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Published in:
Sustainable Cities and Society

Link to article, DOI:
10.1016/j.scs.2016.04.014

Publication date:
2016

Document Version
Peer reviewed version

Energy concepts for self-supplying communities based on local and renewable energy sources: A case study from northern Germany

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Keywords:
Energy concept
Community energy planning
Energy-self-sufficient community
Renewable energies

Abstract:
The reduction of GHG emissions in buildings is a focus area of national energy policies, because buildings are responsible for a major share of energy consumption. Policies to increase the share of renewable energies and energy efficiency measures are implemented at local scale. Municipalities, as responsible entities for physical planning, can hold a key role in transforming energy systems towards carbon-neutrality, based on renewable energies. The implementation should be approached at community scale, which has advantages compared to only focusing on buildings or cities. But community energy planning can be a complex and time-consuming process. Many municipalities hesitate to initiate such a process, because of missing guidelines and uncertainty about possible energy potentials. Case studies help to understand applied methodologies and could show available energy potentials in different local settings. The current case study presents a community energy concept for the inner-city of Elmshorn. By estimating the energy demand, consideration of local energy saving potentials, and available energy potentials within the community, it was possible to develop several energy system variants that virtually allow a heating energy and electricity supply fully based on local, renewable energy resources. The most feasible and cost-efficient variant is the use of local food production waste in a CHP plant feeding a district heating grid. The overall aim is to show that a self-sufficient heat- and electricity supply of typical urban communities is possible and can be implemented in a cost-efficient way, if the energy planning is done systematically and in coherence with urban planning.

1. Introduction

One of the biggest challenges in the coming decades for society will be to transform cities into sustainable and resource-efficient spatial structures. Climate protection, rising energy prices and the dependence on fossil fuel imports demand a shift towards renewable and decentralized energy systems. Up to 40% of primary energy consumption in OECD countries happens in buildings (Pérez-Lombard; Ortiz; Pout, 2008) and up to 80% of this takes place in urban agglomerations (Kamal-Chaoui et al., 2009). Thus, energy - its efficient use and its GHG neutral provision - will be a central task for urban planning in the coming decades (Erhorn-Kluttig, 2011). The available building construction and communication technologies enable the development of smart and zero energy buildings. To approach this task at community scale has many advantages compared to a solitary consideration of individual buildings or at a broader city scale (Sharifi; Murayama, 2014).

The term "community", in an urban context, is understood as a specific geographic area, composed by similar physical characteristics and a set of social networks. A community has no fixed size and can range from a batch of physically similar buildings up to almost a district size area containing multiple uses, but connected by a shared identity. Overarching municipal energy strategies for city scale tend to be too general to have a direct influence on implementation and can only frame actions on a local level. In contrast, communities are distinguished by a higher grade of homogeneity that allows the development of customized energy strategies to happen. It is at the community scale that many technical synergies can be realized, promising that scale effects are reached, and decision makers are mobilized to act in their common interest (Petersen, 2013).

Community energy planning is the design process of finding techno-economically feasible variants to satisfy a community's future energy service needs. In the current study the community's energy demand is excluding transport, thus it is only referring to the operational building energy consumption aggregated to community scale. Usually, to begin, energy data to assess the current situation is collected, followed by targets for the future community energy system. In the end, energy technology variants are developed to achieve the targets (Huang et al., 2015). Besides cost-efficiency, multiple sustainability objectives were added in recent years as decision criteria, leading to a high degree of renewable energy being suggested (Neves; Leal; Lourenço, 2015). The planning entities are often energy utilities, but municipalities could also play a central role: land-use planning, carried out at community scale, can have a significant impact on building energy consumption if synchronized with energy planning. The operational level of municipalities is communities; hence they could be the driver of community energy planning and key actors in the transition of cities towards sustainability.

Still, there are few examples apart from subsidized demo projects of energy-self-sufficient communities. Demo projects are often difficult to adapt to other communities because of differing financial or organizational conditions (Quitzau et al, 2012). Thus, the question is whether or not energy-self-sufficient communities are also applicable in an ordinary context without having an extraordinary financial support and under the use of conventional tools and technologies? Case studies can help to answer the question and elucidate the general planning strategies to achieve this, given that energy-self-sufficiency depends on linking energy demand and locally available energy sources, balancing and setting these in relation to a cost-effectiveness – thus, on drawing the right conclusions from local circumstances.

This is what the current study set out to do. The aim was to find out if in a more or less typical medium sized inner-city town, existing renewable energy potentials within the community can meet the communities' energy demand and whether it is possible to use these potentials in a cost-efficient way. The considered community is a mixed use area currently with a broad spectrum of building typologies, characterized by soon to be renovated buildings and new buildings; a setting that can be found all over Europe and is able to demonstrate barriers and opportunities for the energetic urban redevelopment. Heat demand was estimated based on building typology, age, gross-floor-area, geometry and renovation standard. The local energy potential was estimated in consideration of the local climate, the geologic and hydraulic setting, open space, building typologies, urban design and available waste heat sources. This data was combined with technical and economical characteristics taken from literature and supplemented with qualitative information, such as stakeholders, property information and other attributes related to the local setting.

2. Current state of community energy planning

Building energy performance is influenced by four main factors: urban context, building construction and shape, building energy system, and occupants (Ratti et al., 2005). While energy planning was mainly focusing on the middle two, practice has recently changed from building assessment and modelling to a wider scale that looks at communities and the interaction between all four factors (Petersen, 2013), (Sharifi; Murayama, 2014). After (Bourdic; Salat, 2012), energy-environment models and morphologic models are most commonly used for energy planning on community scale. While morphologic models use intermediate scales of aggregation, which allow insights on the wider urban scale, they are too unprecise and don't take the user into account, whereas energy-environment models have advantages in their usability. They describe the interaction between energy production, consumption and environmental impacts (normally via GHG emissions). The methodology is simple; the application doesn't cost much and is reproducible, but also based on aggregations. Thus, it is limited for stating evidence for single buildings – contrarily, a sufficient data set is not a prerequisite. Because of the simplicity of the methodology, morphologic models would allow municipalities to actively participate in community energy planning.

Municipal administrations are together with local politics and energy utilities important drivers of community energy planning. Energy used to be solely a matter for utilities. With the gas and electricity market in the EU being liberalized and open for different utilities, community energy planning is mainly focused on thermal energy. Energy utilities hold the concession for e.g. district heating or natural gas grids for communities, if granted by the municipality. This requires utilities to be responsible for grid maintenance, grid expansion, energy pricing, but also coverage obligation. With legal tools granted to the municipalities, e.g. from §16 German Renewable Energy Heat Act (BMWi, 2015) or land-use planning, municipalities can indirectly influence heating or cooling energy infrastructure. Hence, while utilities have to ensure the energy supply for the community, the municipality can set the framework and facilitate the community energy concept. The emerging shift towards decentral and renewable energies demands a stronger integration of energy production with energy consumption, hence, with buildings. Municipalities work on a community scale and have the skills to encourage other stakeholder groups such as housing companies, residents or local tradesmen to implement a community energy plan (Erhorn-Kluttig, 2011).

Community energy planning, driven by municipalities, can be divided into several phases (Mirakyan; Guio, 2013). While there is a lot of tools and methodologies available for the more technical and detailed later phases that usually get carried out by the energy utilities or external consultants, there are just a few tools available for the phase of preparation and orientation for decision making (Keirstead; Jennings; Sivakumar, 2012). The same applies to literature: only a few publications sum up available information on community energy planning sufficiently. If municipalities want to compile a community energy concept, they either have to hire external consultants or collect information from various sources, which can be very time-consuming.

In this context, there are three main publications in Germany focusing on community energy planning with the target of developing tools for municipalities to proactively plan communities in relation to energy and, in the long run, merge urban planning and energy planning into a holistic planning approach. Several case studies and practical examples from the En:EffStadt program were published in (Erhorn-Kluttig, 2011) and give a general overview about methods of community energy planning. With material from the IEA EBC Annex 51 the published guidebook on energy planning is going further into detail (Jank et al., 2013). The UrbanReNet project has a rather technical approach to developing energy demand and energy potential archetypes for communities (Hegger et al., 2012). In addition to a few examples of application of the archetypes, in a second step, the development of an automatic planning tool was announced.

These three publications are based on the approach of morphologic energy modeling, thus, they can only serve as orientation for municipalities and can't replace detailed calculations and case-by-case review of the energy concept with actual building data. Still, the current study follows a similar approach, merging economic, technological and urban design figures from literature to estimate energy demand and energy potential in the community.

3. Investigated area

Elmshorn has 50.000 inhabitants and is situated in the north of Germany, located only 30 km northwest of Hamburg. The climate is characterized by cool summers (daily maximum average temperature of 16.9 °C) and mild winters (average 0.1 – 0.5 °C) (climate-data.org, 2015). For this study, an 18.5 ha redevelopment area in the inner-city of Elmshorn was considered. The community called "Krückau-Vormstegen" is distinguished by a mix of abandoned industrial buildings, brownfields used for parking, and occasional residential buildings. Due to the vicinity to the city center, the municipality decided to redevelop Krückau-Vormstegen into a mixed use community as an extension of the inner-city. The 2011 enacted development plan for the community was modified several times in reaction to the changing real-estate market. While some of the old industrial buildings with heritage value and the existing residential buildings (with approximately 210 apartments) should be kept, an additional 550 new apartments are expected to be constructed by 2030. Furthermore, around 60.000 m² commercial and public buildings should also be getting developed. The community consists of 35 old and 53 new buildings. The 88 buildings have 190.000 m² gross floor area in total, whereof one third is currently existing and two thirds will be new developments. The typology is ranging from semi-detached houses to four-story houses and up to big warehouses.

Neighboring in the southwest, partly divided by streets, are several multi-story apartment buildings and two industrial sites. Further surroundings are small to medium sized commercial establishments and the train station of Elmshorn. The inner-city of Elmshorn is typical of medium sized cities in northwestern Germany: commercial and residential use in a mixed typology with just a few sources for waste heat.

The community is currently solely connected to the German power grid and to the local natural gas network. Hence, the heating demand is currently covered by individual natural gas and oil boilers. Both grids are owned by the municipal utilities, enabling the municipality to indirectly influence priority setting in grid expansions. Until the time of this study, there existed no plans for a heating supply of the community despite the imminent start of construction works.

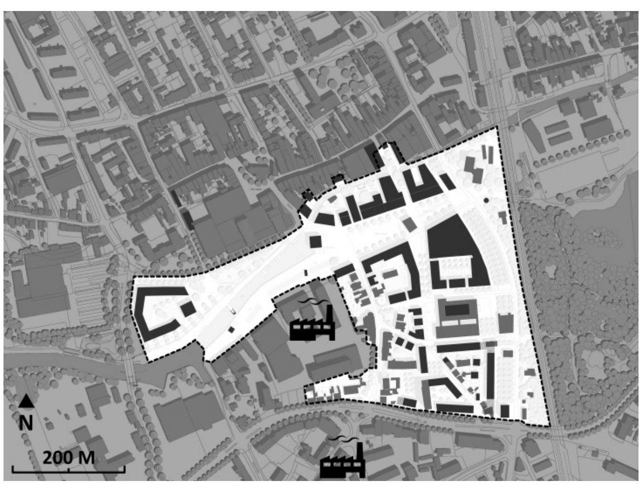

Figure 1: Investigated area (light coloured) in Elmshorn with building stock (grey), new buildings (black) and waste heat sources (icon).

4. Methods and results

4.1. Energy demand

Available data on the energy demand of the community is limited. Despite being the default provider, the municipal utilities couldn't provide measured data on gas or electricity consumption for Krückau-Vormstegen. Because of German data protection regulations, the energy data at apartment or building level is not accessible, making the acquirement of energy demand data a time-consuming and complex process. This generic barrier for community energy planning can't be solved by the current study; however below there is an approach on how to estimate the energy demand described, to help to overcome this barrier.

4.1.1 Current energy demand

The 35 existing buildings were analyzed regarding typology, age, gross-floor-area, geometry and renovation standard. Via site visits, the missing data was estimated and the buildings were clustered according to age, renovation standard and typology: The buildings were classified in 4 typologies (residential, commercial, retail, public buildings) and associated to 5 building age classes. This allowed the estimation of generic energy profiles for each building. The generic energy profiles were enhanced with data on the renovation standard, which resulted for each building to a raised or lowered individual energy demand. The energy profiles were derived from characteristic energy values taken from literature (e.g. Loga; Diefenbach; Knissel; Born, 2011) and applied to the building clusters. These estimations were verified with four buildings, in which apartments or commercial units were offered during the period of the study. The obligation of the landlord to have energy passes in case of sale or rental made it possible to get information about the energy standard of these 4 buildings. The comparison of the estimated values for the building typologies with values from the energy passes showed only a minor deviance (see fig. 2). Thus, the estimated building energy demands can be seen as adequate. A prebound effect was considered approximately with a 15% decrease in relation to calculated energy demand. Similar to the rebound effect, but conversely, the prebound effect describes the performance gap between estimated energy demand and actual energy demand (Sunnika-Blank; Galvin, 2012), used here as security surcharge.

Building ID #1
a) 1900
b) 200 kWh/m²a
c) 202,3 kWh/m²a
d) 73.5 kWh/m²a

Building ID # 15
a) 1980
b) 170 kWh/m²a
c) 167 kWh/m²a
d) 89 kWh/m²a

Building ID #9
a) 1910
b) 275 kWh/m²a
c) 306.6 kWh/m²a
d) 110 kWh/m²a

Building ID #32
a) 1960
b) 190 kWh/m²a
c) 200 kWh/m²a
d) 63 kWh/m²a

Figure 2: 4 Sample buildings from the building stock in the community with information about: a) Year of construction, b) Estimated heating demand after building cluster, c) Heating demand after energy pass d) Estimated heating demand after renovation.

71% of the buildings didn't show any signs of being renovated within the last decade, which resulted in a high heating energy demand of 183 kWh/m^{2}a on average. In case of full utilization, a total end-use heating energy demand of 5.93 GWh/a for the existing building stock was estimated (Variant EB). The total electricity (EL) demand was calculated for 1.1 GWh/a (VDI 3807).

4.1.2 Expected future energy demand

Due to the newly constructed buildings and the poor condition of the building stock, the future heating energy demand will change distinctly. Taking this into account, energy renovation assumptions for all 35 old buildings were made. Based on the building conditions, estimations about energy saving potential were made. Approximate values for energy saving measures of main construction parts were derived from (Moschig, 2008) to find the techno-economic reasonable energy saving potential for each building. The energy saving potential ranges between 20% and 70% energy demand reduction. The average energy saving potential is estimated to be at 54% for the whole building stock. The actual technically achievable energy saving potential is higher, but under socio-economic aspects unreasonable and further unrealistic to be implemented, because of the dispersed ownership structure. For instance, the individual consideration of each building allowed finding adequate renovation strategies for buildings with heritage value and the retention of facades worthy of preservation. Including a security surcharge of 5% for the rebound effect (Haas; Biermayr, 2000) the energy renovation potential of 54% results to a total heating energy demand of the energy renovated buildings of 3.26 GWh/a (Variant EB-R), respectively 99 kWh/m^{2}a.

The heating energy demand for the new buildings can be estimated in two ways: first, in assuming that all new buildings will be built in passive house standard, thus with a heating energy demand of 15 kWh/m^{2}a. The EU directive 2010/31/EU requires an adjustment of the national building regulation to low-energy standard until 2021, which corresponds to passive house standard. To enforce this standard, the municipality of Elmshorn would have to own all plots and demand this energy standard in the sale contract as minimum standard to be realized by the developer in order to get a building permission.

Second, the heating energy demand for the new buildings can be calculated in accordance with the expected tightening of the building regulation in correlation to the year of construction. By dividing the area in different construction phases, it is possible to determine the legally demanded maximum heating energy demand per phase. Summed up, they show the total heating energy demand of the new buildings and at the same time allow being able to roughly predict the development of the heating energy demand in relation to the development of the community.

This results in two heating energy demand variants for the 53 new buildings: if all new buildings are designed as passive house, the heating energy demand is estimated to be 1.02 GWh/a (Variant NB-PH). In the case that the buildings get realized according to the minimum building regulation energy standard and temporal according to the master plan, the estimated heating energy demand is 2.49 GWh/a (Variant NB-BRmin). The estimated total electricity demand for both variants is 2.88 GWh/a. Together with the renovated building stock, the communities' overall heating energy demand ranges between 5.75 GWh/a and 4.28 GWh/a. The overall electricity demand is estimated with 3.98 GWh/a.

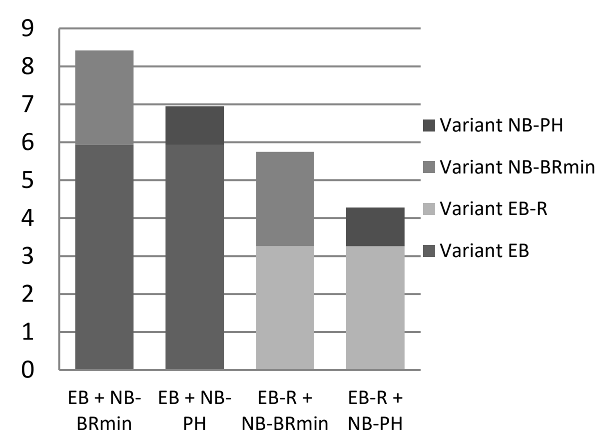

Figure 3: Four demand variants for end-user heating energy demand (in GWh/a). EB stands for the end-user heating energy demand of the non-renovated building stock, EB-R for the renovated building stock, NB-BRmin for the new buildings built after minimal standard of the building regulation code, and NB-PH for the new buildings built in passive house standard.

4.2 Energy supply

There is no data available on the local energy potential from renewable energies at the municipality and municipal works in Elmshorn

The lack of reliable general key figures for local renewable energy potentials in relation to urban design made an individual consideration of all energy technologies for the local setting necessary. This was done by assessing the suitability of each technology in a process of elimination. If the local setting (climate, geology, hydrology, urban design and typology) doesn't allow a technology, it wasn't further considered. If a technology is suitable, its current technical efficiency was set in relation to available production capacity, or available area, to calculate the maximum technological energy potential for the whole community. The energy potentials are listed in table 1 and were calculated as follows:

Table 1
Suitability and technical potential of renewable* energy technologies within the community

Energy source	End energy	Suitability	Energy Potential [GWh/a]
Industrial waste heat	Heat	Partly	1.73 – 3.46
Waste combustion	Heat/ EL	None	-
Drain water heat recovery	Heat	Little	-
CHP (oat peel "biomass")	Heat/ EL	Good	33.18 7.96 - 12.61
Geothermics , near-surface	Heat	Good	1 – 3.1
Geothermics, deep	Heat/EL	None	-
Photovoltaics	EL	Good	1.6
Solar thermal energy	Heat	Good	4.9
Hydropower	EL	None	-
Wind power	EL	Little	-

*Industrial waste heat is not a renewable energy source, if the primary energy source is not biomass. But according to §7 German Renewable Energy Heat Act the use of industrial waste heat can compensate the mandatory demand to use renewable energies for heating of new buildings. The study was performed from the perception of the utilities and the municipality to supply the new buildings with a cost-efficient and low-emission heating. Hence, industrial waste heat and waste combustion were also considered in a first analysis of available energy potential.

In interviews with the two neighboring industrial sites, data on process energy was collected. The cereal producer uses process heat with an average temperature of 55°C. Depending on the shifting production, the capacity of thermal energy ranges between 2-8 MW during weekdays, while the production is stopped during weekends. Due to own use, the available amount of industrial waste heat is subject to seasonal variation. If approximately 5-10% of the process heat are recoverable (McKenna; Normann, 2010), the waste heat potential is considered 1.73 – 3.46 GWh/a.

Additionally, the cereal producer has a yearly amount of 12.000 tons of oat peel from food production at its disposal that is currently sold for 50€/t to different cattle farms. The energy value is at 4.3 MWh/t and the firm is looking for local purchasers. Depending on the energy conversion efficiency, up to 33.18 GWh/a heating energy and up to 12.61 GWh/a EL are available from this source.

The geologic conditions in Elmshorn allow only ground heat exchangers and attached heat pumps. Potential geothermal energy use was mapped for the community in relation to technical parameters from the VDI 4640, the geological setting, and legal guidelines. Depending on the engaged technology, up to 3.1 GWh/a of heating energy are accessible.

Table 2
Comparison of total end-user energy demand and total accessible energy resources within the community

Type of end user energy	Energy Demand [GWh/a]	Energy Potential [GWh/a]
Heating energy	4.28 - 8.42*	Up to 44.64
Electricity	3.98	Up to 14.21

* The projected heating energy demand is declared as a span, because it is depending on renovation of old buildings and building standard of the new developments. The energy potential represents the maximal accessible amount of heating energy or electricity via the use of renewable energy technologies within the community – regardless of actual energy concepts.

Caused by the high density of the community, the use of solar power is only possible if integrated in the buildings; a solar atlas was developed for this purpose. All rooftops in the community were assessed on orientation, opacity and roof pitch, and rated in the sense of suitability for solar use. For the old buildings, this was done via inspection of aerial photography and manual sharding, for the new buildings, the data from the master plan was sufficient. Of the 56.773 m2 rooftop area, 63% were considered as useable for solar or PV use. As a result of urban design and distance requirements, only 75% of the useable rooftop areas were included, resulting in a total useable area of 27.062 m^2. The flat roofs require modules mounted on pillars, which leads to the 2.5 times lower collector surface of 12.888 m^2. Combined with technical specifications (Wirth, 2013), (VDI 6002) and the global radiation from the European Commission Joint Research Center (PVGIS 4), solar heating energy of 4.9 GWh/a or EL production of 1.6 GWh/a is potentially available within the community.

4.3 Feasibility and most cost-efficient supply variant

After the finding that the energy demand of the community can be fully covered by renewable energies (see table 2), a technical proof of concept and a cost-efficiency analysis for the energy supply variants were performed. The aim is to find feasible and cost-efficient energy supply variants. In total, 7 variants of energy supply were designed and compared, while for the demand side, a renovation according to demand variant EB-R got assumed which results in only two demand variants and a total heating energy demand of 4.22 to 5.69 GWh/a.

To avoid unnecessary and time-consuming cost-effectiveness calculations the feasibility analysis was performed first, thus best options become visible and after that the cost-effectiveness can be rated (Neves; Leal; Lourenço, 2015). The analysis is done after a simple exclusion principle: Some supply variants were precluded from the start, because basic parameters were not fulfilled. Instancing, the use of excess heat from the local industrial sites has been eliminated early because of own use in wintertime, production standstill on weekends and varying heat energy amounts. For the remaining supply variants (see table 3), the cost-effectiveness was rated based on the end user heating price as main indicator. The end user heating price is based on cost of investment (energy production facilities and district heating grid, if available), capital costs, fuel, staff, maintenance, and other costs or revenues, like the sale of possibly produced electricity. The environmental aspects were assessed via the total GHG emissions (CO2, CH4 and N2O) arising from heating energy and electricity supply for the community. The missing share of electricity that couldn't be covered by local sources was calculated as purchased in the integrated national network, which was for 2013, according to the GEMIS database, at 580 gCO2/kWh (IINAS, 2013).

Table 3
Overview of energy supply variants

Energy supply variant	Coverage Electricity [in %]	End User Heating Price [in €/kWh]	GHG emissions [in tons CO2-equivalents/a]
- Natural gas (decentral)	0	0.097	3912 t/a
- CHP *[oat peel]* (central)	22 – 31*	0.102	2213 - 2012 t/a
- Boiler *[oat peel]* (central)	0	0.100	2582 t/a
- CHP + solar (central)	16 – 22*	0.134	2336 - t/a
- Heat pumps + PV (central)	17	0.141	2076 t/a
- Heat pumps + solar (central)	0	0.163	2561 t/a
- CHP *[50% oat peel & 50 % wood chips]* (central)	20 – 30*	0.118	2292 - 2171 t/a

* Depending on the brand and the specific energy efficiency of the actually used engine.

Table 4
Key figures energy supply variant "Oat peel CHP with district heating"*

	Heating energy	Electricity
Installed capacity	CHP-1: 300 kW	CHP-1: 75 kW
	CHP-2: 200 kW	CHP-2: 50 kW
	Boiler: 3027 kW	Boiler: -
Coverage of energy demand	100%	22%-31%
End-user energy price	0.102 €/kWh	0.185-0.220 €/kWh
Investment cost	3.1 million €	
District heating temperature	High temperature (90/50°C)	
Length district heating grid	4050m	
Storage tank	20m^3	

*All values shown in this table are just valid for the energy demand variant EB-R + NB-BRmin (full renovation of old buildings and new buildings in minimum standard from German building regulation), which was considered as most feasible for implementation by the author.

The use of solar thermal energy would require big and expensive seasonal heat storage facilities. Heat pumps based on geothermal energy wouldn't be sufficient to entirely supply the community with heating; hence additional solar collectors or PV has to be installed, which demand again expensive storage facilities, leading to heightened heating prices. The possibility of using the oat peels is fortunate in terms of flexibility and cost-efficiency. The use of a medium sized CHP plant with stirling-engines allows feeding a 4.050 meter long district heating grid depending on the current heating demand, making short-term or seasonal heat storage redundant and at the same time co-generating electricity. After the German Renewable Energy Act, the locally available "production waste" oat peel can be declared as biomass. Due to the availability of the oat peel in the community and its favorable price, the heating energy supply variant "CHP [oat peel]" connected to district heating is the lowest priced and most energy efficient variant (see table 3). All calculations are dynamic investment appraisal calculations under consideration of all available subsidies, as regularly performed by energy utilities. With an end-user heating energy price of 0.102 €/kWh the variant is at the same level with the current status for the old buildings, the reference variant (individual condensing gas boilers), which is calculated with an end-user heating energy price of 0.097 €/kWh.

The use of oat peel as fuel requires stirling-engines in the CHP-units. During the period of the study in late 2013, the products available on the market had a thermal energy conversion efficiency of approximately 75% and an electrical efficiency of 18-25%. The CHP-unit is estimated to be heat-operated for energy efficiency reasons, which results in a one-hundred percent heat supply of the community from local, renewable energy sources. At the same time, the energy conversion efficiency allows only an electricity generation of 22%-31 % in relation to the end user electricity demand (variant EB-R + NB-BRmin). Under consideration of all photovoltaic potentials in the community, the 1.6 GWh/a could provide an additional 40%. Thus, the total electricity demand could just be covered with 62–71%.

5. Discussion

The estimations showed that it is possible to match the energy demand with local renewable energy sources in the community of Krückau-Vormstegen. This enables building up alternative energy supply solutions. Despite Elmshorn being a typical medium-sized town for northwestern Europe, it is unlikely that the present most cost-efficient variant for energy supply via locally available biomass in the form of "production waste" can be found in the majority of similar local settings. Still, it shows the need for a detailed qualitative analysis of local renewable energy potentials apart from generic and purely quantitative assumptions.

However, if the oat peel wouldn't be available, it would still be possible to cover the heating energy demand fully by local renewable energies with a mix of solar thermal and geothermal energy – presuming that the building stock is energy renovated. This shows the importance of developing integrated community energy strategies considering both the energy demand and energy supply side. As a restriction, such supply variant would require a seasonal heat storage, which is technically possible, but in urban settings is difficult because of limited space availability and hence, cost-effectiveness.

Cost-effectiveness and technical barriers are the reason why the theoretical energy potential for electricity of 7.96 - 12.61 GWh/a from the oat peel cannot fully be used, which makes a one-hundred percent electricity supply with local renewable energies currently impossible.

The municipalities' will to renew the community with supplementation of new buildings can be a window of opportunity to get in contact with the local building owners and initiate energy improvements of the old buildings. The old buildings are, despite blocking a low-temperature district heating grid to solely supply the new buildings, the main reason why the proposed district heating grid can be operated cost-effectively and low end-user prices can be offered. Like fig. 3 shows, the heat demand arises mainly from the building stock. With the integration of old and new buildings into one network, the high initial costs, the operational and maintenance costs can be spread through many entities, which makes the new energy infrastructure price-competitive. In this way, the community energy concept combines strengths and opportunities from different buildings and technologies.

6. Conclusion

For the investigated community, the local heating energy potential based on renewable energies is up to 44.64 GWh/a. This surpasses the local heating demand ranging between 4.22 and 8.42 GWh/a by far. The same applies for the local electricity potential with up to 14.21 GWh/a facing 3.98 GWh/a electricity demand. Thus, it can be concluded that it is possible to cover the building heating and electricity demand of the community of Krückau-Vormstegen entirely by using local and renewable energy resources. Despite issues with the availability of data and restrictions for the electricity supply, the stated supply variant showed that cost-effective solutions could be implemented in practice. Because of the simplicity, it can be assumed that the stated methodology of matching energy demand and energy supply also could be used in different local settings.

The integration of initial and operational costs should be prioritized higher and the cost-analysis should be extended to all stakeholders. Only end-user energy prices and investment costs, including maintenance for the utility, are analyzed in the cost analysis in chapter 4.3. The heating energy demand variant EB-R for the buildings stock is however estimated as renovated, without including the costs on the demand side – costs for the building owners. In future community energy concepts, these should be included to enable a holistic calculation of costs for all members of a community, which allows an improved balance between measures on the demand and supply side.

Besides the potential energy sources listed in table 2, there exist other useable energy sources and technologies to supply the community such as woodchips or other forms of biomass arising from the management of green areas. In particular, woodchips became a convenient alternative to fossil fuels in the recent years. Due to absence of green areas in the community and proximity, these energy sources are not listed as independent variant in the study because the aim was to ascertain if a rather typical urban community can be supplied by endogenous renewable energy sources. To transform cities into sustainable spatial structures, it is necessary to use these potentials wherever possible. First, the study demonstrates the methodology to find out about feasible energy technology supply variants. Second, in this particular case, it was possible to verify the possibility to supply an inner-city community with energy from endogenous sources.

Still, the indicated process is time-consuming and appears to be too difficult and would demand too many resources of municipalities. A proactive estimation of energy demands, energy potentials and the fitting technologies for the local setting are necessary as basis for discussions between the driving stakeholders in community energy planning. Thus, municipalities first need a wider database on energy demands and potentials (e.g. heat atlas, solar atlas, waste heat mapping) and second, automatic procedures and guidelines need to be developed to support municipalities in performing proactive community energy planning in order to assess and optimize possible energy scenarios. Therefore, the next step has to be to refine the methodology of community energy planning into a community energy planning tool.

Acknowledgements

The author would like to thank professor I. Peters from HafenCity University Hamburg for the feedback during the study and M. Pietrucha from the municipality of Elmshorn for material and support. Further the IEA EBC Annex 63, in which the authors' research is embedded into and from whom his research gets financially supported.

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