HOW TO ACHIEVE OPTIMAL DELIVERY OF ENERGY SERVICES FOR INFORMAL SETTLEMENTS? A METHODOLOGY

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Abstract

The energy situation in informal settlements of Sub-Sahara Africa is often poor. The electricity sector is commonly characterized by unreliable, unaffordable, illegal, or dangerous supply. Energy for cooking and lighting is predominantly based on fossil fuels. One solution to improve the energy supply in informal settlements is the implementation of an Energy Hub. This system can support both individuals and local businesses by providing energy related services. Energy Hubs can offer a variety of different services. Since the structures in the respective informal settlements differ, the services offered should be oriented and selected individually according to the local needs and livelihood of the population. To obtain a properly dimensioned concept tailored to the respective use case, potential services should be classified and evaluated in advance. In this work, a methodology is being developed to find and prioritise driving factors (parameters) that can classify and evaluate the energy services for the use in an Energy Hub. Based on literature and on-site research, eight parameters were identified and prioritised with the help of an expert survey. A clear ranking of the eight parameters was established with the technical and economical parameters scoring high. A graphical comparison of services based on the parameters concludes the work.

Keywords: Energy Services, Energy Hub, Informal Settlements, Sub Sahara Africa, Likert Scala, Evaluation Parameters

1. Introduction

The energy sector in countries of Sub-Sahara Africa (SSA) is in constant transition. Access to electricity has increased by 22 % over the last 20 years (World Bank Group 2023). In particular, the rise in the installation of renewable energy (RE) based off-grid systems helped to improve living conditions in remote and rural regions (Babayomi et al. 2023). In urban areas, the electrification rate is considerably higher than in rural regions (IEA et al. 2023) because the national grid can be expanded more cost-effectively due to the high density of buildings and the

Fig. 1: Exemplary Street in an informal settlement

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associated density of customers. The grid stability, on the other hand, still has potential for improvement compared to European standards (African Development Bank Group 2021; The World Bank Group 2023). Statistics show an almost universal electrification rate for urban areas in several countries of SSA, with more than 95 % in Kenya, Togo, Mali and Rwanda (World Bank Group 2023). However, there are still areas in cities that suffer from poor energy infrastructure and supply. These specific quarters are inhabited especially by the lower strata of society and are referred to as slum regions and informal settlements (ISs) (Mensah 2022; Butera et al. 2015; Cheseto N. Moses 2013). Fig. 1 shows a typical street in an exemplary IS with insufficient basic infrastructure. There are no paved roads, street lighting or running water systems for all residents. Although electrical lines are visible, they are often illegal and thus not laid by the national utility.

Within recent decades, slum upgrading programs have been launched (Anderson and Mwelu 2013). These aim at an area-wide reconstruction and improvement of the infrastructure. However, the implementation of the programms require a high financial outlay and, due to the dense development, considerable structural changes as well as efforts for the residents in the entire settlement. A successful upgrading also facilitates the installation of legal electricity infrastructure due to more structured access to the respective buildings. At the same time, slum upgrading programs face many challenges: The high financial investments, the illegal status of the residents and their consequently low political relevance, power structures formed outside the legal framework, such as cartels (Ndukui 2013). Also due to the high number of ISs, the infrastructure and reality of life in many ISs will not be possible to be improved across the board in the foreseeable future.

The energy supply in ISs is mainly based on fossil fuels, such as candles for lighting or charcoal, kerosene or gas for cooking (Okore et al. 2022). The residents suffer from energy poverty due to their low economic power (Broto et al. 2015). High levels of crime such as theft and vandalism on the one hand and little ability for political participation by residents on the other reinforce a mutual mistrust between the population and authorities as well as the national energy suppliers (Butera et al. 2015). In some countries, national electricity suppliers have withdrawn from ISs by dismantling transformers, leaving the area dark on the short-term and causing supply to be offered by illegal organizations like cartels on the long-term (Mgwali 2022; Kimatu 2021). Due to the high electrification rate in urban areas, this population group always lives close to the national grid, but at the same time cannot benefit from it (Dumitrescu et al. 2020). If they are connected by illegal suppliers, the supply is often characterized by frequent fluctuations and power cuts, dangerous, illegal connections, and often unaffordable tariffs (Broto et al. 2015; Christley et al. 2021). At the same time, the high solar irradiation prevailing in most cities in SSA leads to a large potential for RE, especially solar energy. There are several technological possibilities to improve the energy supply. Besides the option for grid expansion, there are also potential on RE based technologies, e.g., Mini-Grids, SHS or centralized solar kiosks (Besner et al. 2023). One potential solution to improve the energy supply in ISs is Energy Hubs, as shown exemplarily in Fig. 2. This is a compact, centralized off-grid system based on RE generation (generally up to a project size of 35 kW), especially consisting of the combination of photovoltaic (PV) and battery energy storage systems (BESS) (Besner et al. 2023).

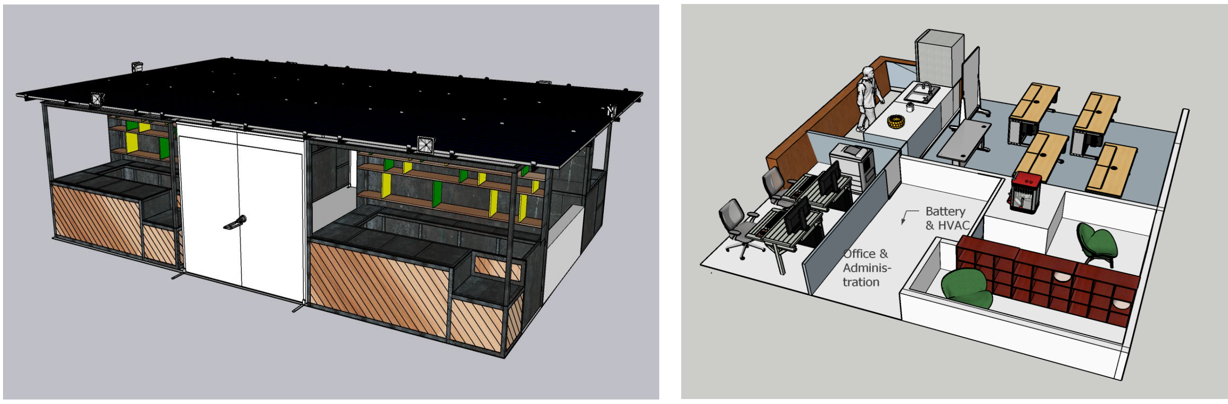

Fig. 2: Exemplary design of an Energy Hub from the outside (left) and inside (right) using the software SketchUp (Trimble Inc. 2023)

The concept is similar to that of a solar kiosk as Tavernier and Rakotoniaina (2016) discuss and can find an answer to the energy related challenges of ISs. If appropriate precautions are taken, the compact design can offer protection and minimise the risk of theft and vandalism. When deploying the Energy Hub, no settlement upgrading is necessary, as only a free, accessible space is required. The services that the Energy Hub can offer are intended to improve the living standards of the local population, as well as to support local businesses. Businesses that depend on electricity for their operations can obtain a space in the Energy Hub and benefit from the Hub's sustainable, reliable electricity supply. Therefore, the Energy Hub can support local businesses by providing electricity for their energy needs, enabling productive use of energy (PUE). At the same time, the Energy Hub pursues the goal of improving educational opportunities within the communities by offering training. The energy services can be used and obtained flexibly according to the users' needs and (financial) possibilities. In the best case, the local population can be involved in the operation of the system, and thereby capacity building is achieved. This can be realized by selecting a group of respected people with experience in selling, trading or offering services, who will take care of the Hub's operation. Theoretically, the mentioned concept can be used in ISs. However, as each IS having individual structures and their resident's individual energy related needs, it is challenging for external stakeholders, such as researchers, authorities, or investors, to analyse which services the Energy Hub should be offering in the respective different ISs. Hence, there is a need to derive the driving factors (parameters) which can evaluate potential energy services for the implementation of Energy Hubs in ISs to improve energy services. However, there is a gap in the research and no scientific information is available about fundamental information that is necessary for Energy Hub designing and implementation. Therefore, the presented study raises two main research questions to contribute to the knowledge:

- How can the energy services that will be offered within the Energy Hub, be evaluated, and subsequently chosen?
- What are the key determining factors (parameters) that can be used to assess the energy services to be provided within the Energy Hub?

Central off-grid systems have been around for several years. However, some concepts did not pass the pilot phase. Most of these systems are implemented in rural and remote areas (Tavernier and Rakotoniaina 2016; Urban and Maphalala 2019; Eales and Unyolo 2018; Frame et al. 2019; Batagarawa and Dodo 2022; THE PULSE Rwanda Ltd. 2022). As there is often no electricity supply in those regions, services which offer basic energy related needs are chosen. Frame et al. (2019) used as market assessment in rural Malawi the offering of a survey to households and businesses with 17 services under consideration. These were up for potential selection for use in the system. The authors inquired from households the willingness to pay for specific services and from businesses their estimation of the success, i.e., number of customers and probability of profit. While this approach is excellent for specific locations, a holistic evaluation of services and the possibility of transferability to other sites is not given. Other solutions, e.g., the operators of THE PULSE Rwanda Ltd. (2022), which offer a network rural PV-centers, are due to their alignment as a business operation less transparent in the methodology of how the range of services has been determined. In urban areas, the situation of energy supply is more diverse (Karekezi et al. 2008). The services offered in an Energy Hub in ISs must be adapted locally to the acute challenges and needs, which requires greater complexity in their selection. If transferability to other ISs within SSA is wished to be achieved, an extensive collaboration with the community of the respective settlement needs to be ensured. The methodology developed in this work for the assessment of different services helps to solve this challenge by proposing a thorough analysis of parameters which helps to evaluate respective energy services.

2. Methodology

The work of this study is divided into five steps. An overview of these steps is given in Fig. 3.

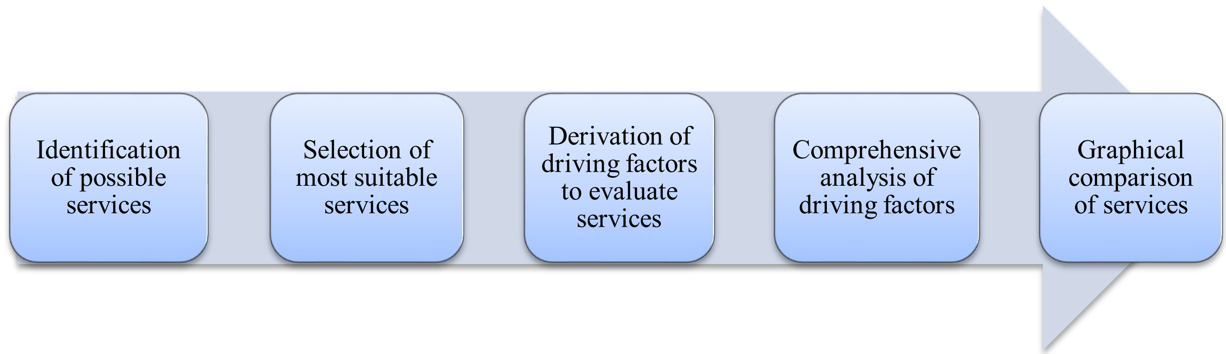

Fig. 3: The individual steps of the work of the underlying study

As a first step, possible energy services which the Energy Hub can offer need to be identified. Literature values as well as research activities are used as a basis for the analysis. During the research in two potential locations, ISs in Nairobi ("Kingstone", Mukuru), Kenya and Maputo ("Hulene B"), Mozambique, quantitative and qualitative data was collected. The quantitative analysis consists of a comprehensive survey of the energy practices and needs, the social and economic conditions and the existing infrastructure of the local population using a pre-developed questionnaire. Both, local businesses (83 in Kingstone, 58 in Hulene B) and households (390 in Kingstone, 229 in

Hulene B) were survey participants. The qualitative data collection involved individual interviews with local businesses and residents as well as the analysis of the utilized electrical appliances in the businesses of the neighborhood. The appliances electrical properties were measured with the help of a current clamp and their usage behavior was questioned to get an impression of potential use cases for the Energy Hub. The possible services are identified based on the already existing businesses in the local area. Furthermore, the question of which businesses and services are lacking within the community was used as an indicator for additional potential services for the Energy Hub.

Since an Energy Hub has limited capacity, confined available space, and a customer clientele with limited economic power, certain energy related services are not eligible for use. For example, providing charging stations for e-mobility may be inappropriate for Hubs in ISs due to the poor road infrastructural conditions and low economic strengths of the residents. Neither can electrically powered vehicles travel to the ISs and thus to the Energy Hub site, nor do their residents have sufficient financial resources to afford this type of vehicle. With this knowledge, the services can be narrowed down and subsequently evaluated. The evaluation is implemented by the introduction of driving factors (parameters). These parameters were derived during the above-mentioned qualitative and quantitative research. In particular, the site visits to ISs contributed to selection, as parameters were chosen in response to local challenges. To obtain verification and validation of the parameters, they are prioritized with the help of an expert survey. For selection and ranking of the parameters according to their relevance, experts from Europe and SSA, who are familiar with the concept of the Energy Hub, were contacted and survey results were obtained. The survey consists of two parts: In the first part, the experts are asked how important they consider the eight pre-selected parameters. Therefore, the Likert scale is being utilized (Susan Jamieson 2023). The scale ranged in five steps from "Very important", "Important", "Neutral" and "Slightly important" to "Not important". The fixed answer options are given a numerical score. Thus, the choice "very important" corresponds to five points, "important" to four points, "neutral" to three points, "slightly important" to two points and "not important" to one point. The coloring indicates analogously a high score in green and a low score in red. The second part allows the participants of the survey to identify other parameters that may be of relevance. Twelve experts were contacted, and ten experts took part in the survey. This results in an expert response rate of 83 %.

The fifth step of the methodology represents the final step, the graphical classification of the services with the aim of obtaining an overview of different options as quickly as possible. For this purpose, the services are evaluated by the parameters, put into a graphical diagram based on their scoring. If the preference of the future planner of an Energy Hub lies in two specific parameters, a graphical comparison of services within the two parameters can quickly help in the decision-making process of selecting services for the Hub.

3. Results

The following section is divided in the six steps. The first five sections deal with the results of the respective methodological step, which were introduced in Figure 3. Section 3.6 presents the limitation of the study.

3.1 Identification of possible services

The mentioned field visits, the quantitative research in combination with the review of literature helped to identify a number of 40 services. The quantitative surveys included interviews with households and businesses in two ISs in Kenya (“Kingstone”, located in the capital city Nairobi) and Mozambique (“Hulene B”, located in the capital city Maputo). The survey covered the realities of life from household size to financial situation, i.e., income and expenditure, the status quo of energy supply, needs and wishes in the scope of energy infrastructure, information on digitalization, hygiene, and sanitation supply structure as well as missing services in the community. The businesses were asked whether their service suffers from the current energy supply and whether they see a potential for business development when improving the energy supply. Qualitative interviews were conducted with business owners in the respective ISs, their energy needs and challenges with the existing energy supply were discussed. Various services were identified during visits to the settlements, through said surveys and interviews. These identified services with their corresponding field are being presented in Tab. 1. They range from basic infrastructural services, such as the provision of showers or restrooms, to the offer for existing services, such as a place for a tailor, to the option of providing a cinema.

3.2 Selection of most suitable services

The during section 3.1 identified services need to be analyzed according to their suitability for offering in the Energy Hub. Tab. 1 shows the for the use in the Energy Hub accepted services, highlighted in green, and services which can be merged into one generic load profile, in lighter green. The second part of the table, highlighted in red, displays the services, which cannot be considered for use in the Energy Hub and are being excluded. The exclusion used to determine which services would not be suitable for the Energy Hub is based on four main criteria and is being presented in the column "Remarks". These are, primarily, the space that a service occupies ("Too much space needs"), secondly the maximum power and energy that a service requires ("Power needs are too high"), thirdly, whether the service has a focus on energy provision or business activities at all ("No focus on electricity"), and fourth, if the service was mentioned or seen during the fieldtrips more than once ("No demand seen during research").

Tab. 1: Overview of services identified, divided into services accepted and excluded for implementation in the Energy Hub

Accepted identified services	**Accepted services to be summed up to one Load Profile "Generic shop"**
Tailor, Barber, Salon, Laundry, Copyshop, Wi-Fi, Grain Milling, Education and Training Centre, Juice pressing, Popcorn Sale, Fridge, Freezer, Cold room, Phone charging station, Lights charging station, Outside lighting	Hardware-Shop, Electronics (repair) Shop, Ice cream sale, Chips sale, Milk or Yogurt sale, Supermarket, Grocery, Chemist
Excluded services	**Remarks**
Shoe Making, Soap Production, Entertainment for children, Community Cooking Activities, Clean cooking, Clean water, Hot Water Provision, Shower	No focus on electricity
Emergency, Hospital, Car Wash, Garage	No focus on electricity Too much space needs
Urban Farming, Waste Management, Recycling	Too much space needs
Bakery	Power needs are too high Too much space needs
Welding, Air-Conditioning	Power needs are too high
Incubators for poultry farming, Oil pressing	No demand seen during research

Due to the dense building construction in ISs, space is an extremely scarce commodity. During a visit to the research area, three open spaces were identified, although only one was found to be a usable open space within the center of the Settlement. This amounts to approximately 50 m^2. While a hospital or emergency room requires a reliable power supply, these activities cannot be accommodated by an Energy Hub for a variety of reasons, most notably space constraints and focus of training and support of businesses. A small pharmacy-shop, on the other hand, could be offered within the Energy Hub. Further services, e.g., the implementation of a waste management facility, also cannot be included due to space restrictions. This is accompanied by the limitation by the second criterion, required power or energy. Due to the limited area, the maximum possible PV power that can be installed on the roof of the Energy Hub is also constrained. In addition, to minimize the cost of the Energy Hub, large power must be avoided to decrease the need for greater battery power and capacity. As an example, a bakery that has to operate an oven with a power of several kilowatts for a few hours before sunrise cannot be implemented in the Energy Hub. The car wash is on the one hand irrelevant due to the lack of accessibility for cars, on the other hand this service needs too much space and thirdly the focus for energy provision is missing. Although the provision of clean water for drinking, cooking, or showering is considered to be of extremely high relevance, the direct focus of these offers is not on the provision of energy-related services. Similarly, the options soap and shoe production need more manual than electrical support, so the reason for sorting out is also considered the focus. A fourth exclusion criterion is the frequency of mentions of the potential service during the research activities. If the service was mentioned only once and not identified again during the on-site visits or the surveys, this service is classified as non-relevant and excluded for further use. The services of hardware or electronics sales store, sale of chips, sale of milk, yogurt or ice cream, chemist, supermarket and grocery store are combined in one service, as their applications and thus their load profiles do not differ significantly. This generalized service is being referred to as the “generic shop”. This includes the equipment lamps, fan, an optional radio and a refrigerator or freezer. Collaborative cooking activities can still be conducted if space permits, but there are no additional necessary arrangements to be made on the part of the Energy Hub design to accommodate the activities. Therefore, no extra service is created for it.

3.3 Derivation of driving factors to evaluate services

In total, eight parameters for evaluation of the pre-selected services have been identified based on limitations and challenges, observed during the field visits, and mentioned quantitative and qualitative research as well as expert discussions. Three criteria played an important role in the selection of the parameters: The Technical, the Economic and the Social dimension. The first criterion analyzes whether the service can be used in the Energy Hub from a technical point of view. This essential criterion led to the selection of the following three parameters: Energy storage requirements, space and electricity required by the service. The second criterion analyses, whether it makes sense from an economic perspective to offer this service. Therefore, the criteria of potential for return of investment (RoI), cost of a service and number of necessary employees were chosen. And the third criterion has to do with the social aspect, especially the acceptance of the Energy Hub by the local community. This involves determining how many residents can benefit from the respective service. Furthermore, the type of operation is examined, i.e., whether a service can potentially be organized or operated by the community itself, or whether this must be undertaken by private individuals. Fig. 4 shows the parameters, which were derived and are suitable for evaluating services which could be offered within the Energy Hub. The parameters are divided into the three preselected criteria of technical feasibility (marked in green), economic properties (marked in blue) and social suitability (marked in purple).

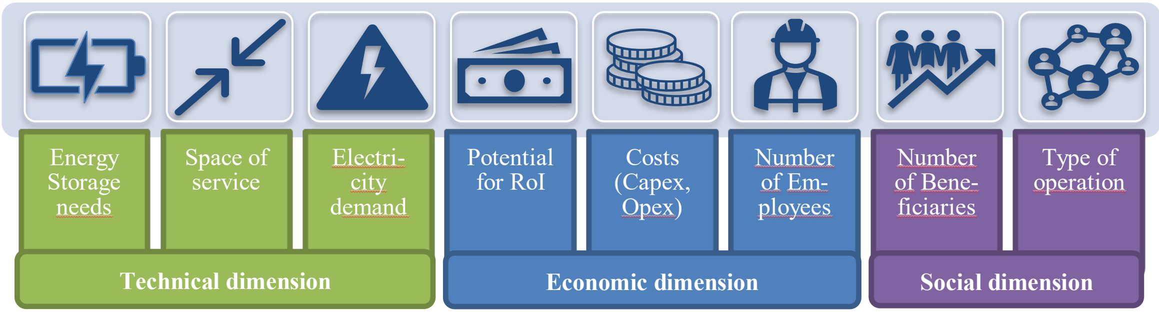

Fig. 4: Derived parameters for evaluating energy services that can be implemented in the Energy Hub

When selecting parameters for evaluation of energy services, attention should be paid to quantifiability, relevance and practicability. Parameters such as “Social Impact” are difficult to quantify, so measuring the "Number of Beneficiaries" is more applicable. Given the limited space available in ISs, a preliminary estimate of the required PV and Energy Hub area per service is relevant. Therefore, the parameter "Available Space" is about assessing how much space the energy service requires within the Energy Hub in meter (e.g., refrigerator around 1.2 x 0.6 m with additional space for door opening). At the same time, a planner must know how much energy and thus PV area is needed (“Electricity demand”), which is quantified in kWp. The parameter “Energy Storage needs” is measured in kWh of battery storage demand per day. The calculation of the RoI (“Potential for RoI”) is in general based on many individual, region-specific, market-dependent prices and variables. Since an analysis of the services based on their RoI is not universally possible due to the varying prices in different countries, a tendency in the form of a ranking is given. This is accompanied by the "cost of a service" parameter, which is used to calculate capital and operating costs. In this case, too, the positions are very dependent on the respective potential location and place of use of the Energy Hub and thus of the service offered. The parameter “type of operation” is analyzing whether a service can be operated by a private person or the community. A typical example of a service run by individuals is the operation of a barber shop. In contrast, a training center is suitable to be organized by several people of the community.

3.4 Comprehensive analysis of driving factors

In the following section, the response of the expert survey is analyzed. When the above introduced methodology is being applied to the response data, the parameters evaluation results in Tab. 2. The table shows the individual ranking proposed by the experts in detail. The individual results are being summed up within their parameter group (“Sum”). To gain a comprehensive, more generalised evaluation, the results are being weighted (“Weighting”). The maximum possible rating of importance is 50 points (equalling a weighting of “1”), which is achieved if each expert considered a criterion to be highly important. With the importance value of 42 of the parameter “Energy Storage Needs”, a total weighting of 84 % is being scored. The resulting ranking of the parameters is displayed in the last row (“Ranking”).

Tab. 2: Results of the evaluation of the pre-selected parameters with coloring from "Highly important" (green) to "Not important" (red)

Parameter / Response	Energy Storage Needs	Space of Service	Electricity Demand	Potential for RoI	Costs of Service	Number of Employees	Number of Beneficiaries	Type of Operation
n = 1	4	5	5	3	5	4	4	5
n = 2	4	5	5	5	4	2	5	4
n = 3	4	5	5	5	4	2	4	2
n = 4	4	5	4	4	3	3	5	5
n = 5	4	5	4	5	4	4	4	2
n = 6	4	5	5	4	5	3	5	5
n = 7	5	5	5	5	4	5	4	4
n = 8	5	5	5	4	5	5	5	4
n = 9	4	5	4	4	3	1	4	5
n = 10	4	3	5	5	4	3	4	5
Sum	**42**	**48**	**47**	**44**	**41**	**32**	**44**	**41**
Weighting	**0.84**	**0.96**	**0.94**	**0.88**	**0.82**	**0.64**	**0.88**	**0.82**
Ranking	**4**	**1**	**2**	**3**	**5**	**6**	**3**	**5**

The highest importance is attributed to the parameter "**Space requirement of the Service**" (Ranking "1"). The services should therefore be evaluated according to their respective space requirements. It can be concluded from the results that a significant challenge in ISs concerns the limited space availability. It is relevant to know how much space a Training Centre with three, five, ten or fifteen seats requires. At the same time, a router (Wi-Fi service) can be hung on the wall and does not require any floor space. The second important parameter, the "**Electricity Demand"** of a certain service, is also related to the first mentioned ("space requirement") parameter. The area of free space, which is covered by the PV system, is limited. Since the Energy Hub is a building and island system with a central rooftop PV, the energy that can potentially be generated with the system is also bounded.

From the experts' point of view, the parameter of whether a service has the "**Potential for RoI"** is the important criterion from the economic perspective. The assessment of services on the basis of this parameter, however, is as already mentioned in section 3.3, more difficult, as both the costs of the services and the income generated by the service differ from country to country.

The **"Number of Beneficiaries"** is considered to be the most important social criterion. Since the Hub is a product that is tailored to a specific community, as many as possible within the community should also benefit from it. Accordingly, services should be examined to determine the extent to which they meet this criterion. One service that could benefit many residents is the charging station for cell phones. A large part of the local population owns mobile phones. In the event of prolonged blackouts or a shutdown of the electricity supply, several community members can use the charging service at the same time. Although the training center imparts knowledge to a limited number of people, in the best case this can lead to many profiteers through the multiplication effect - by passing on this knowledge on to neighbors or family members.

"**Energy Storage Needs**" are not considered very relevant compared to other technical parameters. The storage needs depend on the selection of the different services: security lighting that shines during the night requires more storage than a service that is only open during sunshine hours. However, based on different preferences and local conditions, potential Energy Hub operators could define the availability of their system. As BESS account for a large part of the investment costs in an off-grid system, the capacity of BESS can be reduced in the design of an Energy Hub if, for example, the available funding is limited. The decrease in BESS capacity generally leads to lower system availability. A balance has to be found between the available financial resources, the selected services, the local preferences of the local population and the desired system availability. This can be done regardless of the services chosen, so assessing services based on their individual need for BESS capacity is considered less relevant.

The parameter **"Cost of Service"** is similarly found as less important. When evaluating energy services, the experts identified the RoI as more relevant, since the share of cost of the Energy Hub itself, with its building structure, energy generation and BESS is higher than the services themselves, which is represented by the capital and operational costs for the respective appliances. Furthermore, depending on the financing structure, loans can be granted in various amounts, whereby the total amount, which is influenced by individual services to a minor extent, is less decisive than the potential to repay the loan with interest. Capital and operating costs are input variables of the RoI parameter, which is why the parameter for cost itself is evaluated as less relevant. It is important to consider the costs in particular, since the amount of revenue of the respective service is determined by them.

The evaluation of a service based on the type of possible **“Type of Operation”** is also rated as rather unimportant. The question of whether a service is more suitable for operation by a private individual or by the community is less relevant since the operation of all services can be carried out by both the community and private individuals if organized systematically and respectively. Furthermore, the form of operation depends on many factors, especially the composition of the community, the wishes of the community or the commitment of individuals. The conception of the Energy Hub as well as the selection of services will be designed according to the local operator.

Analogously, the parameter **“Number of Employees”** is classified as less relevant, as the number of staff per service differs depending on the size of the service (for example, for the use five planned shavers for a barbershop more staff needs to be hired then if two shavers are in operation), the opening hours and the type of operator of the Hub.

Suggestions about other possible parameters were also mentioned by the experts. Suggestions were "Safety", “Ownership” and "Accessibility" for customers. These three valuable suggestions are taken into account for the layout of the entire Hub but are not considered necessary for the evaluation of individual services. “Ownership” is being also represented by the “Type of Operation” and will be involved further in the choice of a business model. “Sustainability beyond the donor support period” as well as “affordability of prices for customers” are also important aspects which needs consideration when looking at the big picture of developing the Hub. Another expert cites "urgency and prioritization by the community." This is made possible with the mandatory involvement of the community when initiating a possible building of the Hub.

3.5 Graphical Comparison of services according to diverse parameters

In order to achieve a fast evaluation of different services, this can be implemented by a clear comparison with the help of graphs. In this way, services can be compared on the basis of two parameters. Fig. 5 shows an example comparison of eleven randomly selected services based on the parameters "Space requirements" and "Beneficiaries of service" without detailed axis labeling.

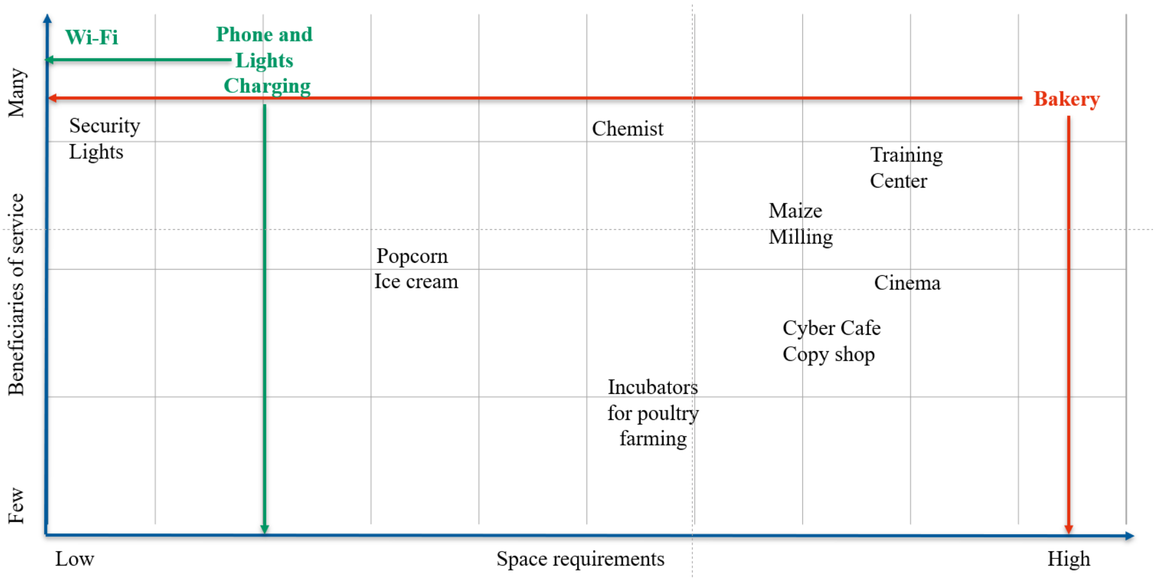

Fig. 5: Exemplary graphical representation of the evaluation of different services based on two parameters

The green-marked area represents services that are particularly suitable for use in the Hub, as it benefits many residents while requiring little space. Similarly, the services in the red-hatched area are less suitable because the necessary space exceeds the scope of the Energy Hub concept. Wi-Fi should be public - and thus available from theoretically everyone in the neighborhood if they are in the vicinity of the Energy Hub. The bakery and pharmacy products can also be purchased by everyone. The cell phone charging service is available to a relatively large number of people, since at least 30 people can use the service in parallel. There are a maximum of two workstations in the cyber cafe or coffee shop, which is why relatively fewer people can use the service here per day. Incubators can only be used by residents who own chickens and have the capacity for operation growth, which significantly limits the number of beneficiaries. Although in theory ice cream and popcorn is also available to everyone, for many it is not an essential, everyday product, which makes the profiteers decrease per day. The Training Centre also has a limited number of courts and training times per day. However, there is room for several people at the same time and the multiplication effect already mentioned increases the number of beneficiaries. The grain mill can only be used by a limited number of customers due to the limited capacity of the mill. From interviews with three millers in the research area of "Kingstone" in Nairobi, a number of customers of up to 25 people per day could be identified (Besner 2022).

3.6 Limitations of the study

No claim is made for completeness in the underlying work. A selection of parameters had to be made and their number chosen in such a way that the analysis is feasible in terms of time and resources while at the same time comprehensively taking all relevant aspects into account. The experts belong to one of two different fields. They are from the area of social sciences or have a technical background. Care was taken to ensure a balanced proportion of experts with the two respective backgrounds. Although the parameter ratings have been selected based on quantifiable criteria (as described in section 3.3), for example, space requirements are described in terms of m^2 definable, the services themselves must often be based on empirical values or with the help of supported assumptions. A comprehensive evaluation of the services exceeds the scope given for this paper, which is why this work concludes with the possible graphical comparison of various services based on two different parameters. The outstanding comprehensive evaluation of the individual services on the basis of the parameters defined in the context of this paper will be carried out in future work.

4. Conclusion

Efforts to ensure a modern, clean, and sustainable energy supply for all must be steadily pursued. In some areas, such as ISs of SSA, the common approach of grid extension or the use of a Mini-Grid is often not possible due to various challenges and local conditions. One solution that can help improve the local energy supply in ISs is the utilization of so-called Energy Hubs. These are a renewable energy based off-grid system with PV and battery energy storage technology, which can support the local community by providing electricity for energy services and PUE. If Energy Hubs are to be set up in several informal locations in SSA, the services that the Hub will offer needs to be tailored to local needs. While there are comparable projects, the choice of services provided by these concepts has not yet been discussed in the literature. Since there are a large number of possible services at the same time and they cannot all be offered in an Energy Hub at the same time, a selection of services must be made. In order to be able to tailor these services to local needs, the services must be evaluated in advance on the basis of various parameters. Therefore, the first step is to identify the services that an Energy Hub can be able to offer. To achieve transferability and adaptability, parameters must be found to analyze, prioritize, and narrow down these services according to suitability and characteristics. The eight within this work derived parameters can describe services extensively. To make an optimised service selection, the chosen parameters are evaluated and prioritized with an expert survey. The most important parameter is to evaluate the services based on their space requirements. Also extremely important, and related to the space requirements, is to identify the amount of energy or electricity needed for each service. In addition to the lack of space for the Energy Hub building, there is the analogous limitation for the PV area provided on the Energy Hub. The two technically justified parameters are followed by an economic parameter: The potential for a service to achieve a return of investment. From a sociological point of view, another indicator is important: the number of those who benefit from the use of the service. In contrast, the experts do not consider the number of employees required and whether the services should be operated by the community or by private individuals to be quite important.

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