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Contributions of Bottom-Up Energy Transitions in Germany: A Case Study Analysis

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Abstract: Within the context of an energy transition towards achieving a renewable low-impact energy consumption system, this study analyses how bottom-up initiatives can contribute to state driven top-down efforts to achieve the sustainability related goals of (1) reducing total primary energy consumption; (2) reducing residential electricity and heat consumption; and (3) increasing generated renewable energy and even attaining self-sufficiency. After identifying the three most cited German bottom-up energy transition cases, the initiatives have been qualitatively and quantitatively analysed. The case study methodology has been used and each initiative has been examined in order to assess and compare these with the German national panorama. The novel results of the analysis demonstrate the remarkable effects of communal living, cooperative investment and participatory processes on the creation of a new sustainable energy system. The study supports the claim that bottom-up initiatives could also contribute to energy sustainability goals together within the state driven plans. Furthermore, the research proves that the analysed bottom-up transitions are not only environmentally and socially beneficial but they can also be economically feasible, at least in a small scale, such as the current German national top-down energy policy panorama.

Keywords: energy transition; energy democracy; community management; bottom-up transitions; energy sovereignty; energy justice

1. Introduction

The need to change the current energy system is now an accepted fact on a global level. Three main factors make this energy shift unquestionable. Firstly, burning fossil fuels is one of the most important factors behind global warming according to the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC-AR5) [1]. Global anthropogenic emissions of CO_2 caused by fossil fuels, cement production and flaring were 0.16 $GtCO_2$/year in 1850, and 34.88 $GtCO_2$/year in 2011;

a 21,800% increase. Secondly, the impending phenomenon known as peak oil means that the current energy system based on fossil fuels should be shifted towards the consumption of other resources. According to the Association for the Study of Peak Oil and Gas (ASPO) "[. . .] world oil production might be down by 50% around 2030." [2]. Thirdly, the current fossil-fuel based energy system, from a social fairness perspective, is creating unjust situations in the Global South: the emotional impact of oil spills [3], the social impact of new electricity grids in remote regions [4], the impact of oil extraction [5], the impact of pipeline constructions in rural areas [6], and/or the energy poverty arising from inequalities in the energy distribution processes [7]. Similarly, there have been increases in energy poverty in the Global North, for instance, in the European Union (EU), where 10.8% of inhabitants have experienced difficulties in keeping their homes warm and a similar percentage in paying their electricity bill [8].

Hence, there is an urgent need for an energy transition towards a new democratic energy system with a low social and environmental impact. In the process of identifying the approach to adopt, there has been a trend towards considering this transition in mainly technological manner as a switch away from using fossil and nuclear fuels in favour of renewable sources. Germany, like other northern European countries, is considered as, socially [9–11] and academically [12,13] leading the way towards a sustainable energy system, and a global example for other countries. Germany currently has the most photovoltaic panels installed in the world with 38.2 GW [14], and has the greatest wind power capacity in the EU with 44.9 GW [15]. Germany's effort in officially enhancing the Energiewende initiative is especially remarkable from a social aspect [16].

The German Energiewende (in English "energy transition" or "energy shift") is an unprecedented national energy transition phenomenon that started nearly 30 years ago as a result of the social mobilization during the antinuclear protests, after which successive governments have manifested their clear ideas for creating a sustainable energy system [17]. The goal of the Energiewende is ambitious, aiming to decarbonize the economic system, reducing greenhouse gas emissions by 40% by 2020 (relative to 1990 levels), and by 80–95% by 2050 [18]. For this purpose, several "top-down" actions were held in Germany in the frame of Energiewende. The most significant was integrated in 2000 after the liberalisation of the electric market, integrating significant feed-in tariffs to boost the installation of solar and wind generation systems. This phenomenon has not only been considered as a set of policy measures, but also as a social process [19] mixing top-down and bottom-up concepts. The second most significant action in Energiewende was held in 2011, when the phase-out of nuclear power by 2022 was established [20].

Nevertheless, if we define sustainable as meeting the needs of the present without compromising the ability of future generations to meet their own needs [21], the current proportion of integration of renewable energies is definitively insufficient, 11% of the total primary energy supply in 2013. It is here that bottom-up initiatives come into play, supporting and enhancing the top-down state-based initiatives [22] to create a wider response in the integration of renewable energies, gaining responsibility of the current energy system impacts and raising the democratic decision-making processes. In fact, recent research has demonstrated that "decentralised initiatives have played a crucial role in the expansion of renewable energy systems (RES) in the German energy system" [23].

In this study, it is considered that up-coming energy transitions are not a simple shift in generation technology, from fossil to RES, but are rather a social shift in the energy management and consumption system [24]. Some research have already detected that the creation of a new energy system (until now mainly analysed in the integration of RES technology [25]) is not a clear and simple technological shift, but is closely connected to the ethics and morals of the inhabitants that consume this energy [24,26]. The connection between the use of energetic resources and social organisation has already been stated [27]. Thus, in this research "energy transition" is understood to be the path to obtain global "energy justice" [26] through "shared responsibility" [28,29].

The need to accelerate the transition process to sustainable energy systems has already been detected due to the limits of the current top-down strategies that need to be complemented and improved [30]. The high potential of integrating decentralized renewable energies has also been noted [31]. Some authors have already referred to the importance of supporting the bottom-up networks in order to obtain deep behavioural changes [32]. Furthermore, it has been found that bottom-up initiatives, even if considered "niches", could impact in offering shielding, nurturing and empowering sustainability transitions [33]. In this context, special effort has been made to understand the potential contribution of grassroots movements in cities to support sustainable transitions [34]. It has been stated that broader contexts, such as cities, can promote the grassroots initiatives or also vice versa, when materialising urban sustainability transitions [35]. More specifically, in Berlin, within the context of the "remunicipalization" process of the electricity utility, and under Energiewende, the relevance of bottom-up initiatives has been argued, not only in implementing a local energy policy but, by creating a specific framing or vision of an energy transition [36]. Grassroots initiatives have been defined as stimulators of collective action to trigger the gain of responsibility and sustainable consumption goals, and prototypical candidates for societal changes [37]. Similarly, the importance to include social-parameters in the analysis of the development of the incoming energy transitions has been revealed [38].

Therefore, it has become relevant to further analyse the social parameters of energy transitions and especially to quote the achievements of the bottom-up initiatives. Thus, the main objective of this paper is to detect the specific achievements of the selected German bottom-up initiatives in their energy transition process so as to assess whether there are elements that enable one to state that there has been a contribution from the bottom-up initiatives to help achieve the national goals. This main objective has been divided into two specific goals; the first one is to qualitatively analyse each case by identifying and classifying the different actions carried out in the energy transition process. The second one is to quantitatively analyse how the new energy system created in each case study diverges from the national average. The differences in energy consumption reduction have been measured according to the total primary energy supply (TPES), residential electricity consumption and the percentage of integration of renewable energies in the consumption system.

The structure of the remaining paper is as follows: Section 2 gives a background on the German energy consumption system, Section 3 describes the methodology used, Section 4 analyses each of the case studies in-depth, Section 5 shows the findings obtained from a quantitative and qualitative point of view, and finally, Section 6 presents our most significant conclusions.

2. Overview of the German Energy Consumption System

In order to have an overall vision of Germany's energy consumption system, two main aspects have been cosidered. Firstly, the current average energy consumption level in Germany, and secondly the sectors where the major consumption of energy normally occur.

2.1. Current Energy Consumption Levels in Germany

To define German energy consumption levels in relation to other countries, its total primary energy supply (TPES) [14] has been compared against its Human Development Index (HDI) [39]. In Figures 1 and 2, 40 countries (chosen through the World Input-Output Database, WIOD, selection criteria [40]) have been compared. Figure 1 shows that Germany is an exemplary case of "medium energy consumption level" and a high HDI amongst high energy consuming countries such as Canada, Luxemburg, the United States, and Finland.

In contrast, countries in the Global South consume less TPES than Germany, yet most achieve an adequate level of HDI. For instance, Indonesia, which presents a high HDI value (whereby "high" HDI according to the United Nations Development Program, UNDP, is equal to or higher than 0.7 [39]), has an average energy consumption which is 78% lower than that of Germany.

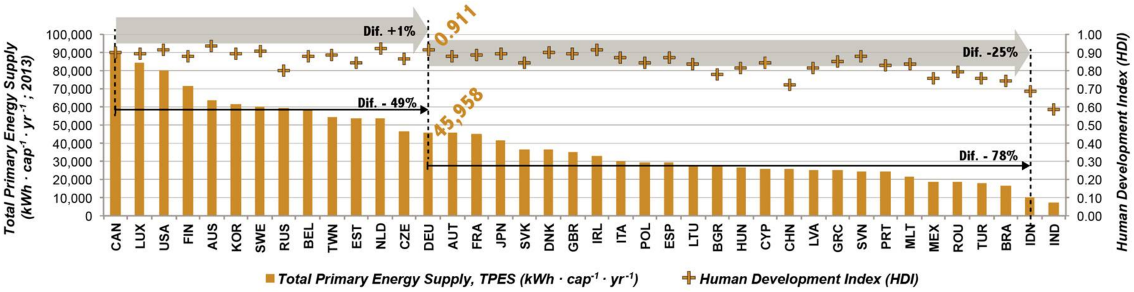


Figure 1. Primary energy supply versus the Human Development Index, based on International Energy Agency (IEA) and UNDP 2013 data.

The high energy consumption of countries in the Global North, such as Canada, and even to an extent in Germany in comparison with that of the Global South, could be justified as the only way to achieve a high HDI. Figure 1 confirms what previous studies have shown: the causal relationship between energy consumption and the level of development ceases to exist in high HDI countries [41].

High energy consumption, justified in terms of reaching a high HDI, is not a problem *per se*. The problem arises when energy consumption data is compared with the ecological footprint (EF) data of the so-called "developed countries". This set of data was collected from the Global Footprint Network (GFN) [42]. When comparing the per capita EF data against the per capita TPES data, it is observed that there is a strong correlation between the two. Furthermore, when comparing the EF against the HDI (Figure 2), it is observed that only two countries, India and Indonesia, are considered "sustainable" according to the amount of resources used. These two countries maintain their resource consumption below 1.7 global hectares, within the capacities of a single planet Earth. The average German per capita energy consumption of 45,959 kWh/year corresponds to an EF of 5.3 global hectares, requiring the resources of 3.12 planet Earths; clearly unsustainable. It is observed that Indonesia, with a per capita energy consumption of 10,099 kWh/year, a figure 78% (Figure 1) lower than the German consumption, is the first country among those compared to fall within the parameters of a sustainable EF (≤1.7 gha, Figure 2).

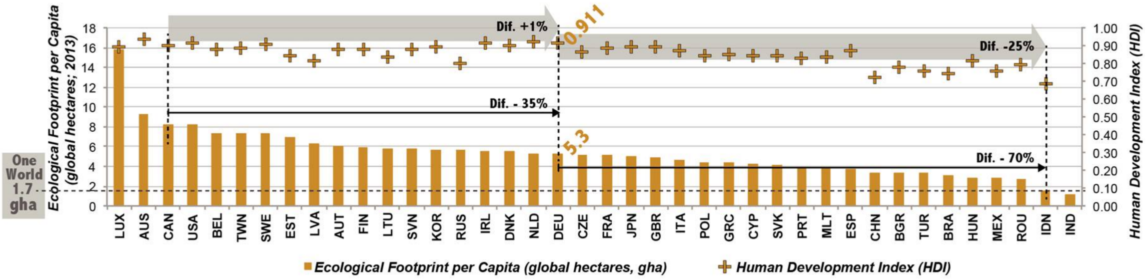


Figure 2. Ecological Footprint versus the Human Development Index, based on GFN and UNDP 2013 data.

For this reason, analysing bottom-up initiatives that could trigger a massive reduction of TPES is of particular importance for the present paper. Energy transitions are considered not only to be a technological approach for increase the renewable energy generation, but also to promote a new life style in which living with new values may help to achieve more sustainable consumption levels. This led us to ask whether there exist different bottom-up cases with energy consumptions of 78% lower than the national average within Germany, with the aim to proportionally reduce the Ecological Footprint to 1.7 gha while maintaining a high level of HDI. These bottom-up initiatives could be considered as models for energy sustainability to be replicated in a global energy transition.

2.2. Current Major Energy Consumption Sectors in Germany

In order to forecast potential sectors for reducing the TPES, the German national consumption data has been reviewed and summarized in Figure 3, which was elaborated by regrouping the IEA data into a Sankey diagram and creating four large consumption groups: electricity consumed in private homes; energy consumed in products, services or transportation (including heat as a service); energy lost in transformation or distribution processes; and the Hidden Energy Flows (HEF) [43].

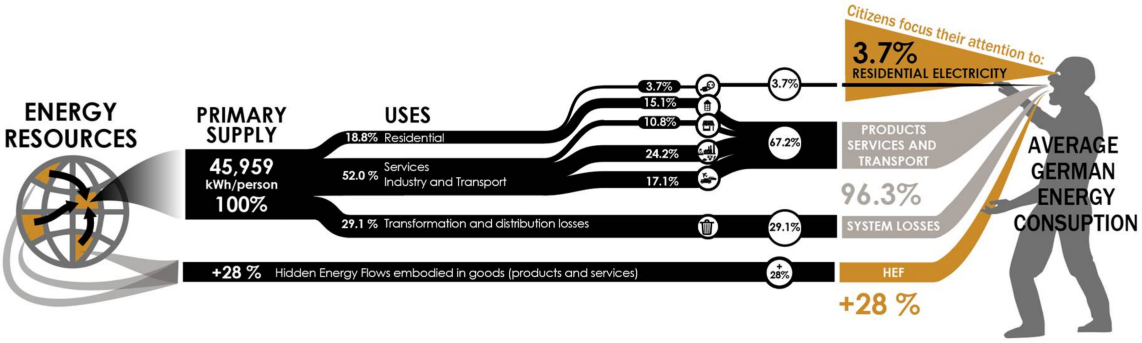


Figure 3. German energy system consumption per capita in 2013, based on IEA data.

Figure 3 shows that the first critical point in the German energy consumption system is the low amount of electricity directly consumed in the residential sector: only 3.7% of the TPES. This shows that trying to reduce residential electricity consumption should not be the principal strategy to reduce the TPES. Changes which a priori could reduce energy consumption, such as purchasing new A+++ low electricity consumption appliances, reduce residential electricity consumption but may increase the energy consumed due to the life cycle of the appliances. Therefore, any action to make reductions within this 3.7% of the national energy system could have serious effects of leading to an increase in the energy consumed in the other 96.3% as a consequence of product manufacturing and transportation. For this reason, this paper outlines that the actions aimed at reducing electricity consumption in private households are not considered sufficient to bring profound changes to the energy system. However, due to its ease of measurement, household electricity consumption level has been quantified as a secondary parameter. Most of the studies in Renewable Energy Cooperatives (REC) focuses on providing renewable electricity to citizens [44–47]. RECs significantly enhances the social capital and democracy [44], but it should be emphasized that they mainly focus on the 3.7% of the TPES (Figure 3). Thus, this paper makes an effort to consider the total primary energy supply in its complexity, with all the difficulties involved.

Secondly, Figure 3 shows that 29.1% of TPES is lost in “transformation and distribution losses”. This is mainly (92.2%) due to the use of fossil fuels during the electricity generation processes in a centralized way. In other words, the greater the use of energy from fossil fuels, the higher the rate of loss in the transformation processes used to generate electricity.

Thirdly, the massive consumption of products and services of the current occidental culture is reflected in the diagram. With only the energy embodied in nationally produced goods taken into account, Figure 3 shows that 67.2% is used to produce goods, services and transportation.

Lastly, data from Arto et al. [48] was used in the chart to include the energy embodied in imported goods and services consumed in other countries. The large amount of imported goods and services create the Hidden Energy Flows (HEF) phenomenon [43], which increases the overall energy consumption value of most countries of the Global North, such as Germany. Therefore, the average national energy consumption in Germany should not be defined as 45,959 kWh but as 28% higher [48].

Taking the third and fourth point together, the high relevance of energy embodied in goods and services can be better appreciated. A similar conclusion was already reached in 2006 by the European Commission in its report “Energy Technologies: knowledge, perception, measures” published by Eurobarometer. It was recognized that the trend towards overestimating the impact of energy consumption in housing was a relevant policy consideration, noting that " . . . respondents seem to have a somewhat vague idea of the ranking of energy consuming sectors: the impact of transport is underestimated while the impact of the housing (heating, lighting, electric equipment and air-conditioning) is overestimated." [49]. This paper has attempted to go further in this direction and to consider "bottom-up" energy transition initiatives as an integral way to face a real shift away from the current energy system towards a low consumption, low impact model.

Figure 3 has been summarized using the Consumption Base Accountability (CBA) approach [50], but in order to understand the influence of other industrial sectors, the energy uses could be aggregated in a different way than the one used in this paper. For instance, the Energy Performance of Buildings Directive (Directive 2010/31/EU) states that worldwide, 40% of all energy is consumed in buildings. This takes into account not only the electricity and thermal energy consumed in households, but also that of industrial and services buildings. In this paper, the main goal is to identify and disaggregate the direct electricity consumed residentially from that embodied in products and services. For this purpose, industrial and services buildings have been considered as part of the infrastructure required to create goods and provide services.

3. Methodology

A case study approach was used to enable us to clarify the specific results and contributions of selected bottom-up energy transition initiatives in Germany. Although similar studies have been approached using the Multi-Level Perspective (MLP) methodology [51], broad scope analysis, like the current one using empirical analysis, although less detailed than other studies using MLP, could focus more on the achievements of the society that is generating the change, and not on the external (regional or national) actors [52]. The "case study" method does not require the control of behavioural events and focuses the analysis on contemporary events [53]. According to Simon [54] "Case study is an in-depth exploration from multiple perspectives of the complexity and uniqueness of a particular project, policy, institution, program or system in a 'real life' context". In each case study, the subject and the object of the case are identified; "a case study must comprise two elements: a practical, historical unity, which I shall call the subject of the case study, and an analytical or theoretical frame, which I shall call the object of the study." [55].

The first step was to select the cases, identifying the eight most important bottom-up energy transition cases in Germany within low energy consumption intentional communities or ecovillages (1) energetically self-sufficient rural villages (2) and sustainable urban neighbourhoods (3). Figure 4 shows the popularity according to the general society in internet (number of citations in the Google search engine) and scientific journals (number of citations in the Scopus search engine). The most cited in each category has been selected. In Table 1 the subjects and objects in the three selected cases have been defined.

Qualitative and quantitative questionnaires were developed in situ for community members in order to collect the energy consumption model description and data of each case. Cases were pre-analysed, contacted, and visited by the main author, conducting interviews of the community members. The goal of qualitative questionnaire was to understand the trigger factors for each energy transition and the underlying collective philosophy so as to describe the nature of each transition. Whereas in the quantitative questionnaire, the goal was to understand if an approximate calculation of the TPES could be made, and to analyse the electricity consumption and the self-produced renewable energy in each case study. Questionnaires were developed by a multidisciplinary research team with the participation of researchers from the University of the Basque Country, "Ecologistas en Acción Euskadi" grassroots confederation, and "Engineers Without Borders", a non-governmental organisation, as a part of a wider project [43]. In each case study, main coordinators or communication representatives were interviewed in order to gather the official data. The findings were compared against the data of average national energy system. The measurement of electric and thermal energy consumption in households is more accurate and affordable than the measurement of the TPES of an initiative. Consequently, in this study, several assumptions were made to obtain a raw TPES value, and were clearly explained in each case study. Although the available data are limited, they are enough to observe that in all case studies, significant results were achieved in comparison with national consumption average trends.

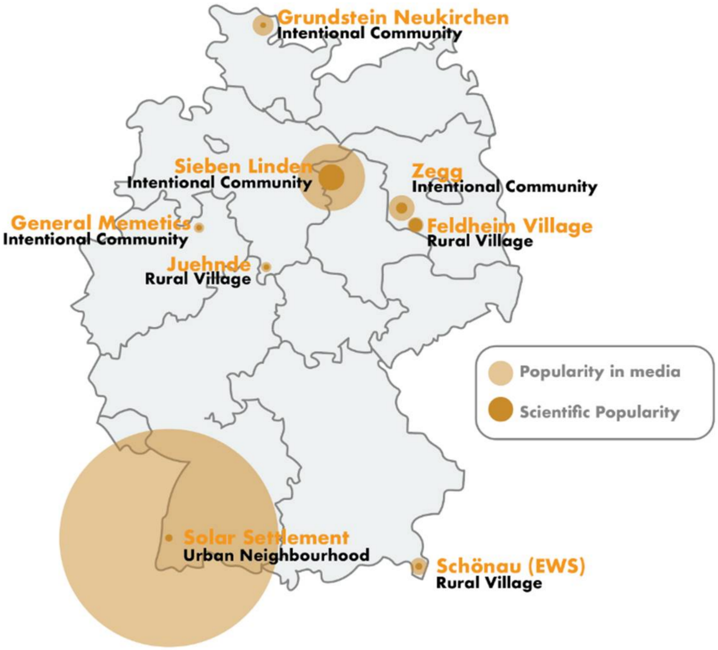


Figure 4. Popularity of bottom-up energy transition cases in Germany.

Table 1. Analysed three case studies.

Initiative	Subject	Object
Sieben Linden (Category: Intentional community, ecovillage)	"A group of people", united by grassroots anti-nuclear movements, created a low-energy consumption community.	Communal use of resources, rather than technological efficiency to reduce energy consumption.
Feldheim (Category: Rural village)	Energy self-sufficient village, linked to a renewable energy generation cooperative.	Economic viability of energy transitions.
Solar Settlement (Category: Urban neighbourhood)	An architect, inspired by sustainable building and living principles, builds an energetically sustainable neighbourhood that produces more electricity than it consumes.	The role of sustainable residential areas in energy transitions.

4. Case Studies

4.1. Sieben Linden

Sieben Linden is an "ecovillage", recognized by the Global Ecovillage Network (GEN) [56]. 140 people (100 adults and 40 children), inhabit it. The original group was created in Gorleben, during the anti-nuclear protests of the 1980s. For this reason, the ideology of the Sieben Linden "intentional community" has been closely linked with the aim of creating a sustainable energy system. It currently co-owns 80 hectares, of which 45 are forestland. In the future, the village expects to reach a population of 250 and 300 inhabitants. This is considered the optimum number of members to have the right balance between sustainability and efficiency in resource management.

Unlike other similar experiences, based on a personal "sacrifice" to achieve sustainable living consumption standards, this community views "austerity" as a gain in happiness by providing a high quality of life in an attempt to achieve a minimalistic material lifestyle. This is achieved through a communal and participatory model of resource management where they have quantified their total energy consumption in kWh per capita. This basic calculation permits the community to choose the adequate patterns and technologies, and to promote a responsible approach towards the environment in all energy consumption (food supply, building material supplies, electricity generation, water purification systems, etc.).

One of the pillars of sustainability in the community has been architecture and the design of places to live. As a general rule, each person has the right to have a maximum amount of 16 m^2 of private space in his or her own house, and 16 m^2 of communal area in the ecovillage; reducing the energy requirement to build, maintain, and to heat in these spaces.

In Sieben Linden, the buildings are designed to consume as less energy as possible. The first home built in the ecovillage, named "Villa Strohbund", was built with no machinery or fossil fuels, using only local or recycled materials. In this first home, the ambitious challenge was to consume only 10% of the primary energy consumed in traditional homes, following the goals dictated by the book "Greening the North" [57]. The energy consumed during the construction of Villa Strohbund was between 2% and 5% of that consumed by a house of the same insulating properties (50 kWh/m^2 per year for heating purposes) [56,58].

The second important pillar of the Sieben Linden energy system was to have a "one earth equivalent energy footprint". To make this measurable target, the community aims to obtain all the resources (especially for heating and lighting) from their own land. The community has an internal energy advisor who states: "Our goal is to live in an energy system where each person only uses the proportional corresponding part of resources of the country; we would like to ascertain that every person on this planet, and future generations as well, have the same right to use the resources" [59]. Based on this commitment, a calculation has been made in Sieben Linden regarding the amount of forestland that would correspond to each German citizen if there was a national equitable distribution. At the same time, the energy from their own forest, grown and managed sustainably, was assumed to be the easiest way to guarantee a non-negative impact energy source [59], with zero net carbon emissions, neutral in CO_2 [60]. According to the basic calculations of the community, if the total amount of land of Germany was equitably divided, given that Germany has an area of about 360,000 km^2 and 80 million inhabitants, the available area per capita should be 4500 m^2 per person, of which 2200 m^2/person are forests for wood extraction (see Table 2).

Table 2. Equitably divided use of available land in Germany (data provided by Sieben Linden community [59]).

Land Use in Germany	($m^2 \cdot cap^{-1}$)	(%)
Land used for food	1600	36
Land used for Forestry purposes	2200	49
Non-usable land (road, rivers, city . . .)	700	16
Total available land per capita in Germany	**4500**	**100**

The calculations estimated in Sieben Linden, shown in Figure 5, indicate that by managing biodiversity properly, of 2200 m^2 of forestland, 6.5 m^3 per hectare per year could be cut down. Of this, around 23% (1.5 m^3) is left in the field to increase biodiversity, and 5 m^3 of timber is used as firewood, equivalent to 1650 kWh embodied thermal energy. This energy could be extracted in efficient stoves with an annual rate of 1450 kWh residential heat per person and year.

These basic calculations conclude that, with the current 40 hectare forest owned by the ecovillage, Sieben Linden is consuming 30% more wood than their corresponding national average: instead of harnessing 2200 m^2 they are using 2857 m^2 per person to generate 1.43 m^3/person of firewood. In order to lower their thermal energy consumption, and by linking this to the primary aim of building sustainable shelters, Sieben Linden has built more efficient homes, such as the "Libelle" house. In this efficient house, due to the installation of 66 m^2 thermal solar roof panels and a heat accumulation water-tank of 10,000 L, solar heating power of 1980 kWh/person per year is achieved. In the Libelle house, wood consumption is reduced by up to 0.6 m^3/person annually; taking into account that each person consumes 0.5 m^3 of wood in public spaces, the total consumption stands at 1.1 m^3/person, exactly the theoretically fair quantity based on national consumption. However, their new goal is to continue experimenting by using less industrialized products (such as solar panels) to avoid the consumption of the embodied energy contained in industrial products [61]. Table 3 shows the average annual thermal and electricity consumption of a person in Sieben Linden [59]. It can be observed that the energy consumed in homes is 60% less than the national average.

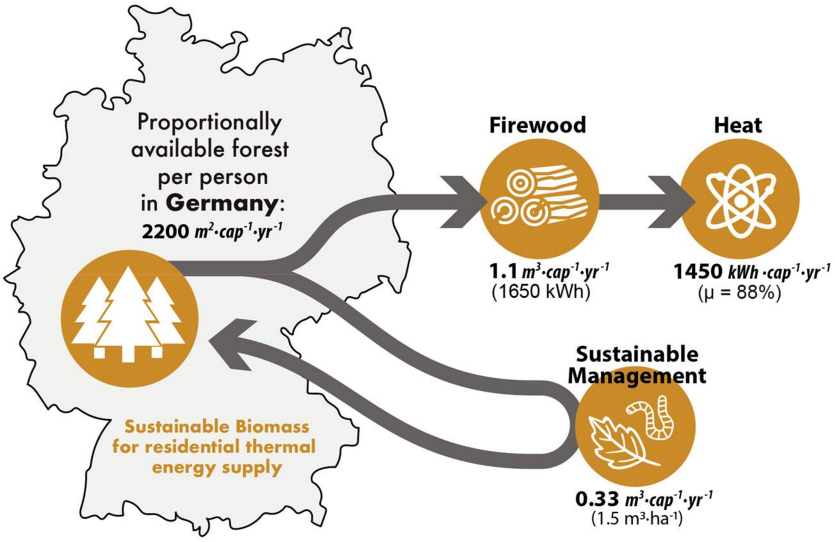


Figure 5. Sustainable managed forests firewood based energy extraction capacity in Germany according an equitable sharing, concept developed by Sieben Linden ecovillage.

Table 3. Residential energy consumption per person in 2013.

Residential Consumption Items	Sieben Linden Community ($kWh \cdot cap^{-1}$)	Germany (2013, IEA) ($kWh \cdot cap^{-1}$)
Heating	3500 (firewood + solar)	5650
Residential Hot Water	600 (firewood)	793
Cooking	400 (propane)	595
Electricity	350 (300 solar + 50 grid)	1586
Generation, transmission and distribution losses	130 (propane and grid)	3535
TOTAL	**4980**	**12,159**
Compared to the National consumption level	41%	100%

The third important pillar of energy sustainability has been the reduction of items or tools within the communal use of them. Owning less industrial products enables the community to reduce the embodied energy consumed in the equipment manufacturing process. In Sieben Linden there is an average of one washing machine for every ten people and one car for every twelve people (the average rate in Germany is one car for every 1.5 people [62]). There is a "free store" at the entrance to the community house where clothes and used objects are exchanged, giving them a longer life. It is also significant that they have not only drastically reduced the number of private vehicles, but their use (approximately 300 km/person annually).

Lastly, the fourth pillar is the food supply system. Sieben Linden currently produces 70% of all the fruit and vegetables it consumes with an aspiration to become 100% self-producers. The rest is purchased from an ecological wholesaler. In addition, all the meals served in the common dining room are vegetarian or vegan, significantly reducing the energy and greenhouse emissions needed to produce, process and transport food [63].

To conclude, in Table 4 the complete energy consumption has been summarized, forecasting the TPES of the ecovillage. Although there may be some inaccuracies in these first calculations (especially in the case of the industry and services and non-energy uses consumed in the community [59]), the data provides us with insight into this energy transition case. Indeed, Table 4 shows that Sieben Linden's primary energy consumption could be about 77% lower than the German national consumption. The aggregation of the data in Table 4 was elaborate following the criteria shown in Figure 3, but here transformation and distribution losses have been proportionally incorporated into each sector, whereas in Figure 3 they were identified as one separate item.

Table 4. TPES per person in 2013.

Area	Sieben Linden Community ($\text{kWh}\cdot\text{cap}^{-1}$)	Germany ($\text{kWh}\cdot\text{cap}^{-1}$)
Residential	4980	12,159
Transport (food and persons)	4800	11,059
Industry, Goods and Services	1000	18,307
Non energy uses	0	4434
TPES	**10,650**	**45,959**
Compared to the National consumption level	23%	100%

In summary, in Sieben Linden the human need for a different cultural approach to life [64] has helped move towards an energetically sustainable model. This cases shows that "the shift from fossil to renewable energy could potentially counter the growth orientation of economic activity" [65].

4.2. Feldheim

The village of Feldheim is characterized as being the only electrically self-sufficient village in Germany with 100% of its electricity supply coming from their own generated renewable systems. Feldheim supports 128 inhabitants with several business activities. The main activity is livestock farming, comprising two medium-size farms, one with 400 cattle and the other with 600 pigs, that mainly feed on local fodder and vegetables. For this reason, in the calculations contained in this paper, the thermal and electric energy required in the village has been considered as TPES, considering that the energy embodied in goods exported from the village and the goods imported into the village are similar.

In Feldheim, the community decided to create its own renewable energy generation system and to have the right to choose where to invest their savings, in which energy generation source and technology and not to delegate or deny any responsibility for this impact in the banking system. In our current society, most citizens are seldom given the right to choose the kind of energy generation technology in which to invest our own savings. People generally keep their savings in the bank, where the money is then used to invest in different sectors and different forms of power generation. Banks tend to invest in the power generation that provide the fastest return on investment and only communicate the sums of these returns to their customers. The investors have a reduced control over the energy system that they are funding and lack responsibility in terms of the generated socio-environmental impacts. These impacts are often not evident to the actors since they are hidden from them due to three factors: they occur physically far, far in time (becoming exponential in the future), and affect a different social class from which they were produced.

The decision to create an own renewable and low-impact energy system was started in 1995 by creating "Energiequelle" energy cooperative [66]. In this process, three highly complex concurrent factors were the base of the creation of the cooperative: the availability of the energy infrastructure, the knowledge of economic funding models, and in particular, the necessary approval and active participation of all partners [67]. During the creation process, the participants realized that this form of managing their savings was environmentally, socially and financially profitable as a direct result of the revenues.

Today there are 47 windmills with 71.1 MW of installed capacity, producing 175.1 GWh per year. A small 500 kW biogas plant was also built to provide electricity and to heat community houses and shelters for cattle rearing throughout a 3000 m long district-heating grid. In addition, a 2.25 MW solar photovoltaic generation plant was built. A 400 kW biomass plant was also constructed for emergencies, which is normally not functional but is ready in the event of a power outage. The advantage of biomass is that wood can easily be stored long term, to be used when other renewable sources are unavailable.

Lastly, Feldheim has become a reference for its new experimental technology program for lithium batteries. As a solution to the intermittent nature of power generation and the inability to store renewable energy, a 10 MW ion-lithium pilot plant was launched. This puts into practise the concept of Integrated Community Energy Systems (ICES), which is a "more bottom–up solution which can capture all the benefits of distributed energy resources and increase the global welfare [...]", as well as a "comprehensive and integrated approach for local energy systems where communities can take complete control of their energy system and capture all the benefits of different integration options [...]" [68].

In 2013, as shown in Table 5, electricity production in Feldheim stood at 135.9 GWh and consumption at 855.95 MWh [69], meaning that only 0.63% of its electricity production was self-consumed. The rest was sold to the grid and to the national energy market. In addition, they consume 2.57 GWh of locally-produced thermal energy. This means that the assumed TPES, if we combine the electric and thermal consumption, comes to 3425.95 MWh/year, or 26,765 kWh/year per capita. This basic calculation does not account for the energy embodied in all the products and services that the citizens of Feldheim consume outside of the village of Feldheim. However, it has accounted for the total energy requirements for the meat production system, which is mainly consumed outside of the community, in an aim to approximate a real TPES level. This means that these first calculations could be improved in further research by incorporating these parameters.

Table 5. Electrical and thermal energy production in Feldheim (data provided by the Neue Energien Forum Feldheim).

Energy Type	Installed Energy Power (MW)	Yearly Produced Energy (GWh·Year^{-1})
Wind	74.1	128.8 electric
Biogas	0.5	4.4 electric + 2.4 thermal
Biomass	0.3	0.17 thermal
Solar PV	2.25	2.7 electric
TOTAL	**77.15**	**135.9 electric + 2.57 thermal = 138.47**

Energiequelle has come to play a crucial role in the village and the project has become "a joint project by the residents, the local Farmers' Cooperative and Energiequelle" [69]. This partnership between citizens, private cooperatives, and public management, creates a local public-private partnership (ppp). This model is not only a successful form of energy management, but also encourages improved human relationships, as "Feldheim shows a high degree of cooperation among actors, including formal arrangements between the village as a political body and the renewable energy company Energiequelle." [66].

It is estimated that in 1995, before the electricity generation system of the village was changed, €500,000 was spent each year on the electricity and thermal energy supply [70] (accounting for not only residential demand, but the demands of the medium-size pig and cattle farms). Nevertheless, they are currently consuming the most cost-effective supply of thermal energy in Germany and in 2014, when the average price stood at 28 c€/kWh, in Feldheim they were paying only 17.4 c€/kWh [70]. Regarding electricity, the cost is even lower, at 9 c€/kWh.

From an economic perspective, the community has emphasized that electricity-grid investments were made with private funds whereas the district heating received a grant of 50% of its total cost: €1.73 million [69]. As for the subsidized payment rates for wind electricity production, the German government previously financed wind projects for up to 20 years at 8.93 c€/kWh [71]. However, in 2014 this figure was reduced to 8.9 c€/kWh for the first five years, and later on to 4.95 c€/kWh [72]. In these particular cases it can be seen how an incentive to use renewable electricity through grants, if done properly, contributes towards encouraging energy transition and helps society to move beyond the fossil fuel energy system. This experience confirms a Fraunhofer Solar Institute report which, providing a comparison of production costs of each technology in Germany [73], affirms that the cost of electricity from onshore wind plants can equal the costs of coal and combined cycle gas generation plants.

Nevertheless, this case study shows that large national energy companies do not always support these kinds of energy sovereignty initiatives. During this process, in order to facilitate the integration of the electricity generated, the cooperative requested that E.ON, a privately-owned energy supplier, integrate renewable resources directly into their network, but the refusal of E.ON encouraged Energiequelle to build its own network in Feldheim. Having seen that it was feasible, E.ON and three large German companies proceeded to block other attempts to create local networks, which is why other sustainable communities only use 40–60% from renewable sources [70].

4.3. Solar Settlement

Located in Vauban (Freiburg) and designed by architect Rolf Disch, Solar Settlement is one of the most highly acclaimed sustainable urban neighbourhood or housing complexes in the world [74]. Disch applied the PlusEnergy concept in this complex of 59 dwellings, shopping centre, offices, and parking area. It is the first housing community in the world to have a positive heat and electric energy balance [75,76]. Disch coined the concept PlusEnergy in 1994 to signify that the energy consumed in a building is lower than the energy produced [77]. The balance includes the electrical and thermal energy externally purchased and the excess of generated electricity sold to the grid. The consumers therefore get to play a new role in the energy system by becoming energy producers.

Planning for the Solar Settlement began in 1997 with the buildings constructed between 2000 and 2006, within the Vauban district, where sustainability was becoming an important leitmotiv. The Vauban neighbourhood, created in the 1990s, is called the "green neighbourhood" by the Freiburg city council [78]. Its origins go back to the Self-governed Independent Shelter Initiative (SUSI) [79]. The SUSI community, formed by young people seeking a new lifestyle system, set up an 'intentional community' [80,81]. They sought a sustainable lifestyle: consuming local organic products, reducing their energy consumption, using only public transport and bicycles, regenerating natural green spaces in the neighbourhood, generating their own heat and electricity, etc. This encouraged more people in the area to build sustainable buildings, especially passive houses [82]. Today, 5500 people live in 100 buildings in Vauban, emitting an annual average of 0.5 tonnes of CO_2 per capita, compared to the city average of 8.5 tonnes per capita [83].

This formed the context behind the development of the Solar Settlement apartment complex. Together with urban planners from the city of Freiburg, Disch planned the area as coherent real estate and aimed to sell it after construction to private homeowners. The total investment for residential buildings and the service building amounted to €51.6 million. However, before work started, the banks were only willing to grant mortgages for houses with buyers in place and for this reason, the "Freiburger Solarfonds" (Freiburg solar real-estate funds) were created. These private real estate funds collected money from investors for the housing units that could not be sold to private investors, to rent them out to tenants after construction [74].

Hence, there are two different types of ownership models for the Solar Settlement houses and solar photovoltaic installation on roofs. While half are private, the other half belongs to the "Freiburger Solarfonds" cooperative. In the second case, the houses are rented out to families, but the electricity produced on the roof is sold by the cooperative to the grid. Despite this, the balance between the electric energy generated and surplus electric thermal energy consumed, remains positive if average consumption levels are assumed. Solar Settlement apartments are 75–162 m^2 [84] and most are 3-story with a 60 m^2 garden each. The current average occupancy rate is 2.9 people per house [74] and they are occupied by upper middle class families with high incomes [85].

Disch also tackled energy use in the transport sector and the transportation model for the neighbourhood. The complex was designed as a vehicle-free area with pedestrian and cycle access, changing the design of the houses to hold a wooden shed for bicycles, instead of a garage. The community has been carefully integrated into the neighbourhood and into the city of Freiburg in terms of public transportation, with tram access included in the design.

Adjacent to the housing complex, a service centre called "The Sun Ship", the first commercial building with PlusEnergy certificate, was designed. The building is located on the main street and acts as a barrier to sound and pollution, contributing to the peace and tranquillity of the Solar Settlement. On the "Sun Ship"'s two underground floors are 138 parking spaces for residents, service area staff and customers. On the ground floor are two organic supermarkets whose function is to promote local products; a company specialising in the sale of natural pharmaceutical remedies; a social bank contributing to the local development projects based on ethical principles; and a Research Institute Ökoinstitut e.V. (EcoInstitute) which has been developing projects to reduce energy consumption since 1977. One of its most significant publications was "Laying down the pathways to Nearly Zero-Energy Buildings" [86] addressed to politicians. Historically, the institute has encouraged the development of sustainable culture, offering research facilities and technical support to social movements, for example to those fighting nuclear energy, of which the recent study on "The Risks of Nuclear Energy" is an example [87]. The other four stories hold offices, for organizations mostly working on engineering and sustainable architecture, such as the Rolf Disch architecture studio, and services such as healthcare. Finally, on the deck, nine of the dwellings of the project complex are located.

The power utility company used by the vast majority of the inhabitants is ElektrizitätsWerke Schönau (EWS). This company was set up in the town of Schönau by the local anti-nuclear movement, which emerged after the Chernobyl accident. EWS defines itself as "nuclear-free sustainable" energy, guaranteeing a 100% renewable source energy supply. The firm is managed as a cooperative where "Citizenship is the owner". EWS also promotes the reduction of residential electricity consumption and send consumers a scale to show whether their consumption figures are either "very suitable", "adequate", "high" or "excessive" in each electricity bill. The EWS recommendation is to consume between 375 kWh and 725 kWh of residential electricity per person, annually.

This research study has taken the electricity and thermal data for four families in order to verify that the PlusEnergy concept is being achieved. Table 6 shows the calculations for the average electricity and thermal consumption per person. The average figure for thermal energy requirements was 19.45 kWh/m^2, almost in line with the Passive House certificate level. The electricity consumption was 577 kWh/person, in compliance with EWS recommendations, which is significant. As a further step, Table 7 compares the total energy production per house with their average energy consumption. The average consumption per house is currently 13.7% lower than the corresponding electricity generated by the photovoltaic system located on the building roofs.

Finally it should be outlined that some authors have pointed to whether the goals of equality, justice and sustainable ideas should be linked with market-oriented growth [88]. Some authors consider that the Solar Settlement energy sovereignty project in Freiburg is directly linked to the neoliberal style of development and as such is directly opposed to the idea of "sustainable development": "the idea of 'sustainable development' in its current form is nothing more than an oxymoron" [88]. At the same time, this project has been criticized for being no more than an "urban legend and appears as rather detached from the local residents' practices and daily routines of living the Solarsiedlung" [74]. These theoretical criticisms do not completely counter the findings of this paper since in this case study, the main focus regarding energy reduction goals has been on heat and electricity reduction in households rather than on the importance of measuring TPES. In Solar Settlement the TPES has been estimated, in considering the reduction of residential heat and electricity consumption to be the only reduction gained in comparison with the national average TPES.

Table 6. Consumption table for Solar Settlement families.

	Family_1	Family_2	Family_3	Family_4	Average	Values
Adult	2	2	2	2	2	-
Infants	3	2	3	2	2.5	-
Household size (m^2)	160	160	130	130	145	-
Electricity (kWh·year^{-1})						
2011	3335	2389	2500	2088	2598	577 kWh·cap^{-1}
2012	3399	-	2431	2440		
2013	-	-	2202	-		
Heater + Hot Water (kWh·year^{-1})						
2012	-	-	2593	2329	2821	19.45 kWh·m^{-2} 626 kWh·cap^{-1}
2013	4002	3200	2393	2408		

Table 7. Accomplishment of the PlusEnergy concept in Solar Settlement: production and consumption table.

(A) Solar Settlement Photovoltaic production		
Installed solar generation capacity	333	kW
Average generation	314	MWh·year^{-1}
Average total generation by house	**6280**	kWh·year^{-1}·home^{-1}
(B) Solar Settlement Electric and Thermal consumption		
Average electric consumption per household	2598	kWh·year^{-1}·home^{-1}
Average thermal consumption per household	2821	kWh·year^{-1}·home^{-1}
Average total consumption per household	**5419**	kWh·year^{-1}·home^{-1}

5. Results

5.1. Quantitative Results

The quantitative results provide the necessary information to evaluate the specific achievements in the energy transition processes of the selected case studies. The analysis takes into account the energy consumption reduction accomplished and the self-produced renewable energy. Although the accuracy is expected to be improved in future analysis, it could be observed that in all case studies, significant results were achieved in comparison with trends in national consumption.

Summarizing the TPES, as shown in Figure 6a, the most important quantitative result has been achieved in Sieben Linden ecovillage, where, due to changes to their material lifestyle and as a consequence of their consumption system, residents were able to reduce TPES by 77% in comparison with the national average. This means that (assuming the correlation between energy and global use of resources) from the average national ecological footprint (EF) of 5.3 gha (Figure 2), in the ecovillage they have an EF of 1.2 gha. Therefore, taking into account that 1.7 gha is the maximum limit for using "the resources of one single world", we could roughly assume that the Sieben Linden ecovillage could be defined as being energetically sustainable. Similarly in Feldheim, the TPES is 42% lower than the national average, but in this case the energy consumed by the village from the outside in the form of goods and services needs to be calculated more accurately in future analysis. In order to forecast the TPES for Solar Settlement, due to the lack of data it has been assumed that reduction of residential heat and electricity consumption is the only reduction achieved against the national average TPES.

Although representing just 3.7% of the national TPES, the residential electricity consumption in Figure 6b, shows that in the Solar Settlement neighbourhood, they are able to reduce the average household electricity consumption by 66% and by 79% in Sieben Linden. However, building materials used in the Solar Settlement have apparently higher quantity of embodied energy than locally purchased low-tech materials used in Sieben Linden. Further Life Cycle Analysis comparative studies could be done to clarify the significance of these figures. In order to calculate the household electricity consumption in Feldheim, due to the lack of data, it has been assumed that the same percentage reduction in TPES will be reached in residential electricity consumption. It should be underlined that in any event, reductions in residential electricity consumption cannot be used as a benchmark to forecast a real energy transition.

According to the self-generation capacity of renewable energy shown in Figure 6c,d, it can be observed that while the German national average has the capacity to generate almost 5000 kWh of renewable energy, which represents 11% of the national TPES, the Feldheim case study shows that this amount could be significantly increased. With the right investment, they have reached a production level of 1 million of kWh per year and per person, over 4000% of the state average. This demonstrates that there are considerable opportunities for RES integration when new social and economic models are implemented. Nevertheless, further research is required to analyse whether this goal could be achievable without public subsidies in investments or the feed in tariffs. In Solar Settlement, 16% integration has been reached, somewhat higher than the national average. Lastly, in Sieben Linden, it is shown that although the renewable energy generated is 9% lower than the national average, due to the reduction of TPES needs, they have achieved a 41% integration of renewable energy, almost four times the national average. This shows how reducing TPES could directly benefit the creation of a renewable based sustainable energy system.

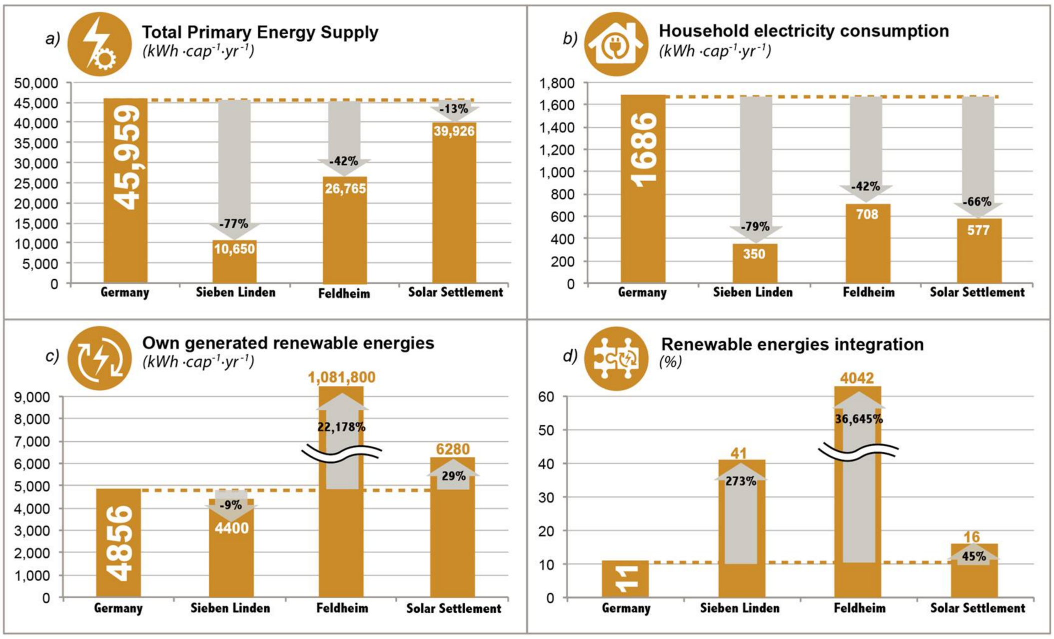


Figure 6. Goals achieved in the three case studies in comparison with the national average.

It should be emphasized that, as shown in Figure 3, RES integration not only reduces the social and environmental impact of the energy system, but also reduces the loss sustained during energy transformation and transportation processes (entropic energy loss owing to the use of a centralized fossil-fuel based system) which make up 29.1% of the TPES in Germany.

5.2. Qualitative Results

Table 8 outlines the most important learnings for the creation of a sustainable energy system, which have been identified in the three case studies. Firstly the “achievements” of each case have been pinpointed, to provide other bottom-up initiatives and communities with the key learnings to contribute to their own moves towards their own energy transition. Secondly, given that each case has also encountered difficulties during their transition process, the major challenges faced have been presented in order to raise awareness of these and to encourage reflection as to how to overcome them.

Table 8. Qualitative results extracted from the case studies.

	Achievements	Challenges
Sieben Linden	- The communal use of the space, and the construction of low energy consumption infrastructures (during their full life cycle, and not only when using them) could be a solid base to start a transition process. Participatory processes help during the creation of new living concepts. - Using local resources like local firewood not only increases the awareness of the availability of such resources, but also enables consumption to be measured within parameters of replicability. - A shift in consumption values based in voluntary and satisfactory austerity, and on a communal use of products and services, leads to a sharp decrease in total primary energy consumption. A change in the food supply system towards a local vegetarian diet could directly affect the energy consumption.	- There are difficulties when measuring the real dependency on national public services, such as transport infrastructures, health, education, security, political framework, etc. - It is not yet known how to scale up small low-energy consumption communities to regional and national level where personal human connections become weaker. - How to handle the needs for privately produced technological products (such as cars, computers, cell-phones, solar panels, etc.) or the private managed banking system has not yet been properly defined.
Feldheim	- Communal economic investment in renewable energy technology makes low carbon energy generation systems economically affordable. - The opportunity to decide in which generation technology (wind, nuclear, solar, coal, etc.) to invest their own savings makes individuals and communities directly responsible for the social and environmental impact of the energy model created. - The community has created new jobs in the energy sector and has also participated as an experimental research center.	- How to move towards a high electricity vector use model. In order to become energy self-sufficient the community is trying to shift other indirect forms of consumption, such as transportation, to the electric grid. - How to become an electric island. The community needs to invest funds in an experimental energy storage system. - How to achieve same RES integration goals without public subsidies during installation or feed in tariffs. - How to measure the real TPES consumption of the neighbourhood in a more accurate way.
Solar Settlement	- Energy consumers also become energy producers with the PlusEnergy concept which breaks down the current "wall" between producers and consumers. - The fast development of private sustainable initiatives can be greatly accelerated in sustainability-sensitive environments such as sustainable neighbourhoods, as happens with Solar Settlement in Vauban.	- How to reduce the overuse of technological solutions containing high quantities of concealed embodied energy. The PlusEnergy concept does not account for the energy consumed by these infrastructures and houses during the full product life cycle. - How to measure the real TPES consumption of the neighbourhood in a more accurate way.

6. Conclusions and Policy Implications

As stated, the main goal of the paper is to detect the specific achievements of the selected German bottom-up initiatives in their energy transition process, especially analysing the reduction of total primary energy consumption (1); reduction of residential electricity and heat consumption (2); and the increase of renewable generated energy and even attaining self-sufficiency (3).

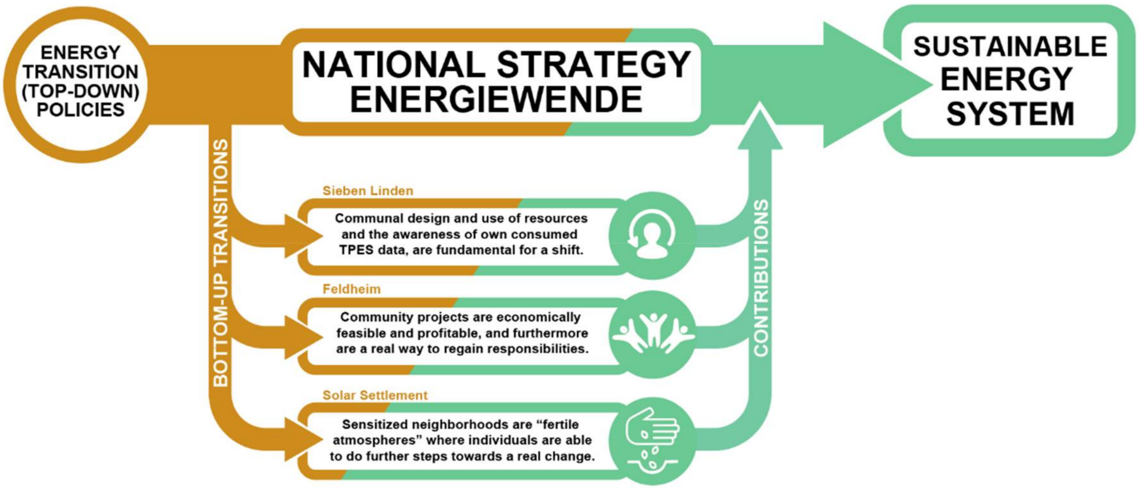
The case studies show that the national goals are achieved better than in the average German city/town structure. Therefore, within the current German structure, bottom-up initiatives are able to significantly boost a change in the energy system. These bottom-up case studies show that within the energy transition, technological improvements are losing their status as the only important factor. In contrast, social factors and their direct effect on both reducing energy consumption and enhancing high integration of renewable energy, are being seen as increasingly important aspects.

The existence of bottom-up communities is especially relevant as this gathers a sufficient amount of people (a critical mass) to put energy transition ideas into practise. Definitively, moving towards a sustainable energy system means increased discussion of communal or public energy uses, their impact, approaches to energy management and the decision-making processes involved. Thus, a creation of a new energy system seems to be closely linked to the democratization of the current energy system.

Likewise, the awareness and the aims of bottom-up intentional communities to achieve social and environmental energy justice is a catalyst for participatory processes to generate actions aimed at changing the current energy system. These participatory processes play a critical role in constructing new infrastructures and buildings for energy-efficient models, as shown especially in the Sieben Linden case study, with reductions of up to 77% in TPES. In these initiatives it has been detected that the social engagement of architects, designers and engineers to maintain an active dialogue with the user, in order to adapt their designs more effectively to the real energy needs of people and communities, brings a new model of communal living with direct effects on energy consumption. In a similar way, the Solar Settlement case study shows that social and environmentally aware communities, such as the Vauban neighbourhood, where there is already a trend towards a more sustainable approach to life, are fertile atmospheres where individuals, such as architects, could take further steps in sustainable proposals, for instance the PlusEnergy concept.

Lastly, these three case studies show that the new energy system can be economically viable when personal savings are invested in community projects, shown especially in Feldheim, when renewable energy generation systems are installed for its own consumption and selling purposes, since (for electricity) these have shown production figures of 4000% higher than those for consumption. Furthermore, deciding collectively where to invest personal savings is a way of reclaiming the responsibility for our personal role in "energy justice".

Figure 7 graphically synthesizes the conclusions drawn in this paper, which are direct assumptions from the qualitative and quantitative results. This research demonstrates that the bottom-up analysed initiatives can contribute relevant achievements in enhancing the absolutely necessary energy transition, contributing to the national strategy to accelerate gaining the stated goals.



Communal design and use of resources and the awareness of own consumed TPES data, are fundamental for a shift.

Community projects are economically feasible and profitable, and furthermore are a real way to regain responsibilities.

Sensitized neighborhoods are "fertile atmospheres" where individuals are able to do further steps towards a real change.

Figure 7. Summarize of contributions from the analysed bottom-up transitions to national transition strategy.

Due to the close relationship between top-down and bottom-up initiatives in Germany, such as the feed-in tariffs, it is difficult to isolate the specific effects of bottom-up initiatives from the national top-down ones. Thus, the achievements found in this study need to be carefully understood in a national context. Further studies should be done in order to define how the proposals of bottom-up initiatives could successfully be replicated in the reality of other countries in order to boost a global low socio-environmental impact energy transition.

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