Furthermore, weaknesses of the matrix lie in the evaluation criteria themselves. While the self-sufficiency rates are easy to understand and can be entered given the available data, other criteria without clear definition always carry uncertainty. Settlement density and structure, for example, have only been roughly divided into three categories, while the quotient of population size and area would have to be calculated for settlement density. This numerical value alone is of little use, however, since additional scales would have to be defined that divide the various numerical values into ranges, which are then based on a point evaluation. In this first draft of the evaluation matrix, only three of these areas were introduced. For a further development of the matrix, it would therefore be advisable to implement more areas with defined boundaries. The same applies to the settlement structure. The purpose of the technology portfolio evaluation criterion has already been explained, but so far this criterion only measures the quantity of different technologies, but less their quality in relation to the location and project under investigation. An additional or expanding criterion in this regard could help to improve the accuracy of the matrix.

Although the respective weighting factors could be validated to a certain extent on the basis of the researched projects and their comparison with each other, the number of projects is manageable and should be expanded in future investigations and further development of the matrix. In addition, it must be noted that the factors can only represent a snapshot and should therefore be updated and adjusted at intervals.

Despite these criticisms, the evaluation matrix can be used as a tool to categorize, evaluate and compare "100% renewable energy"-projects. Strengths and weaknesses of the projects can be revealed. In addition, circumstances that contribute to or counteract the success of such projects are concretized. Particular emphasis should be placed on a broad technology portfolio and a high level of citizen participation in order to achieve the self-sufficiency goals in the electricity, heat and transport sectors and, ultimately, the overarching goal of 100% renewable energy supply.

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