

Selection of key performance indicators (KPIs) in the transition towards low-carbon urban communities

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Keywords

key performance indicators (KPI), sustainable communities, energy efficiency measures

Abstract

Energy used to cover local energy demand is contributing to climate change and many other environmental issues. Sustainable and smart energy communities are gaining increased attention worldwide, as a response to the understanding that these existing patterns of local energy use need to change. Key Performance Indicators (KPIs) can be useful tools to help with the planning, development, and monitoring of smart energy communities, but it can be challenging to identify the most relevant indicators for different projects. This article presents a new methodology for selecting KPIs that can be used to monitor the transition of local communities towards low carbon/smart energy communities. The methodology consists of the following main steps: 1) Identify the relevant objectives and goals at different scales 2) Conduct a literature study to build a list of appropriate KPIs to assess performance towards these identified project objectives and high-level goals. 3) Select the most relevant KPIs through the method of Multiple Attribute Decision Making (MADM). 4) Obtain user feedback on the outputs of Step 3 and perform the process iteratively – refining the chosen KPIs until agreement is reached that they are the proper KPIs to measure progress towards the goals and targets.

The method for selecting KPIs as presented in this article can be applied to a range of different projects. In this article, the methodology has been applied and tested in a Norwegian setting, resulting in a list of KPIs that hopefully can be applied to other projects in the future.

Introduction

It is now well established that energy use contributes to climate change and many other environmental issues. While the effects of climate change will be global, the energy use that contributes to it is mainly a consequence of local energy demand. International agreements, as well as individual nations, regions, and communities, have set ambitious climate protection goals requiring increases in energy efficiency and reductions of greenhouse gas emissions (GHGs) (UN 2015). Local authorities are expected to play a key role in reaching these goals and hence, the topic of smart energy communities is gaining increased attention. In Europe this is represented by the multitude of different directives, research programs, and projects that have emerged in the past few years. These include the ‘Clean energy for all Europeans’ package with the promotion of Local Energy Communities (LEC) in the Electricity Market Directive, and Renewable Energy Communities (REC) in the Renewable Energy Sources Directive. The European Energy Research Alliance program (EERA) ‘Joint Program Smart Cities’ is developing new scientific methods and tools to support European cities in their transformation towards smart cities (EERA 2017). The European ‘Smart Cities and Communities Programme’, supports the planning, deployment, and replication of 100 ‘Positive Energy Districts’ (PEDs –neighbourhoods with annual net zero energy import and net zero CO₂ emissions) by 2025 (TWG of the European Strategic Energy Technology 2018). ‘+CityxChange’ is a smart city project developing feasible and realistic demonstration projects in climate-friendly and sustainable urban environments in different cities around Europe (+Cityxchange 2018). In Norway, the Research Centre on Zero Emission Neighbourhoods in smart cities (ZEN Research Centre) is contributing to the transition to a low carbon

society by developing solutions for future buildings and local neighbourhoods with zero greenhouse gas emissions (ZEN Research Centre 2018).

There is currently no unified definition of a Smart Energy Community (SEC). In this article, the following working definition for smart energy communities (Walnum et al. 2017) is used:

A Smart Energy Community is an area of buildings; infrastructure and citizens sharing planned societal services, where environmental targets are reached through the integration of energy aspects into planning and implementation. The Smart Energy Community aims to become highly energy efficient and increasingly powered by renewable and local energy sources and lowered dependency on fossil fuels. Its spatial planning and localization consider reduction of carbon emissions also through its relationship with the larger region, both through the design of energy systems and by including sustainable mobility aspects of the larger region; it further encourages sustainable behaviour through its overall design from building and citizen scale to community scale. The application of open information flow, large degree of communication between different stakeholders and smart technology are central means to meet these objectives.

USING KEY PERFORMANCE INDICATORS (KPIs) IN THE PLANNING OF SMART ENERGY COMMUNITIES

Key Performance Indicators (KPIs) generally consist of measurable parameters, which demonstrate progress towards an intended goal in a project. While KPIs can simplify the planning, development, and monitoring of smart energy communities, it is often challenging to identify the most relevant KPIs for different projects (CITYkeys 2016).

The development of smart energy communities is often a consequence of national and international research, policy, and goals. In the planning and monitoring of smart energy communities, KPIs can be useful tools for comparing international, national, or regional scale goals (high-level goals) to the project objectives on city or community scale (low-level goals) where experience shows that there is often a missing link (CITYkeys 2016). Local planners may set ambitious objectives for local community projects based on national and international goals, but they may still lack a clear understanding of which measures actually contribute towards reaching the high-level goals (Leal and Azevedo 2016). Some KPIs work well on multiple levels and can be used in local energy planning as well as in monitoring performance towards national and international goals. Such KPIs are called cross-scale or cross-level KPIs (CITYkeys 2016). When selecting KPIs for the smart energy community approach, it is vital to include cross-scale KPIs to ensure that local authorities get an overview of how the smart energy community performs in relation to the high-level goals.

There are already several existing indicator systems for city planning, including the Reference Framework for Sustainable Cities (RFSC 2015), the working group for Global Indicators Facility (ISO 2019), and the EU research and development project CITYkeys (CITYkeys 2016). Although these indicator systems work well for many city applications, there is

no broadly accepted indicator system that reflects the 'smart energy community/city' approach (European Commission 2015). Previous work is also limited in application within and across scales, lacking both a methodology for defining a framework for choosing indicators for planning smaller scale local communities or neighbourhoods, or proposing indicator sets that can link the low-level project objectives to high-level goals.

SCOPE

The scope of this article is to present a new method for selecting the most relevant cross-scale KPIs for planning and monitoring the transition of local communities towards smart energy communities. The method has been applied to two case studies in Norway, resulting in a final list of 11 KPIs that can be used for planning and monitoring the transition of local communities towards smart energy communities in Norway. Though project objectives and KPIs may vary between specific projects, the common framework for selecting KPIs in smart energy community projects proposed in this article can be applied to any project.

Methodology for selecting KPIs for smart energy communities

The proposed methodology for selecting suitable cross-scale KPIs for smart energy community projects consists of four main steps:

1. Identify the project objectives, goals, and targets across all relevant scales.
2. Conduct a literature study to build a list of appropriate KPIs to assess performance towards these identified project objectives.
3. Select the most relevant KPIs through the method of Multiple Attribute Decision Making (MADM). The literature study in step 2 may result in a long list of indicators. Some of these may not be suitable for measuring the performance of the goals identified in step one, and others may be redundant. The method of Multiple Attribute Decision Making (MADM) (Yoon and Hwang 1995) is a method that can be used with problems that involve multiple, possibly conflicting criteria where it is necessary to narrow down a long list of options. In this step, all the indicators are rated on different decision criteria (attributes) that are considered important by the researchers. Indicators that rate below the minimum criteria set by the researchers (or are considered redundant) are discarded systematically. A complete description of this process is presented in the next section.
4. Acquire feedback from the users. The chosen set of KPIs from step 3 must be able to measure the success of the goals identified in step 1. In step 4, the users give feedback on the performance of the chosen set of KPIs. Steps 2–4 are performed iteratively until the chosen KPIs can be used to measure the progress on the project goals and targets in a satisfactory way.

The methodology is described schematically in Figure 1.

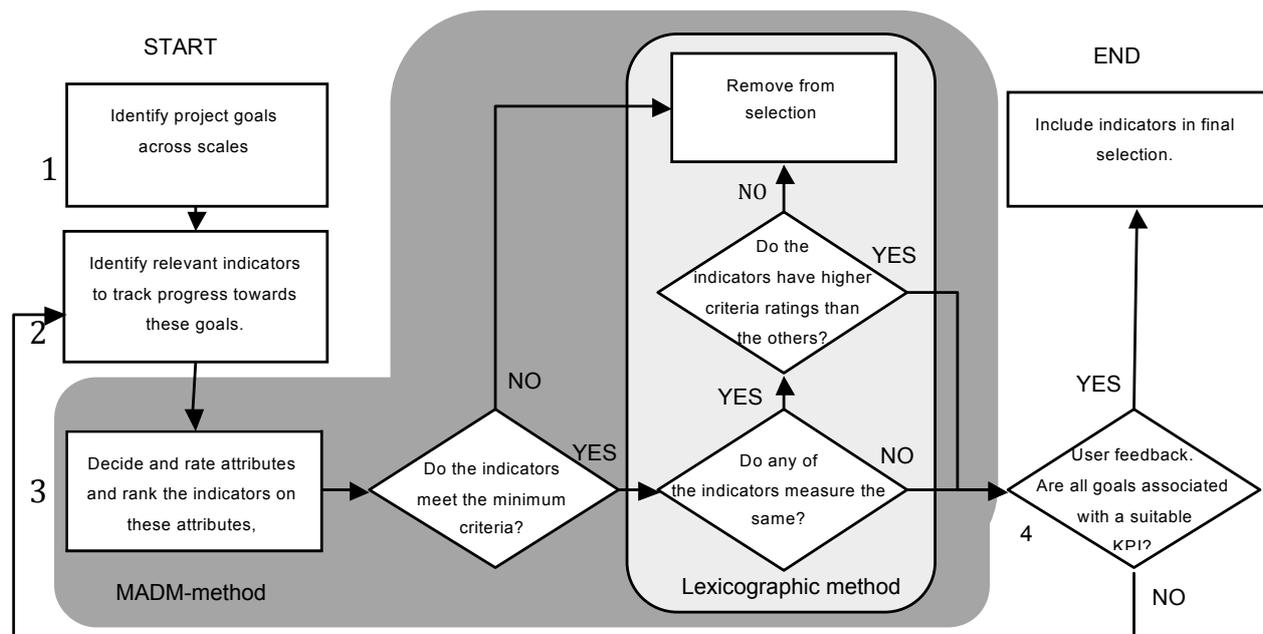


Figure 1. Methodology for selecting relevant key performance indicators in urban planning projects.

Application of the methodology

A wide range of European and international research addresses smart and sustainable energy use at city and country scales (CITYkeys 2016). The experiences from these projects have not yet been transferred to Norwegian planning practices.

The proposed method for selecting KPIs in this article has been applied in a Norwegian research project (PI-SEC) in order to find a set of KPIs that can be used in a range of different local community projects in Norway. The objective of PI-SEC (Planning Instruments for Smart Energy Communities) is to deliver efficient planning instruments for integrated energy design at the neighbourhood scale, designed for the Norwegian planning context in cooperation with public stakeholders. This is done by using results and drawing experiences from European initiatives, such as CITYKeys¹ and EU Smart City Information System². In addition to the expertise on smart energy communities within the project researchers, the project has a reference group consisting of both Norwegian municipalities and international experts with experience from inter alia EERA Joint Program Smart Cities. The approach in PI SEC differs from the established systems as success is measured on goals set by the municipalities themselves, and not by predefined rules or scores etc. such as in BREEAM. The users are free to choose the goals and KPIs that they themselves find most relevant, hence making the approach more flexible and adjusted to local conditions, but also more challenging when comparing different projects.

One of the main challenges identified in PI-SEC is how to define cross-scale KPIs for measuring progress on different goals in different projects.

During the application of the method, two very different case studies were chosen in order to find the necessary KPIs that

could be applied to measure progress in a range of different smart energy community projects in Norway. The following case studies were chosen in the Norwegian setting:

- Ådland in Bergen, which is a new development with 600 to 800 dwellings and a community centre.
- Furuset in Oslo, which is a renovation of a suburb from the 1970's with 9,500 inhabitants, with a building stock containing residential, public, and commercial buildings.

The selected cases are both large ongoing development projects with ambitious goals with respect to energy performance and related GHG emissions, but they are very different in most aspects, e.g. building types and building standards in the areas, the size of the areas, the number of inhabitants, and the geographical location.

The following sections describes how each step in the proposed methodology was applied in the PI-SEC-project to establish a set of KPIs that can be used for smart energy community projects in general in Norway.

STEP 1: IDENTIFICATION OF LOCAL, REGIONAL AND NATIONAL GOALS

When planning the development of smart energy communities, local planners often set ambitious goals and targets for energy performance and GHG emissions. Usually, these targets and goals set at neighbourhood level will be strongly linked to the energy and emission targets set for the city, the region, and the nation. A good set of KPIs should be able to measure the progress towards all of these cross-scale goals.

Identification of goals and targets in case studies can be conducted by receiving direct user feedback, or by studying available plans, regulations, and other sources for the community and the higher levels. Either way, while working with the goals and targets in a case study, it can be useful to make a structured list of the targets and goals linked to the case and sorting them by scale and theme.

1. <http://www.citykeys-project.eu/>

2. <https://smartcities-infosystem.eu/>

When the methodology was applied to the Norwegian setting, the researchers tried to identify the relevant goals connected to the development of the areas Furuset and Ådland on building level, neighbourhood level, city level, and country level. The goals were mainly identified by the researchers through analysing municipality plans, regulations, standards, incentives, national targets, and goals set in research programs that the communities took part in (both pilots were part of the ZEN Research Centre, and they also took part in other research programs for smart energy communities). The municipal planners and other users were also involved through discussions in project meetings, and by giving feedback on project reports made by the researchers.

All the identified goals and targets were sorted by the following themes:

- Carbon emissions
- Energy consumption
- Energy generation
- Energy grid capacity
- Green mobility in the energy system
- Smart energy management,
- City environment
- Citizens (stakeholder involvement).

Some of the goals identified were linked to predefined KPIs. In these cases, the KPIs were listed with the goals.

Table 1 shows some examples of goals, from the total list of goals that were identified in the case studies (Sørnes et al. 2016). The purpose of the table is to give an idea of how the findings were structured. The identified goals were listed under geographical scale of application (in the column marked “scale in the table”), by predefined themes and by KPIs that were linked to the goals.

Although the goals identified in the case studies are specific for the case studies, many of these goals are common for cities and communities in Norway with declared policies on becoming greener and improving overall energy efficiency.

STEP 2: IDENTIFICATION OF POSSIBLE KPIS THROUGH A LITERATURE STUDY

Conducting a literature study is the second step of the methodology, and this is a good way to identify possible KPIs for projects that are linked to several goals and targets. The main reason for conducting a literature study at this step is that it is not always obvious which KPIs to use to measure progress on different goals in a project. In some cases, a goal may be directly linked to a specific KPI. For instance: if a neighbourhood has a goal to reduce the specific energy use of residential buildings, the KPI “Specific energy use [kWh/m²]” is the obvious KPI to use. However, for other goals there may be several KPIs and KPI units that can be used to measure progress on the same goal. For instance, a goal may state that “energy efficiency should be increased by X %”, and there are several KPIs that can be used to measure this goal. For qualitative goals there may not be any obvious measurable KPIs. In some cases, it may be necessary to use several different KPIs to measure progress on the same goal.

For the Norwegian setting, the literature study included an analysis of several international programs, collaborations, standards, and certifications, such as CITYKeys (CITYkeys 2016), BREEAM NOR (NGBC 2012) and ISO 37120 (ISO 37120 2018).

During the literature study, all possible KPIs that were identified were sorted by the following categories:

- Theme (energy consumption, energy generation, carbon emissions, green mobility, safety of supply, outdoor lighting and non-technical)
- KPI unit
- Scale of application (building, neighbourhood, region, city, country).

Smart grid topics, such as storage and flexibility, were not included in the KPI set as this is beyond the scope of the PI-SEC project.

After the literature study was complete, a total of 220 KPIs were identified as possibly relevant for the cases of Ådland and Furuset. For the interested reader, the list can be accessed in a separate report (Sørnes et al. 2016).

STEP 3: SELECTION OF THE MOST RELEVANT KPIS THROUGH MULTIPLE ATTRIBUTE DECISION MAKING (MADM)

It may be overwhelming to the users to have a set of KPIs that contains too many KPIs. It is not likely that all the KPIs identified in the literature study in step 2 are needed, or that the KPIs can be used to measure the progress on the goals identified in step 1. As proposed in the new methodology, the MADM method is used in order to select which of the KPIs from the literature study to include in a final set of KPIs (Walnum, et al., 2017).

The MADM method (Yoon and Hwang 1995) can be used when deciding in problems that involve multiple, and usually conflicting criteria, or “attributes” as they are called in the MADM-method. For example, when buying a new car, the following multiple attributes may be considered: price, comfort, fuel economy, safety, maintenance cost, appeal and so on. In this case, the criteria are likely to be conflicting and the MADM-method can be used to make the decision. When choosing which new car to buy, any analysis using the MADM-method always begins by establishing the attributes (decision criteria) that can measure relevant goal accomplishment (“Buying a new car”). Attributes can either be quantitative or qualitative. The attributes are rarely equally important to the decision maker, and attributes are therefore ranked relative to the others (“price is more important than comfort, but comfort is more important than appeal, etc.”). Once the attributes are chosen and ranked, a strategy for eliminating the options must be selected. There are several different MADM-strategies for ranking and eliminating options and 13 are identified by Yoon and Hwang. Which strategies to use depend on the decision problem.

The purpose of using the MADM-method in the context of selecting KPIs for the smart energy community approach is to aid the users in systematically choosing the best KPIs from a range of possible KPIs.

As in the example with the car, the MADM-method always start by selecting the most important the decision criteria

Table 1. Some of the goals and targets identified at different scales that are relevant to the development of the local urban communities Ådland and Furuset in Norway.

Scale	Themes	Source	Main goals	Main KPIs
Country	Energy consumption Carbon emissions	EU Energy performance of buildings directive (European Parliament 2010, 2018)	Improve energy efficiency of buildings New buildings should be nearly Zero-Emission Buildings (nZEB) by 2020	Energy use (kWh) CO ₂ -emissions
	City environment	Pollution Control act (Lovdata 1981)	Protect outdoor environment against pollution and better the waste treatment	Concentration levels of pollutants (PM, SO _x , NO _x ...)
City	Carbon emissions Energy consumption	Green strategy for Bergen municipality (Bystyret Bergen 2016) (Bergen kommune 2016)	Fossil free building sector in Bergen by 2030	CO ₂ -emissions Energy use (kWh)
	Green mobility	Urban Environment	Enable more people to use public transport, cycling and walking	Public transport use
Neighbourhood	Carbon emissions Energy generation Energy consumption Green mobility Smart management City environment	Voluntary certificates and standards for pilot project in the ZEN Research Centre)	Sustainable neighbourhoods The greenhouse gas emissions related to the operation of the buildings should be zero on an annual basis. Local energy generation should balance the energy use, and maybe also the embodied energy in the neighbourhood materials.	Energy use (kWh) Power Carbon emissions Transport use
	City environment	Planning and building act: Zoning plans	Sustainable development in the best interest of individuals, society and future generations	Qualitative
Building	Energy consumption Energy generation	Energy performance certificates (European Parliament 2010, 2018)	Provide information on the energy efficiency of buildings and the recommended improvements	kWh delivered/m ² floor area

Table 2. Ranked attributes used to rate the 220 KPIs identified in the literature study on the relevance of measuring the progress in the PI-SEC pilot projects.

Ranking	Attribute	Description
1	Relevance	The KPI should have a significant importance for the evaluation of the one or more of the goals or targets identified in the PI-SEC pilot projects. Irrelevant KPIs should not be included.
2	Availability	Data for the KPI should be easily available.
3	Measurability	The identified KPI should be measurable (qualitative).
4	Reliability	The definition of the KPI should be clear and not open to interpretations.
5	Scalability	The KPI should be applicable across scales; building, neighbourhood, city, district and country.
6	Familiarity	The KPI should be easy for the users to understand (municipal decision makers, researchers and consultants), and the definition should have a meaning in the relation to the policy goals in the PI-SEC pilot projects.
7	Phase application	The KPI should be applicable (either measurable or possible to simulate) in several phases of the projects: planning, regulation, design, construction, operation and end of project.

(“attributes”) for the decision problem before ranking them against each other. The simplest way of ranking the attributes is by arranging the attributes in declining order of importance. Table 2³ shows the selected 7 attributes for selecting

the most useful KPIs for the two Norwegian cases, and how these attributes were ranked (from most to least important). The selection of attributes and the ranking of the attributes are case specific. It may be necessary to choose other attributes and/or rank the attributes differently in other projects.

After deciding on the attributes, a three-step process follows in order to decide on which KPIs to retain in a final KPI set:

3. Five of these chosen attributes were identified in the research project CITYKeys (CITYkeys 2016). The attributes “scalability” and “phase application” were not identified by CITYKeys, but were included due to the need for indicators in the to be cross scale.

1. *Rate the KPIs on the attributes (from Table 2).* After deciding and ranking the attributes against each other, all the KPIs identified in the literature study must be rated individually on all the attributes. In the Norwegian setting, the 220 KPIs was rated on each of the 7 attributes in Table 2 on a Likert-scale from 1 to 5, where 1 is no/little, and 5 is very much (Likert 1932). E.g: If a KPI was considered “not relevant” by the researchers, it was given the rating 1 on the “Relevance”-attribute. If a KPI was considered “very relevant” it was given the rating 5 on relevance. If the KPI at the same time was impossible to measure it was given a rating of 1 on the attribute “Measurability”.
2. *Remove irrelevant KPIs (The Conjunctive MADM-Method).* The first elimination step follows the Conjunctive MADM-method (Yoon and Hwang 1995). The purpose of this elimination step is to remove the KPIs that rank poorly on the most important attribute. In the Norwegian setting “Relevance” was ranked the most important attribute. Hence, the KPIs that were rated as irrelevant (with a rating below 3 on relevance) were immediately discarded. The KPIs that were rated as highly or very relevant (with a rating of 4 or more on relevance) were passed through to the second elimination step. The KPIs that rated between 3 and 4 (as they were considered to be “somewhat relevant”) were either retained or discarded on the basis of discussion between the researchers based on how they rated on the remaining attributes.
3. *Remove redundant KPIs (Lexicographic sequential elimination method).* The second elimination step follows the lexicographic sequential elimination method (Yoon and Hwang 1995). The purpose of the second elimination step is to exclude redundant KPIs. KPIs that measure something unique should be retained in this step. KPIs that measure the same as other KPIs are compared against each other based on the attribute ratings of the KPIs. When several KPIs measured the same in the Norwegian setting, the KPI that had the highest rating on the attribute “relevance” was kept, while the others were discarded. If several KPIs measured the same and were all equally rated on “Relevance”, the KPI rated highest on “availability” (which is the second most important attribute in this decision problem) was retained, while the others were discarded, and so on.

By applying this methodology, the 220 KPIs identified in step 2 were reduced to 21 KPIs.

STEP 4: FEEDBACK FROM THE USERS

It is crucial to receive user feedback to find out whether the chosen set of KPIs can adequately measure progress towards the goals identified in step 1. This can be done by testing the KPI set on the actual cases and getting user feedback on the performance of the KPIs. If the feedback reveals that the chosen KPIs list is not satisfactory, new KPIs should be proposed and evaluated through the method described in step 2–4 in an iterative process until the KPI set is suitable.

In the Norwegian setting, feedback on the 21 chosen KPIs from step 3 was obtained through group interviews with the users (project participants, users from the two municipalities, scientific experts, energy consultants and representatives from

organizations working for energy efficiency and smart communities) and by testing the KPIs in the pilot projects Ådland and Furuset.

The testing of the KPIs was done by implementing the KPIs in a scenario calculator tool developed in the PI-SEC project called “PI-SEC Scenario Calculator Tool” (Walnum et al. 2019). The purpose of this tool is to collate information about the current status and planned development in a community and calculate the KPIs.

Figure 2 shows an example of some results from this scenario calculator, where the KPI “total CO₂ emissions [tonnes CO₂ eq/year]” is tested for the Furuset area in different future scenarios. Here, ‘Initial’ shows the current situation in Furuset. ‘Baseline’ is a reference scenario with a business as usual development. ‘S01’ and ‘S02’ are two proposed development scenarios with different ambition levels, and the Goal column shows the overall goal for the neighbourhood on the KPI.

12 qualitative group interviews and workshops were conducted between September 2017 and March 2018 in order to receive user feedback on the chosen KPIs and on the scenario calculator tool. The number of participants in each interview varied from 2 to 13 people. Notes were taken during the interviews, and some of the interviews were transcribed, categorized, and analysed.

In the pilot cases it turned out that some of the KPIs were not as available or measurable as first predicted. These KPIs were re-evaluated. Examples of KPIs with currently no information or little relevance were; “number of filling stations with fuel from renewable sources for public access”, “peak load consumption”, “peak load production” and “use of secondary heat”.

The user feedback on the KPIs focused mainly on mobility, environmental impact of materials, and emission factors. The municipalities were especially interested in KPIs on mobility. A suggestion from Oslo Municipality was to include more KPIs related to public transportation:

Now you are into something central; transport is very expensive, and we must make it green. That is what governs these plans the most. We have little influence on the development in the building sector, but we can have a strong influence on local transportation. (Municipality)

Based on these inputs, KPIs for mobility were included in the final KPI set.

There were also discussions in the feedback meetings on whether the environmental impact of materials should be included as a KPI. The energy consultants evaluating the KPIs and the Scenario Calculator stated:

It is essential to include materials. However, it is OK that this is calculated outside of the tool and is implemented as kgCO₂/year. (Energy consultants)

As an initial solution, an option to supply emission data for buildings (rehabilitation or new buildings) as a total value per year of the building lifetime was added to the KPI set and the scenario calculator.

When “Step 4: Feedback from the users” is conducted according to a regular planning process, instead of as a part of a research project, it is suggested to have 2–3 meetings with key planners/users for feedback on the KPIs.

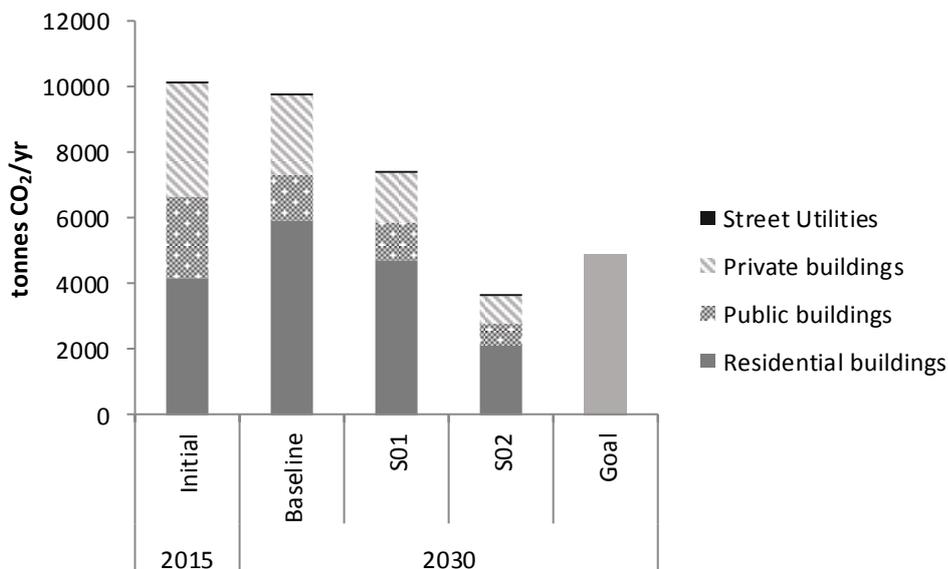


Figure 2. Example of results from the scenario calculator for evaluating KPIs in development areas.

Table 3. Chosen KPIs for the Norwegian setting.

KPI (high level)	KPI unit
Energy use total	kWh/m ² , /inhabitant, /user
CO ₂ emissions	Tonnes CO ₂ -eq, /m ² , /inhabitant, /user
% of renewable energy sources (RES) in district heating	% of total mix
% of buildings with Energy Certificate at each of the grades	% of total stock
Installed Capacity of renewable energy sources	kW, /m ² , /inhabitant, /user
Generated energy by renewable energy sources	kWh, /m ² , /inhabitant, /user
# Buildings with installed Solar PV	Total number
# Buildings connected to a thermal district infrastructure	Total number
% of travel by bike, walking or public transport	% of each mode of transport
# fossil free construction sites	Total number
Registered oil boilers	Total number

Results: KPIs selected in the PI-SEC project

After completing this iterative process of selecting suitable KPIs to be used in the PI-SEC Project, the KPIs listed in Table 3 were selected for the PI-SEC project. In addition, the KPIs were split into relevant sub-categories not listed here. The sub-categories are e.g. thermal and electric energy demand, energy source, building type/ownership, mode of transport. The energy and emission data are split into the categories “stationary”, “mobility” and “embodied”.

Discussion: Experiences and challenges related to the selection process

In this article, a new methodology for selecting KPIs to be used for planning and monitoring of smart energy communities has been proposed, and the method has been applied to a Norwe-

gian setting. The proposed method has proved to be applicable in a real-life case, but there were some challenges linked to the process.

The method involves using multiple attribute decision making (MADM) methods for selecting suitable KPIs for a project from a set of possible KPIs. Using the MADM-method has a few challenges:

Using the MADM-method for selecting the most relevant KPIs for the project turned out to be a useful way of structuring the selection process, but the researchers considered that rating all the KPIs against the chosen attributes was a time-consuming task. As only the most important attributes were applied in the selection, the complexity of the task could be reduced by considering fewer attributes.

All of the attributes chosen in the example application were qualitative attributes. In order to be able to compare the KPIs

with the MADM method, the attributes had to be synthetically quantified based on subjective evaluation. Due to this, when the chosen attributes are qualitative the MADM-methodology works better as a tool for stimulating discussions of possible KPIs than directly choosing KPIs.

The involvement of stakeholders revealed some opportunities and challenges linked to obtaining user feedback: The researchers wanted to include the stakeholders and users more in the process of selecting possible KPIs for the project (step 2 and 3). This proved to be challenging, as step 2 resulted in a very large list of possible KPIs, and the task turned out to be overwhelming for the users. It proved necessary for the researchers to spend more time than the users on these steps, in order to select and evaluate the initial set of KPIs in the project.

The users were crucial for identifying important KPIs related to their work challenges, but the researchers experienced that the users rarely considered the bigger picture. Having a broader view in mind is important when choosing the most suitable KPIs. However, it is important to note that the KPIs used by the key stakeholders daily are (mostly) highly relevant for local energy planning.

The researchers had ranked “relevance” as the most important attribute, but the feedback from the users gave the impression that “availability” may be as important to the users. This was corrected for in the testing of the first set of chosen KPIs by removing the KPIs that proved to have low availability of data. This could have been avoided by involving the users more in step 3 during the ranking of the attributes (decision criteria).

The visualisation of different KPIs, such as energy use and production, proved to be a motivating factor and a useful experience for different user groups. A great challenge in the process of identifying KPIs and developing a scenario calculator has been to find the relevant municipal employees working with tools that map overall energy use and related emissions. Collecting data/information for the tool is time consuming, and the responsibility for monitoring and evaluating energy and GHG emissions is unclear. Even if the municipalities legally have the responsibility for energy supply, many municipalities transfer this responsibility to private- or intermunicipal companies, which may have more experience and competence. The result of this transfer of responsibility from the municipality to private actors is that the municipalities may not have employees with the requisite experience or competence on energy and GHG emissions.

The final KPIs chosen for the scenario calculator in this research project were based on what is legal and technically possible in Norway today. In the future, it may be possible to obtain more information through monitoring and instrumentation, and this might change which KPIs that are most relevant. As area planning often takes many years, sometimes decades, the KPIs should be general and not limited to the use of specific technologies, as this can change quickly.

The application of the methodology to the Norwegian setting resulted in a list of KPIs that can be used in a range of Norwegian local planning projects. This list can hopefully be used for many applications to reduce the workload of future projects where KPIs are needed. The final list of KPIs found for the Norwegian setting is long, and not all the KPIs listed may be relevant for all applications. In these cases, it might be helpful to apply steps 3–4 from the methodology on the proposed

list of KPIs for the Norwegian setting. The choice of KPIs is project-specific, but the method for selecting KPIs as presented in this article can be applied to many other projects. The methodology has proved to be applicable to real life case studies and may be a helpful methodology for selecting high quality KPIs that are relevant to specific goals.

Conclusion

KPIs are helpful and essential tools for planning and monitoring the development of smart energy communities. This article has presented a new methodology for selecting the most relevant KPIs for monitoring the transition of local communities towards low carbon communities. The methodology consists of the following main steps: 1) Identify the relevant objectives and goals at different scales. 2) Conduct a literature study to identify possible KPIs that can be used to describe the performance on the goals and targets identified in step 1. 3) Select the most relevant KPIs through the method of Multiple Attribute Decision Making (MADM). 4) Acquire user feedback and perform the process iteratively until the chosen KPIs can be used to measure the progress on the project goals and targets.

The methodology has been applied to two Norwegian cases, and the selected KPIs have been tested in a planning tool called the PI-SEC Scenario Calculator, developed to aid an efficient planning process towards sustainable communities (Walnum et al., 2019). The methodology has proved to be applicable to real life case studies and may be a helpful methodology for selecting high quality KPIs that are relevant to specific goals.

The methodology requires getting user feedback, which proved to be both useful and challenging. The users are crucial in identifying important KPIs based on their work challenges, but the researchers experienced that it can be challenging to involve different user groups, and that the feedback from the users failed to identify KPIs for the general case of transitioning communities towards low carbon communities.

The hope is that the development of the Pi-Sec Scenario calculator and the KPIs this calculator is based on (<https://www.ntnu.edu/smartcities/pi-sec/publications>, see “tools”) will make the selection of KPIs easier for further energy smart area planning.

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Acknowledgements

This study is funded by the Research Council of Norway's EnergiX programme (ref. no. 255130/E20). The material reflects the authors' views; the Research Council of Norway is not liable for any use that may be made of the information contained therein. The authors also gratefully acknowledge the support from the Research Council of Norway and several partners through the Research Centre on Zero Emission Neighbourhoods in Smart Cities (FME ZEN).

