COST Action 19126

Positive Energy Districts European Network

Deliverable 3.2

Review methods in the monitoring, evaluation and replication of PEDs and PED Labs

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Executive Summary

The main aim of the report is to present the methodologies used for monitoring and evaluation frameworks of PED or PED relevant projects and PED Labs founded in different parts of Europe. The common evaluation framework defines the Key Performance Indicators (KPIs) for the evaluation of the demonstration projects. At the building scale, the monitoring At the district scale, the assessment and the monitoring will cover the whole area, taking in consideration the interaction of buildings, the common active systems and flexibility strategies. This framework will be implemented during the integrated design and the evaluation of the demo plus energy buildings and neighbourhoods when operational.

Basic definitions of monitoring and evaluation with a general description of the KPI concept are explained in section 2. Different project documents are used besides guidelines like SCIS, Set Plan.

In section 3 the monitoring and evaluation frameworks of Making City, Cityxchange, Pocityf, Atelier, Sparcs and Syn.ikia are briefly explained. There are a lot of similarities between different projects. According to the context, characteristics of cities or the concept of the projects there are some differences which are emphasized in relevant subsections.

Section 4 focused on monitoring and evaluation methods of PED Labs where there is limited information. Since PED Labs are mostly used to try innovative technologies there are not specific targets to be achieved unlike most Horizon 2020 projects. The stakeholders also differ with each technology which makes the governance harder. We have LNEG from Portugal, CEDER-CIEMAT from Spain, ZEN from Norway and Zero Plus in four different countries (Cyprus, France, UK, Italy).

In section 5 we tried to analyse the replication strategies but was able to find limited information.

As an Annex there is a list of commonly used KPIs as well as some project specific ones which can inspire other projects or PED areas. Within Annex 2 a KPI definition template produced from the examples of the projects and PED Labs searched has been included.

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1. Introduction

European Union (EU) has developed a framework that aims to reduce the emissions from buildings by improving the energy efficiency at the building level. The Directive on Energy Performance of Buildings (EPBD) initiated in May 2010 states that a nearly ZEB is a building with a high efficiency in terms of energy utilization and an energy demand that is mostly covered by on-site renewable energy generation (EU Parliament, 2010).

The latest "Fit for 55: delivering the EU's 2030 climate target on the way to climate neutrality" proposes to start applying emissions trading from 2026 for road transport and buildings. Although the system that will be build will focus on the upstream fuel suppliers it is expected to accelerate the transition towards positive energy cities (EC, 2021).

PEDs are still at the innovation stage experimenting the technologies, planning, monitoring and replication strategies. There are good practices thanks to some dedicated cities and EU Horizon 2020 program. Cities have the leading role in the integrated and holistic planning of PEDs, aligning it with their long-term urban strategies (SET Plan, 2018). Knowledge institutions, universities, technology providers (private or public) are the main stakeholders to support PEDs and PED Labs. Within the SET Plan a pathway towards PED has been developed including six modules. Monitoring and Evaluation and Replication are two of these modules.

PED Labs, as seeding ground for new ideas, solutions and services, will be developed according to place-based needs and local context baselines. PED Labs will follow an integrative approach including technology, spatial, regulatory, financial, legal, social and economic perspectives. Based on experiences in the Labs, **PED Guides and Tools** will be developed to support replication and mainstreaming. This includes, e.g. PED definition, national PED certification, a process towards one standard in digital planning, construction, and building information management of PEDs, guides on funding and business models, guides for capacity building and PED planning tools (SET Plan, 2018). Module 4 and Module 5 of the Set Plan is about the topic of this deliverable M&E and replication.

Module 4 PED Replication and Mainstreaming will be driven by cities, including PED development in their city strategies, providing the necessary pre-conditions for PED deployment and the actual deployment and maintenance of PEDs.

Module 5 PED Monitoring and Evaluation on each point of the pathway will help to constantly make improvements and adaptations along the circle. PED Labs and PED Replication and Mainstreaming are by nature driven by individual cities, whereas the development of PED Guides and Tools take place at national and European level and the PED Monitoring and Evaluation activities will be carried out locally, but will be linked and synthesized at national and European level as a support action to speed up the process of PED replication and mainstreaming.

PEDs are a new concept. There are many definitions of PEDs that have been discussed in different guidelines and researches. PED Labs are identified as a specific type of urban living lab for the demonstration of PED technologies and solutions. Although they build on ongoing urban transitions and on proven energy efficiency and renewable energy measures, key innovations in PEDs especially the processes, methodologies and governance issues are still being piloted and the actual benefits are not yet fully validated. Monitoring and evaluation of PED pilots, projects and PED Labs, therefore, is essential. The potential impacts of PEDs cover a range of different domains, from the greenhouse gas emission reduction achieved to the positive social impacts realized in the area. This implies that the monitoring and evaluation approach will encompass a range of different methodologies from different disciplines (EU SCIS, 2020).

According to COST 19126, PED and PED relevant Case Studies are defined as "District-level project with high level of aspiration in terms of energy efficiency, energy flexibility and energy production" (COST_19126, 2020). The project does not necessarily have to meet annual energy positive balance, if it meets at least several other aspects of the JPI UE PED Framework definition which describes Positive Energy Districts as energy-efficient and energy flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructure and interaction between buildings, the users and the regional energy, mobility and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability. On the other hand, COST 19126 also identifies PED Labs as pilot actions that provide opportunities to experiment with planning and deployment of PEDs, as well as provide seeding ground for new ideas, solutions and services to develop. PED Labs will follow an integrative approach including technology, spatial, regulatory, financial, legal, social and economic perspectives.

Partners involved in the COST action 19126, contributed to the Ped Projects Inventory that is developed within WG1. Regarding this research; Atelier, POCITYF, CityxChange, MAKING-CITY, Syn.ikia, SPARCS, RESPONSE, Smart Capital Region programme - Quartier à Energie Positive and EXCESS projects are listed as PED focused projects whereas ZEN, LNEG Portugal, ZERO-PLUS are displayed as existing PED LABs.

Chapter 4 of this report will focus on *Monitoring and Evaluation Definitions and Basic Concepts* which will be guided to Chapter 5 as Monitoring and Evaluation of PED Projects that are listed above. Key Performance Indicators for evaluation of the monitored data are defined and listed in these sections. Chapter 6 focuses on Monitoring and Evaluation of PED Labs. Since PED concept is new in the market and research area, there is still not so much research on replication strategies. Projects, case studies and LABs are being designed and developed and replication activities will follow afterwards. Section 7 of this report aims to review of Replication Strategies oof Different Projects, PEDs, PED LABs.

2. Monitoring And Evaluation Definitions And Basic Concepts

The European Commission technical definition for monitoring is; using systematic collection of data on specified indicators to provide management and to also provide the main stakeholders of an ongoing intervention with indications of the extent of progress and achievement of objectives and progress in the use of allocated funds (OECD, 2009) (European Neighbourhood Policy, 2021).

Monitoring uses data collected before implementation of the PED and after completion (operational phase). The data range from the energy produced from renewable energy sources to the engagement of the stakeholders. The main question to be answered on the basis of evaluation is whether PEDs could have a significant positive contribution to a city's environmental, economic and social goals, and how they can be upscaled and replicated (SCIS, 2020).

The European Commission technical definition of evaluation is; a systematic and objective assessment of ongoing or completed interventions (actions/policies), their design, implementation and results according to the following criteria: relevance, effectiveness, efficiency, sustainability, impact, coherence and EU added-value. It assesses how well a specific measure has worked (or is working) and whether it is still justified or should be changed.

M&E systems can therefore enhance the implementation of Positive Energy Districts, and increase their visibility and impact. This requires, however, using the M&E results to improve ongoing and future implementations. Key Performance Indicators are widely used to monitor and evaluate if expected outputs are achieved.

Key performance indicators (KPIs) are a proven approach to monitoring and performance-based evaluation. They measure the effectiveness of a project towards the achievement of specific key objectives. The process of selecting KPIs also assists in clarifying the project's measures of success. KPI's are measures that an organisation can use to measure and compare the performance and progress in achieving the predefined targets.

KPIs are associated with a critical goal or a specific target that leads in accurate and measurable results. Each KPI is a metric but not every metric is a KPI; the same metric may be a KPI on one level but not on another. That means that KPIs are a dynamic concept that changes according to the circumstances and need to be redefined in each case (SPARCS, 2020).

KPI's are accepted to be a management tool allowing monitoring of progress, enabling evidence-based decision-making and helping the development of future strategies. KPI's also contribute to the successful communication of results and achievements. However, it is important to remain aware of the limitations and risks associated with the use of KPIs (SCIS, 2020):

1. Limitation. A balance needs to be made between the number of KPIs used and the level of detail and comprehensiveness of the monitoring. It is inevitable that a typical number of 30 to 60 KPIs for complex and broadly scoped Projects cannot cover all impacts in full detail.
2. Bias in monitoring. In some evaluation areas (e.g energy), it is easier to clearly define quantitative impacts, based on metering. Other areas are more difficult (e.g. citizen engagement). The risk is that in evaluation, more attention is paid to the "easy" impacts, which are not necessarily the most important ones.

3. False sense of accuracy and precision. For example, an outcome that a PED pilot achieves in terms of a certain surplus in annual energy can only be interpreted with insight on the level of ac-curacy (range of uncertainty) and precision (systematic errors), for example, if the energy surplus appears to be 2% but the error and/or uncertainty range is 5%, claiming the PED status cannot be done for sure.
4. Uncertainty in the baseline. A critical starting point in any monitoring and impact assessment is the assumed baseline: what would happen with the district without the PED project? Often, the baseline is based on the current situation and business-as-usual.

When we review the best practices, it can be said that both top down and bottom-up approaches have been used in choosing the KPIs selected. Top-down approach examines other EU standards and smart city projects to come up with a proposal that will facilitate the communication with smart city platforms and networks while bottom up moves from specific data being gathered at the demonstration areas to answering the evaluation questions (Atelier, 2020). Most of the projects have gone through the KPIs used in certain guidelines (CIVITAS, Citykeys, SCIS, etc.) or previous smart city or PED projects to be able to benefit from their experiences. In most of the guidelines the KPIs characteristics are described as;

1. Relevant: Indicator should have a significant importance for the evaluation process and serve as much as possible the ATELIER objectives and city (LH and FC) needs. The indicators should be selected and defined in such a way that the implementation of the smart city project provides a clear signal in the change of the indicator value.
2. Available: Data for measuring the indicator should be easily available (limited time and effort needed). Indicators should be based on data that will be provided by the data owners (developers, solution providers, etc.) or collected from a deployed sensoring system or open (public or private) services.
3. Measurable: The indicator should be capable of being measured, preferably as objectively as possible. Indicators that seem to be too much disturbed by interventions not directly linked to ATELIER action would be avoided.
4. Reliable: The definition of the indicator (and the calculation method) should be clear and not open to different interpretations. ATELIER's indicators will be common to the two LH cities and their corresponding PEDs. The calculation method might be slightly different in terms of the frequency of measurements, specific variables considered, etc. We will make these differences clear and try to minimize them.
5. Familiar: The indicator should be easily understood by users – non experts. ATELIER provides a complete description of the indicators and the references that allow estimating them in a trans-parent manner. The names of the indicators are clear and self-explicative.
6. Complementary: the indicator should keep a low correlation with the others representing a clear differentiable effect or impact and therefore, the indicator provides an added value to the evaluation process.
7. Benchmarkable: the indicator should support comparability to reference values for which it is necessary to provide a clear definition of the baseline (BAU) and if needed other reference values of different sources. The indicator should support to be reasonably aggregated or disaggregated, if necessary, therefore allowing the estimation at different geographical boundaries or temporal scales. As such, the indicator should build on flexibility and transparency of data and calculations, to ensure that the underlying data can be properly used for the parameters, interpretation in relation to comparative values. In addition, the indicator can be subject to normalisation along different dimensions in

order to support benchmarking across interventions and different components of the other SCC or PED projects.

The areas that mostly need to be evaluated by KPIs are the ones where cities mostly have to measure their smart city performance, taking under consideration factors such as (SPARCS, 2020):

Energy: with the usage of indicators covering for example the energy efficiency, the RES integra-tion, CO2 emissions reduction, the air quality, the smart grid stability, etc. The main objective of the all the PED project is to create PEDs that is replicable for the lighthouse and fellow cities. The design of PEDs combines; renewable energy production, increased energy efficiency and flexibility, energy autonomy and zero emissions. Thus, the KPI framework on energy is built to allow the monitoring and evaluation of these different themes.

Mobility: Positive Energy Districts (PEDs) within the Horizon2020 program require interaction and integration between buildings, the regional energy, mobility, users and ICT system. Mobility is important to reduce energy use and greenhouse gas emissions and to create added value and incentives for the consumers. In most projects PEDs increase EV charging opportunities while using local RES where possible to minimise the energy use. Mobility might also create a surplus of energy and be used to balance the local energy system. There can also be KPIs to evaluate the improvement of air quality in the PEDs.

Environment: Energy related greenhouse gas emissions and the reductions because of renewable energy use, energy efficiency (improved insulation, glazing, etc.) and other interventions. Some of the projects are evaluating the interventions from the life cycle perspective taking into account broader environmental impacts on human health and resources. Some projects also takes into account the onsite impacts on human health, water resource consumption, and the well-being of residents/building users. These include selected air pollutants emissions (i.e. particulate matter, nitrogen oxides), water consumption, and indicators that are related to user com-fort or experience in the environment, such as received noise, temperature and humidity.

Economy: Development of sustainable business models is crucial for the replication of the strate-gies to increase PED areas. The KPIs cover measurements for the energy costs reduction, reve-nue streams from market transactions, the energy network investment, the business models vi-ability, the return on investment as well as the incremental payback period, etc.

Social: Social performance is crucial to estimate the extent to which the PEDs facilitates the in-volvement of citizens in the planning, decision-making and implementation activities through so-cial citizen-driven innovation mechanisms. This is crucial for the replication of the projects. Usually indicators used are related with citizen engagement, the user acceptance, the comfort and air quality, number of new jobs created, etc. taken under consideration and

Technology: with indicators for system interoperability, conformance with standards, ICT solutions performance, compliance of functionality to the user requirements being in focus.

Smart city indicators are categorized in different aggregation levels such as city level and project level; but depending on the needs of the project, the categorization can be more specific, including single building, set of buildings and neighbourhood/district. The different approaches will be explained under each pro-ject section. KPI frameworks are usually identified in detail to assist partners, KPI owners, data owners in the calculation. The supporting KPIs help understand better the reasons of the

Generally, the indicators in a smart city context are divided into five types (Arthley&Stroh, 2001, SPARCS, 2020). Input indicators, process indicators, output indicators, outcome and impact indicators. Within the works done by projects most references are made for outcome (project level) and impact (city level) indicators.

Besides the monitored and gathered data there are several calculations that need to be made using different variables to be able to reach the defined KPIs. The KPIs and their definitions can be found in the Annex 1 at the of the report.

Annex 2 is a sample template used by many projects to define the KPIs and how they are calculated to be able to have unified, benchmarkable results. They also work as a guide for the project partners.

Besides the most used KPIs there project specific KPIs in the list. The reason to put some of the project specific KPIs is to be able to inspire the others to include similar KPIs that would fit to their context.

3. Monitoring And Evaluation of Ped Projects

Since the PED projects are evaluated according to monitoring and evaluation results, they mostly have a separate work package related with the subject. The projects are making detailed plans to be evaluated annually on the basis of the monitoring results and the impact assessments carried out under work packages, as well as the assessment of progress of all WPs. When possible, the interim evaluations are supposed to result in internal corrective actions in case the targets are not met by the actual performance. The evaluations are also expected to produce lessons learned and recommendations on PED development, replication and exploitation.

Baseline Approach: When evaluating, savings are determined by comparing measured consumption or demand before and after the implementation of the PED, following the measurement and verification approach specified by International Performance Measurement and Verification Protocol (IPMVP), or with a reference situation, making suitable adjustments for changes in conditions. Good practice requires that the estimation of the baseline is well integrated into the process of identifying, developing, and deploying the interventions implemented within the projects or any other energy conservation measures (Atelier, 2020).

The baseline or reference value represents the state without the interventions being implemented. The PED projects have similar approaches to be followed for baseline values. Baseline calculations differ depending on the application area. In each baseline calculation, the boundary for the analysis has to be clearly defined. For example, when the boundary of the analysis is at an existing building, a baseline refers to the actual situation before the refurbishment, when the intervention relates to improving the energy efficiency or service level of the building. For new building developments, the baseline refers to the business-as-usual practice, which can be derived from building regulations or by utilizing measured data from same type of buildings (Making City, 2020). In these cases, methodologies such as IPMVP (EVO, 2012) can be directly applicable. IPMVP is a best practice methodology commonly used for measuring, computing and reporting savings achieved by energy efficiency projects at end user facilities. This protocol establishes how to perform the evaluation of, for example, energy savings by comparing measured consumption before and after implementation of energy actions making suitable adjustment for changes in conditions (Making City, CityxChange).

The frameworks used, also consider and build upon the approaches to evaluation by other Smart Cities and Communities (SCC) projects.

Some of the project evaluation frameworks identified by projects integrate a traditional performance-based assessment approach together with a reflexive approach. Some of the frameworks consist process evaluation to better understand what is working and what is not working and take in time action for correcting course throughout the project life.

International Performance Measurement and Verification Protocol (IPMVP):

IPMVP is a “best practice” methodology commonly used for measuring, computing and reporting savings achieved by energy efficiency projects at end user facilities. This protocol establishes how to perform the evaluation of energy or other savings by comparing measured consumption before and after implementation of the actions/interventions making suitable adjustment for changes in conditions. Thus, the period prior to the implementation of the improvement measures is selected and the current situation is measured in order to define the “baseline period”. Once these measures are applied, a suitable period of time is determined, and the energy use is once again measured in order to define the “post-retrofit” performance period. Then, the comparison of baseline period and reporting period is done following this general M&V equation:

Appropriate adjustments shall be done by taking into account changes in the existing conditions and calculate the Adjusted-baseline Energy. Adjustments include routine adjustments and non-routine adjustments.

Routine adjustments refer to the so-called Independent Variables, which are parameters expected to change regularly and have a measurable impact on the energy use of a system or facility. Routine-adjustments are usually done by developing valid mathematical models including factors derived from regression analysis correlating energy to one or more than one independent variables, such as outdoor temperature, degree-days, occupancy, etc.

Non-routine adjustments refer to the so-called Static Factors, which have an influence in the energy consumption but are not usually expected to change. In the case of buildings, such Static Factors can include: Amount of space that is heated or air conditioned, building envelope characteristics, such as new insulation, windows, doors, air tightness, etc

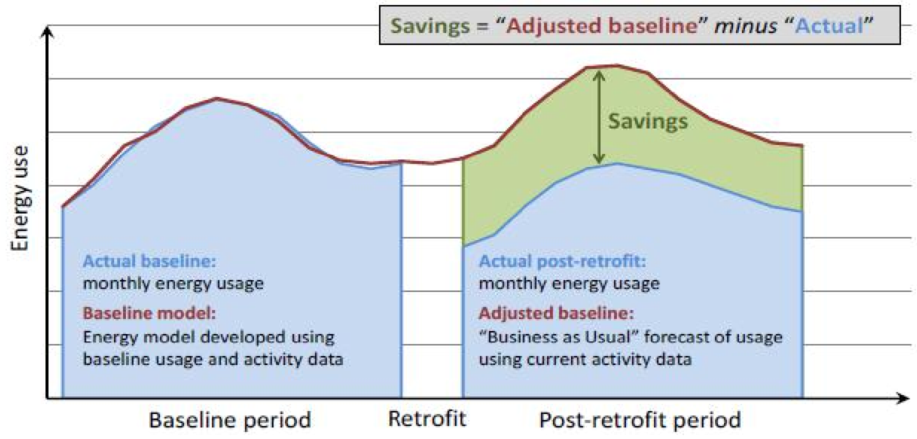

Figure 1: IPMVP Evaluation, Source: EVO 2012

Data Management Plans

All the projects are indicating that they are following FAIR H2020 principles and GDPR regulations when capturing, handling and storing data. At the beginning of the project a data management plan is prepared to identify clear methodologies and shared tools.

The Data Governance Model of the Monitoring and Evaluation methodology is connected with the Data Management Plan. The responsibilities for collecting, storing and sharing data are usually identified in the data management plans.

Data providers and KPI responsibles are obliged for generating new datasets in the context of monitoring and evaluation, and therefore endorse the already established methods as defined in the data management plan. In many cases, Data providers also provide specific datasets which, however, is not necessarily the case for all KPIs and underlying data.

3.1 Making City

MAKING-CITY evaluation framework has been defined to monitor and evaluate the effectiveness of the project actions and interventions, compared to the initial situation, initial objectives and expected results. The main references for developing the evaluation framework and monitoring protocols have been first of all SCIS (KPIs, monitoring guide etc.), but also other recent H2020 funded smart city initiatives including CITYkeys, MatchUP and MySmartLife projects.

The scope of the MAKING-CITY monitoring protocol is twofold, firstly in order to measure the performance of the actions deployed to reach a validation of PED concept and secondly to evaluate the impact at city level. A set of 20 indicators has been defined for each of these two levels and they can be found in the deliverables D5.1 "City level indicators" and D5.2 "Project level indicators".

In the case of quantitative data, it is necessary to distinguish the method of obtaining the city level indicators from those of the project level. The city level indicators are obtained from official sources, local, regional, national databases and city plans. in order to calculate the quantitative indicators at project level, it is necessary to establish a protocol for monitoring the actions implemented in the project, which is presented in this deliverable and is detailed for each of the demonstration areas in both lighthouse cities.

The KPIs have been divided into five main categories: Energy & Environment, Mobility, Economy, System flexibility and Social & Residents. On the other hand, project actions have been divided into four categories: High performance buildings, Renewable energy systems online, Other technical actions and Non-technical actions.

The starting point for selecting project level KPIs has begun with analysing the scope, objectives and focal target points of the project; what kind of indicators are needed to keep track on the performance of the PED areas, and what is most relevant in these cases. The next step was to analyse the BEST tables, the project objectives, and the list of PED actions and interventions, comparing them to the main reference indicators systems. In the comprehensive evaluation process, it is more reasonable to concentrate on larger action categories and applications areas, and not so much on single actions. In many cases, it is not feasible to monitor actions at individual level, as they are usually part of some larger complex or entity, e.g. actions related to building retrofitting.

Monitoring programme concentrates on monitoring all the incoming and outgoing energy flows for each building of the district and for the whole district separately. Monitoring must handle all the energy types that flows to building/district at own pipes separately (e.g. electricity from grid or thermal energy from district heating pipes or gas from gas pipes). The focus of Making City project is on the performance of the PED areas.

SCIS Technical monitoring guide defines four monitoring phases for quantitative data (SCIS, 2018b):

1. Definition

2. Implementation

3. Monitoring

4. Voluntary long-term monitoring

Monitoring of qualitative data consists of the following phases following the guideline of SCIS:

1. Context definition

2. Selecting the techniques, approaches, and tools

3. Collecting the data: The first data collecting phase is implemented right in the beginning. The purpose is to research residents' current status, consumption behaviour, expectations, motives for changes in their behaviour, etc.

The feedback data collection is implemented in the later phase of the project, collecting detected and actual results; what are the concrete changes, how satisfied and pleased the people are and how succeeded the goals of the project were.

4. Analysing the data

3.2 CityxChange

CityxChange project sees M&E as an answer to questions on project progress, to see if the implementations of certain project interventions have the intended results, whether something else can be done to achieve the expected goals and objectives. It uses predefines KPIs for ongoing monitoring and assessment.

A standardized approach to M&E is applied in the project using a KPI Framework specifically developed to assess the performance and success of demo interventions in achieving the targets. The framework has 33 KPIs across three main themes; integrated planning and design, common energy market and communityxchange to analyse the project results. The defined calculation methodologies and parameters of each KPI are to be applied throughout the project lifecycle to ensure that data is monitored consistently and accurately. The three main themes and relevant KPIs differ from most of the projects with more focus on governance, social and economic impacts in the cities with less technical KPIs related with the project areas.

Within the project there is a KPI framework with roles identified as KPI owner who takes the lead in the implementation, testing and monitoring of the interventions implemented within the demo projects, have the responsibility for the monitoring of a specific indicator. Data owners, are parties that act as complementary partners to KPI owners. They are technical experts to provide technical support, tools and data that assist in the implementation of certain interventions. This support contributes to the success of the intervention. Data owners are also responsible for the management of data monitored during the project. Each KPI has an agreed calculation method for all LHCs and FCs to be consistent, accurate and comparable.

The project is following the SCIS monitoring guide defining four phases of monitoring over the project lifecycle. Phase 1: being the definition section, Phase 2: Implementation, Phase 3: Monitoring Phase 4: Long Term Monitoring.

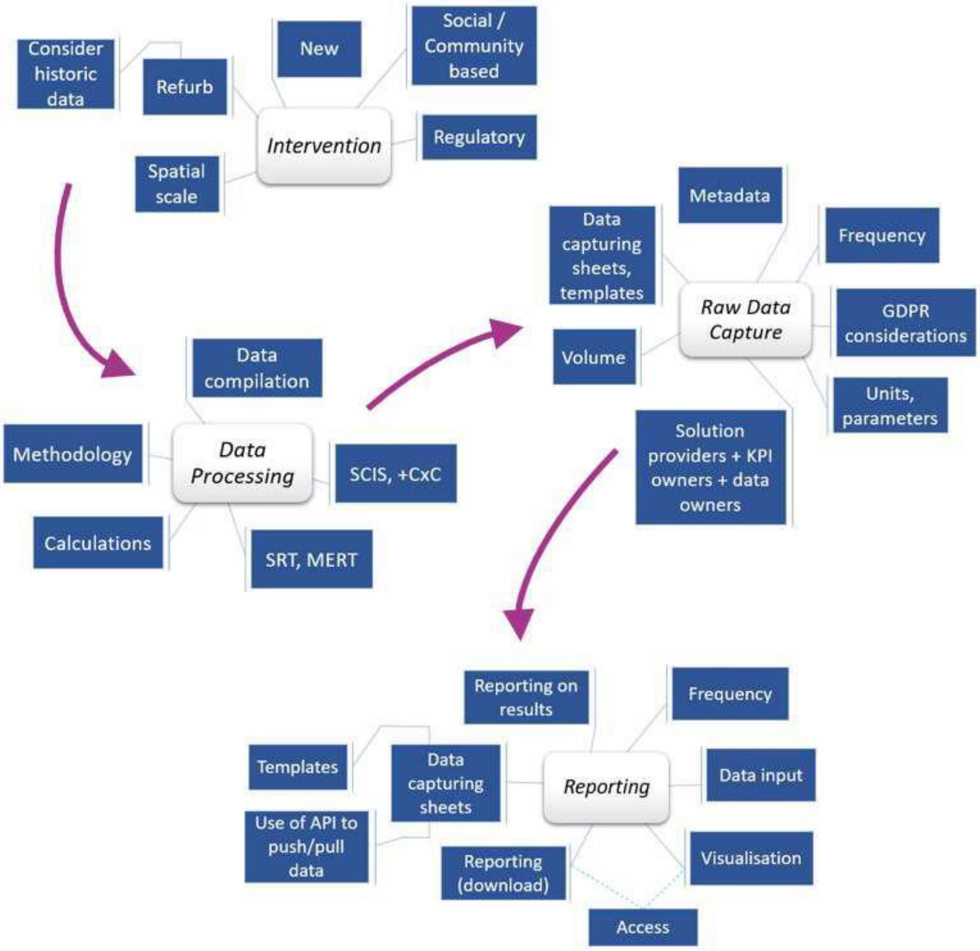

Figure 2: Data Capturing and Reporting Process of CityXchange, 2020a

The project has standardized meta data collection sheets including description, scope, quality and validity, KPI – Data owner details, additional solutions provider and many details regarding the data.

Defining the system boundaries and temporal scales

Within the DoA of the project there are references to spatial scales of project interventions, reporting and analysing in different ways. The spatial scales are explained briefly below.
Sub-city District: is divided into three.

- Demonstration site where building and street level where interventions are implemented.
- Demonstration area where several project interventions are executed.
- Demonstration district can contain several demonstration areas.

City Level: Analyses the project results at a broader level.
Project Level: The aggregation is at highest level on expected impacts. Results are aggregated to show the total impact of the project.
The data will be stored in an open platform MERT, a project specific online dashboard that will provide visualization of the aggregated data. The platform will capture, store and model the data inputs. The format of each data is defined to be consistent for all KPI owners.
The KPIs selected by CityxChange, for monitoring and evaluation differ a lot from the other similar project.

Evaluation Framework

The evaluation strategy has been collectively agreed upon to measure the important aspects of each demo projects. Although the definition, core aspects and parameters of each KPI has been predetermined the calculation methodology might differ to be able to adapt to local context.

3.3 Pocityf

The definition of POCITYF related KPI dimensions is of utmost importance for a holistic identification of appropriate indicators: the selected KPIs cover the four Energy Transition Tracks (ETTs), as well as the main stakeholders' groups of POCITYF and reflect LH city needs. Eight (8) dimensions have been defined: a) Energy; b) Environmental; c) Economic; d) ICT; e) Mobility; f) Social g) Governance; h) Propagation.

The integrated Solutions (IS) are aggregated to Energy Transition Tracks. The KPIs need to provide metrics for monitoring both the performance and impact of each IS as well as a more holistic picture of the progress. There are 4 Energy Transition Tracks (ETTs) defined in the project.

1) Innovative Solutions for Positive Energy (CH)Buildings and Districts
2) P2P Energy Management and Storage Solutions for Grid Flexibility
3) e-Mobility Integration into the Smart Grid & City Planning
4) Citizen-Driven Innovation in Co-creating Smart City Solutions

An initial KPI pool has been reviewed and reduced based on transparent criteria: the indicators relevance to the project needs and objectives, availability of measuring data, measurability, reliability and familiarity by non-experts. The list contains 63 indicators.

Output-oriented KPIs; are concrete indicators for monitoring the progress and effectiveness of implementation (e.g. specific yield, Improved data privacy) The assessment level can be performed under the Integrated Solutions and Energy Transition Tracks clustering.

Impact (outcome) oriented KPIs: These indicators should assess the benefits of interventions as well as the higher-level goals to which POCITYF will contribute (e.g. Energy Savings, Greenhouse gas emissions). The KPIs assessing the impact-oriented evaluation level are extremely important as they can be considered as the end-result POCITYF is pursuing, through its implementation activities.

The spatial level of indicators for POCITFY does not differ significantly from the other projects.

Building level: The assessment boundary in the building level integrate the energy needs per area of application (heating, cooling, DHW, etc.), energy technologies supplying these energy needs, energy storage units, delivered energy to each energy supply unit per energy carrier, ICT measures at the building level, mobility measures at the building level and socioeconomic measures at the building level.

Building Block (set of buildings/PEB) level: The assessment for a set of buildings is done by aggregation of building units. The indicators can then be calculated for the sum of the buildings as a group.

District (PED) level: The level of district is composed by the aggregation of different entities. Indicators can be calculated for the sum of these entities along with district specific KPIs relevant to mobility, ICT measures, socioeconomic and environmental aspects. The boundary of the district and corresponding energy flows must be defined properly. Following SCIS, the information is required to define the energy system comprises: a) Energy carriers used at the implementation area level and the primary energy factors corresponding to this area b) Demonstration units involved (buildings, energy supply units (ESU), storage units and distribution systems) c) Delivered energy to each ESU and building allocated to the corresponding energy carrier d) Output energy of each ESU and, if applicable, output energy exported out of the boundary allocated to the amount of delivered energy carrier e) Energy flows between technologies and buildings (which ESU is supplying which building or ESU). Due to the complexity of these systems, indicators can only be calculated if a full set of data is available.

City level: The scaling to a city level is a complicated procedure as POCITYF solutions target building blocks and districts. Nevertheless, a generalised evaluation on city level can be performed by focusing on the previous granularity levels and projecting impact on a city level. Similar to the description for the District (PED) level, the boundary must be defined properly including all dimensional indicators. Aggregation and averaging methods can be used towards this evaluation.

KPI cards include details of clustering and evaluation levels of the KPIs. The distribution/clustering of the finalized KPIs into Energy Transition Tracks and Integrated Solutions is presented in table formats.

Evaluation Framework

There is a total of 63 KPIs, 32 are impact-oriented while 31 are output-oriented. There is a balance of KPI's that shows the impact and that assess progress and performance. This balance is greatly pronounced in the Technical (7 impact-oriented vs 8 output-oriented), Environmental (5 vs 3), Social (2 vs 3) and Governance (3 vs 2) dimensions. KPIs dealing with Propagation are all impact-oriented (4 vs 0) as they assess compatibility, scalability and diffusion potential of solutions. These KPIs are balanced by ICT ones which are purely output-oriented (0 vs 7) as they focus on ICT progress and performance while the impact of ICT is mainly assessed indirectly under other dimensions (e.g. resulting energy savings).

In the spatial scale of evaluation, 36 (57%) KPIs are to be evaluated on a building level, 38 (60%) on a PEB level, 52 (82%) on a PED level and 55 (87%) on a city level. KPIs dealing with Mobility are to be evaluated only on a district and city level, owing to their broader granularity of application. 29 (46%) KPIs are to be evaluated on all four spatial levels, 7 (11%) on three out of four, 17 (27%) on two out of four while 10 (16%) KPIs on only one spatial level. For example, KPI - E.4 Energy Savings applies to all spatial granules as energy related interventions might be applicable on a building (e.g. BMS), PEB (e.g. PV systems), PED (e.g. DHC) or city (e.g. V2G). Contrarily, KPI - EN.5 Climate Resilience Strategy can and should be evaluated only on a city level as it assesses to what extent the city has a resilience strategy and action plan.

3.4 Atelier Project

Atelier project defines the scope of the evaluation as the full ATELIER project, with two demo cities as well as city vision, replication, citizen engagement, collaboration and dissemination and exploitation work packages (Atelier, 2020).

ATELIER's work package on M&E has multiple **objectives** as it aims at providing the required data for progress and performance reporting of the PED-related measures performed in the project, but it also wants to profile itself as supporter to the other work packages of the project in order to evaluate the effectiveness and status goal achievement of the activities performed in the other work packages, as well as the impacts the PEDs measures achieved. Therefore, WP9 aims at regular feedback provided to the other work packages of ATELIER in order to inform, discuss and evaluate the performance indicators jointly.

Principles of Monitoring and Evaluation by Atelier Project

- Monitoring is instrumental for evaluation
- Transparency of the M&E framework for all stakeholders
- Shared ownership across the project by all partners of the project
- Additionality; is the difference of the program or interventions according to the baseline
- Evaluation is used as a feedback mechanism
- M&E framework should be a process instead of a fixed system

Defining the system boundaries and temporal scales

Each of the specific actions and/or interventions implemented in the LHCs or FCs are applied to have a certain impact within predefined and delineated system boundaries. The system boundaries within which ATELIER's KPIs and their baselines will be monitored, evaluated and defined are defined below. Note that a certain indicator or its baseline can be evaluated or defined at multiple scales (or within multiple different system boundaries) if necessary. The KPIs monitored will be in different levels. The definitions, calculation methodologies are all identified in predefined sheets.

City Level: Some actions of the project apply to the entire city, especially non-technical actions. At the same time, and in terms of impact assessment the energy performance of the PED will be estimated with broader boundaries moving from the district level to, for example, the city level.

Project Level: The project level comprises impacts within the project that have been determined in the DoA.

Technology Level: Some of the KPIs need to be evaluated at the technology level, for example, the cost of carbon mitigation can be quantified for each of the implemented technology (eg, solar PV, geothermal network, improved insulation, etc.), so that priorities among technologies can be better understood, considering different local context (e.g. climate, stakeholders, etc). This is especially essential as the financial budget for replicating the smart city solution can be limited, thus in-depth and up-to-date understanding at the technology level is important, and solutions shall be prioritized depending on their performance at the technology level.

There are 33 KPIs with different levels that reflect different aggregation levels, where level 1 deals with overarching project objectives related to the two demonstrators in Amsterdam and Bilbao; level 2 refers to specific objectives of individual WPs and their related interventions and actions. Level one and level two are core KPIs of ATELIER, where level 3 provides supporting information as needed for an in-depth evaluation of higher-level KPIs.

Evaluation Framework

Different from many projects ATELIER have a set of questions to be answered for a better evaluation. Questions taken from the preliminary deliverable can be updated by the end of the project. The project does not just focus on the energy related results as mentioned in the previous parts. The evaluation considers both direct and in-direct impacts of the project both within the boundary of the PEDs and in the broader context at the City/EU level. Direct impacts refer to the expected impacts resulting from ATELIER project interventions whereas in-direct impacts refer to the secondary impacts which occur not as a direct result of the project but are often associated with complex systems and pathways. The questions to be answered are:

1. What are the characteristics of the generic PED design that the demo represents? What is the contribution of the specific technological components/innovations of the demo to its performance? What are essential design elements and what are variations with a certain design?

2. How do the ATELIER demo PEDs perform in terms of GHG emissions and energy positivity? Does the demo have a net energy surplus and zero GHG emission, If not, why not? In conclusion, can the PED concept be validated?

3. What is the (positive or negative) impact of the PED demo on the wider district and city in which it is located? What happens with the area between the PEDs?

4. How can the PED demo be upscaled and replicated within and across cities? If yes, for what kind of cities?

5. What is the contribution of the upscaled and replicated PEDs to the city's long-term targets in energy transition, climate and circularity?

6. How should citizens and stakeholders be involved in PED planning and PED design, roll-out and city planning?

7. What business models are needed to secure roll-out and replication and how can the business case be established

8. How should policy makers and legislators promote and speed up PED implementation and scale-up in city planning? What information and capacity for cities is needed for PED implementation and scale-up?

Atelier project will be using a performance-based approach like most of the others to provide a useful framework for analyzing causal logic and assumptions in the project. It should provide explanations as to why interventions did (or did not) lead to the desired outcomes, and help identify assumptions, enabling factors and stumbling blocks.

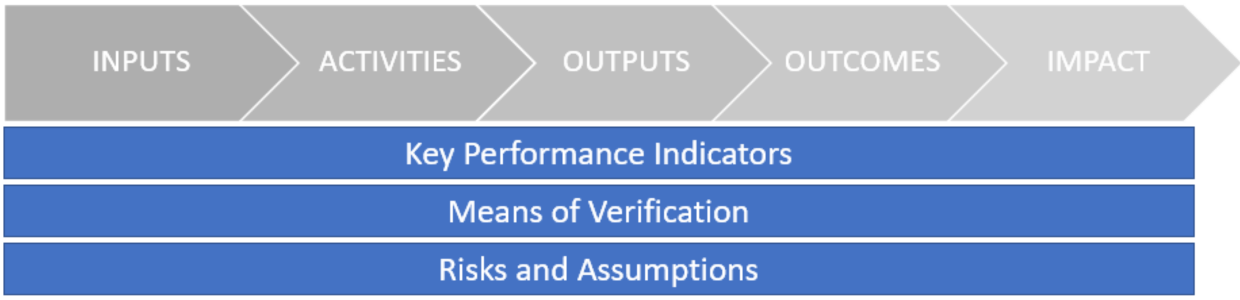

Figure 3: Overview of performance-based assessment approach to evaluation of ATELIER, 2020

Economic impact and business development along with social impact and citizen engagement have a mutual relation with the energy and mobility implementations. The results will be input to the environmental evaluation of the impacts of the interventions as well as knowledge gathered for sharing with cities/EU.

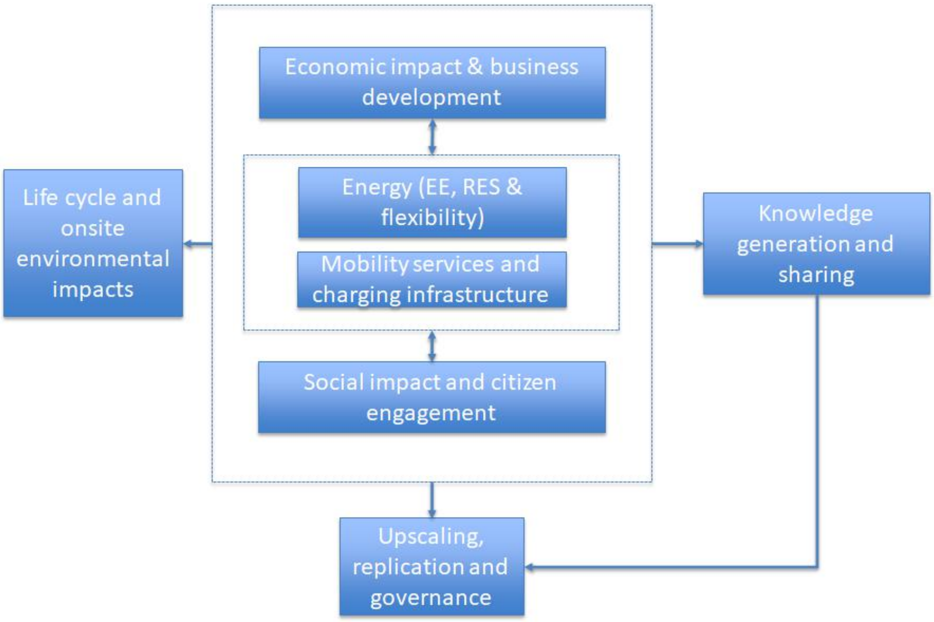

Figure 4: Evaluation Areas of ATELIER project, 2020

ATELIER project related the KPI's of different levels with each work package to be able to evaluate the project as a whole but not just the energy interventions. The predefined KPI explanation sheets provide the answer for specific details like frequency, spatial level, data collection process, KPI formula, data provider, KPI owner, performance driver who can influence the performance being monitored.

3.5 Sparcs

The SPARCS project emphasizes in achieving carbon free urban communities by implementing and integrating actions in various levels such as e-mobility (e-mobility hub), technologies for the energy positivity of buildings and districts (ICT solutions), smart heat, flexible grid management (Virtual power plant), energy storage (regenerative geothermal system, seasonal phase change material thermal storage and big batteries), along with citizen's engagement, smart business models and city governance.

Within SPARCS, a number of 44 innovative interventions consisting of various actions, are applied in the two Lighthouse Cities and focusing on the interconnection between buildings and districts, advanced management and efficiency of RES-generated energy, surplus energy storage, transition to electromobility, development of business models and in Positive Energy Districts urban planning.

Thus, the interventions planned in SPARCS are divided into five demonstration actions and three levels of assessment. These categories are:

Demonstration actions

- Positive energy transformation
- Electrical mobility
- Digital Integration
- New Economy
- Urban innovation ecosystem

Levels of assessment

- Building block level interventions (BBL)
- District level interventions (DL)
- Macro level interventions (ML)

The Building Block Level interventions aim to provide buildings with innovative technologies transforming them to energy infrastructures capable to integrate renewable energy systems, energy storage and electric vehicles. At the same time, existing energy management schemes of buildings are upgraded with new operational functionalities where the energy consumers are producers as well; the main purposes of business and financial models in this level are the participation in multiple alternative markets through the ownership of assets and the increased citizen involvement.

The District Level interventions aim to the optimization of energy use considering behavioural patterns, among the surplus of produced energy in buildings, that are heading towards the district energy infrastructures such as Virtual Power plant and local energy storage. Bidirectional EV-stations are emplaced among the district and thus, e-cars can potentially be used for peak load control. Meanwhile user centric platforms are deployed, and virtual energy communities are established providing a peer-to- peer energy exchange and advanced control of the energy flow.

The Macro Level interventions aim to leverage the demonstrated solutions in building block and district levels in respect of city planning. Regulatory and financial aspects are planned and implemented, while investment projects and actions ensure the successful replication of the demos deployed in a city level. The participation of citizens in urban planning will form the basis for the upcoming innovative ecosystem and will lead to the carbon free city vision.

In order to assess the status quo on sustainable development of any given city the Morgenstadt assessment framework defines KPIs, identifies Key action fields and Impact factors; each one of these three level of analysis, provides different information for the city. The three indicator categories are:

a) Pressure Indicators - indicate which pressures exist on the city system from the different sectors and from the social, economic and environmental point of view.

b) State Indicators - describe the current state of the environment, the society, the economy and the different technology sectors within the city.

c) Impact Indicators - show which impact the city system has on the environment, the society, the economy and long-term resilience.

The target of SPARCS is to develop a methodological approach allowing cities to have at their disposal an integrated strategy that paves the way to effective transformation in their urban ecosystems. Upon the successful realization of the decarbonisation targets of the lighthouse cities, with the deployment of tailor-made interventions, addressing their needs, requirements and ambitions, the key targets are:

(i) the increased integration of renewable energy in the generation process,

(ii) an optimized waste heat management method,

(iii) the optimization of the local energy systems in presence of distributed renewable, storage, demand side management and e-mobility energy resources,

(iv) an improved energy performance of buildings and districts through human-centric building control optimization, advanced retrofitting and optimization of district-wide network operation,

(v) and the reduction of GHG emissions and improvement of local air quality and urban well-being.

These key targets are concretized into economic, environmental, social and technological aspects, captured in project's contract via general impacts and eleven supplementary impacts, planned to be evaluated in the Lighthouse and Fellow cities participating in the project. The initial 29 Key performance indicators are listed within the Annex. The KPI's are derived from the impact analysis performed, accompanied by originating impact and the planned assessment level.

Out of the 29 KPIs identified for the SPARCS project and performing a sequential verification starting with the Morgenstadt framework, 11 were taken from the Morgenstadt framework as part of pressure, state or impact indicators. Another 11 are used in the context of SCIS, CITYKeys, CIVITAS or the Triangulum frameworks. 7 KPIs are not in use from any of the analysed assessment frameworks and could be considered as enhancements towards their modernization, to capture the needs of modern Smart City projects, such as those of SPARCS.

Evaluation Framework

Evaluating the project execution needs to be covered by two complementary actions, namely the impact evaluation that was in focus in all previous steps and the process evaluation, which is the object of analysis in this step. SPARCS is the only project examined that mentions the Mongenstadt framework within European cities. It defines, categorizes and forms a KPI list, identifies Key action fields and impact factors providing information for the current status of the cities and future potential actions

While impact evaluation includes the evaluation of a wide range of technical, social, economic and other impacts of the measures being implemented by the cities, the process evaluation involves the evaluation of the processes of planning, implementation and operation, aiming to understand why measures have succeeded or failed, including the roles of information, communication and participation. Building upon this objective, the process evaluation procedure targets to develop new findings about factors of success, and strategies to overcome possible barriers during the implementation phase by analysing all relevant information.

The process evaluation will be performed by the lighthouse cities with support of the technical partners and consists of the following activities:

1. Agree on common measures and "focused" measures for impact and process evaluation (LH cities and technical partners);

2. Produce evaluation plans containing a time planning when process evaluation surveys and interviews will take place (LH cities);

3. Provide guidance on process evaluation (Technical partners to LH cities);

4. Collect data for the process evaluation (LH cities);

5. Perform process evaluation on preparation, implementation and operation phases (LH cities with the support of technical partners);

6. Perform "focused" measures process evaluation (LH cities with the support of technical partners);

7. Report to the technical partners in the form of the Measure Evaluation Results Template (LH cities to technical partners)

Process evaluation activities, together with enhancements or changes on the steps proposed from the CIVITAS evaluation framework, will be thoroughly presented in the updated version of the delivery. SPARCS is one of the rare projects that emphasized the e valuation of the process.

3.6 Syn.ikia

The syn.ikia definition of a Sustainable Plus Energy Neighbourhood (SPEN) discloses the main mission of the project according five main objectives:

(a) the net zero greenhouse gas emissions and carbon footprint reduction,

(b) the active management of annual local or regional surplus production of renewable energy and power performance (self-consumption, peak shaving, flexibility),

(c) the cost efficiency and economic sustainability according a life cycle span,

(d) an improved indoor environment for affordable living, well-being and satisfaction for the inhabitants, and

(e) the social inclusiveness, interaction and empowerment related to co-use, shared services and infrastructure.

The common evaluation framework defines the Key Performance Indicators (KPIs) for the evaluation of the demonstration projects which will be implemented at two levels: building and neighbourhoods. The selection of the main assessed categories and KPIs have been based in a holistic and exhaustive methodology which highlights the multiple dimensions when talking about sustainability in districts. At the building scale, the monitoring will be carried out in selected dwellings of the neighbourhoods in each of the four climatic zones and at whole building level. At the neighbourhood scale, the assessment and the monitoring will cover the whole neighbourhood, taking in consideration the interaction of buildings, the common active systems and flexibility strategies. This framework will be implemented during the integrated design and the evaluation of the demo plus energy buildings and neighbourhoods when operational.

Energy security, energy equity and environmental sustainability will be handled by identifying five categories that allow addressing this multidimensionality nature according to the goals of the syn.ikia project and the SPEN definition. The five categories defined are:

- Energy and Environmental, which address overall energy and environmental performance, matching factors between load and on-site renewable generation and grid interaction
- Economic, addressing capital costs and operational costs
- Indoor Environmental Quality (IEQ), addressing thermal and visual comfort, as well as indoor air quality
- Social indicators that address the aspects of equity, community and people
- Smartness and Energy Flexibility

The shift of scale from single buildings to neighbourhoods means also the need to control and fully understand the energy flexibility from clusters of buildings at an aggregated level. A cluster of buildings implies that several buildings can either be located physically next to each other or not be physically connected but have the same aggregator controlling and managing their energy flexibility. An aggregation of the energy flexibility from several/many buildings is thus required, in order to ensure an impact to the energy systems and grids, especially if compared to the limited energy flexibility effect of a single building e.g. in Net ZEBs. Energy flexibility is one of the focus areas of Syn.kia project as it is emphasized by the selected KPIs. Another focus area that differs from other projects is the emphasize on democratization which is also reflected by KPIs like democratic legitimacy and diverse community.

Data preprocessing

The data collected following the assessment guidelines must be go through a standard quality assurance protocol (DQA) before being plugged into the calculations. DQA can be partially automated, but it is also possible for the auditor to perform all tasks by hand. The potentially automated tasks include various missing data measures, while the remaining tasks are compiled as a criteria checklist, all of which must pass for the DQA to pass. DQA must be performed each time a new survey is taken, or a new data source is acquired. DQA is not necessary for mapping and screening, unless they are supplied through third-party, or automated means (e.g. POIs filled up from open-source online GIS, or consultation reports are screened by an NLP engine).

Auditing social performance

Social performance on building/neighbourhood scale is audited by plugging in adequate quality input data to the calculations for each different indicator. The outcomes are either shown as numerical scores, in some cases supplemented by lists of descriptive features. Once the results are published, two steps remain to be taken: (1) setting up target values for monitoring, and (2) optionally expanding the scope of monitoring to audit performance distribution.

4. Monitoring and Evaluation Methods of Ped Labs

4.1 LNEG Portugal

LNEG, an R&D institution, develops research to support public policies and respond to issues emerging from society in the fields of Energy and Geology and Geological Resources.

The activity is developed at national and international level and materializes in support to the State, research under contract and research carried out within the scope of the mission of knowledge and enhancement of the territory's endogenous resources.

One of the projects is related with NZEB_LAB. The vision of NZEB_LAB Research Infrastructure is to set up and consolidate a Research Laboratory Infrastructure, which congregate the existent facilities in Portugal in the domain of the Building Integration of Solar Energy and Net Zero Energy Buildings (NZEB) to serve the National and European Industrial and Research Community to the goal of accelerate the integration of new systems and components in buildings in order to achieve the NZEB concept (LNEG website, 2021).
Through the research developed by NZEB_LAB, the RI strategy aims to develop and promote optimal pathways for achieving zero energy buildings standards, widespread adoption at national level by 2020, of optimized NZEB energy design and operation concepts suited to Portuguese climatic conditions and construction practices, in association with industrial partners.
The studies are focused on several uses of solar energy from power generation (SOLAR XXI), solar thermal systems (LES). The ultimate goal is to introduce technologies for NZEB to be able to provide flexibility to respond to user's needs and become active contributors of energy production in the neighbourhoods and districts.
The team is divided to three activities;

- A1: Coordination, Consolidation and Dissemination and Training
- A2: Research Activities
- A3: Access and Service provided

Although there is not much information about the reports or publications produced the activities suggest that there are studies on the subject for the use of the technologies in different parts of cities.

4.2 CEDER-CIEMAT Spain

CIEMAT (Centre for Energy, Environment and Technology Research) is a public R&D institution assigned to the Ministry of Science and Innovation of Spain. This Centre is focused on energy, environmental and technological research with the aim of transferring knowledge and technology to society, supporting and encouraging innovation and changing the economic model (https://www.ciemat.es/). CIEMAT is composed by five Departments: Energy, National Fusion Laboratory, Environment, Technology, and Basic Research. Within this structure, the Energy Department is made up of five Divisions: Renewable Energy, Solar Platform in Almería (PSA), Centre for the Development of Renewable Energy (CEDER), Combustion & Gasification and Nuclear Fusion.

The Centre for the Development of Renewable Energy (CEDER) is located in the middle-north region of Spain (Soria) and it is specialized in applied research, development and promotion of renewable energy (http://www.ceder.es/redes-inteligentes). Among the facilities of this

Centre is the urban laboratory CEDER-CIEMAT lab whose main objective is to assess the performance of different configurations of energy networks at the district level. This PED-Lab infrastructure is an energy district that covers an area of 640 ha and connects six office buildings with energy generation installations by means of two energy rings: electrical grid (in operation phase) and thermal network (in the implementation phase).

The buildings of this PED Lab can act as energy demanders or suppliers depending on the climatic and operational conditions. The majority of these buildings are constructed with conventional technologies but some of them are implemented efficient measures. These buildings are operated as offices although its versatility allows it to simulate various load configurations.

The electrical grid incorporates different distributed generation systems, electricity storage and flexible loads (Figure 5). Generation systems are at low voltage and are divided into two types: adjustable and non-adjustable. The first typology is made up of renewable systems: one 50 kW wind turbine and eight different photovoltaic systems with a total energy production of 116 kW using monocrystalline, polycrystalline and thin film panels. The second typology consists of an engine generator of 100 kVA and a reversible hydraulic system. The storage systems are made up by one pumping system and batteries systems (lead-acid and lithium-ion). The analysers used provide systems consumption data.

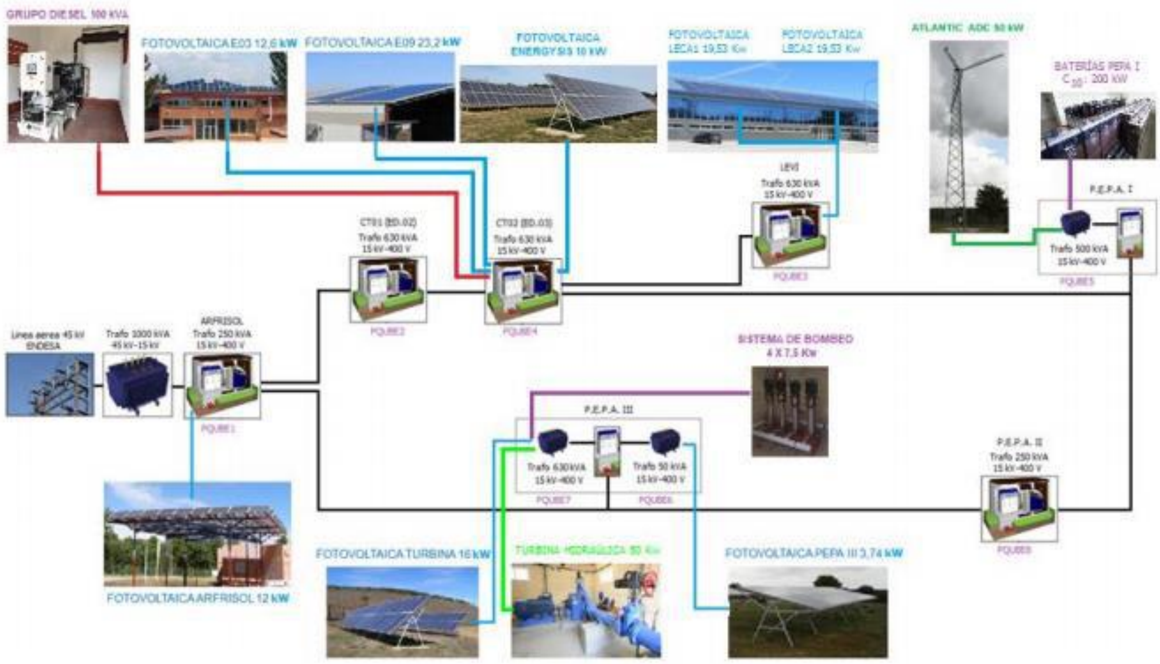

Figure 5: Electrical grid scheme of CEDER-CIEMAT

(Source: http://www.ceder.es/instalaciones-*redes)*

The existing thermal network is composed by two 300kW biomass boilers and 90 kWh water thermal storage tanks. This network will shortly be expanded with the integration of an existing bioclimatic building equipped with 70kW solar thermal panels. Two thermal rings will be developed (Figure 6): low temperature (90ºC) and high temperature (150º-250ºC). The low-temperature ring is made up by two Stirling engine cogeneration boilers (Synthetic gas 20kW thermal, 1kW cogeneration). One of them is a biomass gasification boiler and the other one is a gas boiler (propane 14 kW thermal, 1kW electric). The high-temperature ring has a thermal generator made up of Fresnel solar concentrators and an ORC cogeneration system fed directly from the solar concentrator. Thermal oil is the fluid that circulates through this high-temperature installation. The high-temperature ring is interconnected with the low-temperature ring through an oil/water heat exchanger. This network has thermal storage systems in the modalities of: aquifers, boreholes, phase change materials, cold storage with geothermal exchange ground recovery and thermal storage at very low temperature with zeolites.

Figure 6: Thermal network developed in CEDER-CIEMAT (Source: http://www.ciematr.es)

These facilities have been granted considerable flexibility, and are able to operate in different phases with different configurations, meaning they can adapt to the requirements that must be demanded of a “test bench”. A control system is also connected to the central node, so by combining all these systems and infrastructures, it is possible to design and perform virtual analysis, or test strategies for ICT, related with district installations or decentralized facilities. The optimization of different energy configurations is carried out by combining experimental campaigns in real conditions of use and theoretical models.

4.3 Zero Emission Neighbourhoods Research Centre

Norwegian University of Science and Technology (NTNU) Energy is one of the four strategic research areas at the Norwegian University of Science and Technology (NTNU) in the period 2014 - 2023. NTNU Energy represent the energy research at NTNU with its 600 researchers.
One of NTNU Energy's central activities is to establish and support interdisciplinary research teams that address energy related issues in society. NTNU Energy host nine such teams within the research fields of hydrogen, battery, on- and offshore wind power, CCUS (carbon capture, utilisation and storage), low- and middle-income countries, society, smart grids, solar energy and hydropower.
In addition, NTNU hosts three Research Centres for Environment-friendly Energy Research: Hydrocen on hydropower, NTRANS on the role of the energy system in the transition to a zero-emission society, and **ZEN on zero emission neighbourhoods** in smart cities.
In the Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN research centre), a neighbourhood is defined as a group of interconnected buildings with associated infrastructure 1), located within a confined geographical area 2). A zero-emission neighbourhood aims to reduce its direct and indirect greenhouse gas (GHG) emissions towards zero over the analysis period 3), in line with a chosen ambition level with respect to which life cycle modules and building and infrastructure elements.

The research question that needs to be answered by the research center is; how should the sustainable neighbourhoods of the future be designed, built, transformed, and managed to reduce their greenhouse gas (GHG) emissions towards zero?

The scope of the ZEN definition includes the following seven categories, whereby each category may have a set of one or more assessment criteria and for each of those a set of key performance indicators (KPIs). The categories were chosen by stakeholders through a set of workshops (ZEN, 2021).

- **Greenhouse gas emissions (GHG):** in this instance refer to greenhouse gas (GHG) emissions expressed in terms of kg of CO2 equivalence calculated according to the IPCC AR5 report in a life cycle perspective. Direct GHG emissions are those taking place directly from a source as consequence of an activity resulting in the GHG emissions, whilst indirect emissions are those occurring through indirect pathways. For example, the GHG emissions from driving a car includes not only the direct GHG emissions that come out of the exhaust pipe, but also the indirect GHG emissions that take place when oil is extracted, shipped, refined into fuel and transported to the petrol station, and also the indirect emissions caused by producing, using and disposing the car.
- **Energy (ENE):** In physics, energy is the potential to perform work, or the amount of work performed over a period of time. Mathematically, energy is the integral of power/load over time. In relation to an energy system (e.g. electricity or heat), energy is the load on the grid over time and is measured in (kWh).
- **Power/load (POW**): In physics, power/load is the instantaneous rate at which work is performed. Mathematically, power/load is the time derivative of energy. In relation to an energy system (e.g. electricity or heat), power is the instantaneous load on the grid and is measured in (kW). It may also refer to the average value of energy in one hour, and should then be measured in [kWh/h].
- **Mobility (MOB):** In this context, mobility refers to inhabitants' and other users' transport patterns within, to and from the neighbourhood. Holiday trips and goods traffic are included.
- **Economy (ECO):** In this context, economy refers to economic sustainability, expressed mainly in terms of life cycle costs for buildings, energy and other infrastructure within the neighbourhood, as well as total life cycle system costs from the surrounding energy system. Some other economic aspects will be covered in the innovation category.
- **Spatial Qualities (QUA): In** this context, spatial qualities refer to a neighbourhood that is connected, mixed and have access to a diversity of urban attractions. It also refers to the process, the stakeholder
  dialogue, and the use of local knowledge in planning and design.
- **Innovation (INN):** Innovation in ZEN is broadly defined as new or improved products, services, processes, organisational forms and business models that is utilized to gain value creation or be useful
  to society. Innovation is further defined and specified in an innovation strategy and workplan.

Most of the KPIs selected by ZEN are similar to other smart city or PED projects. The main difference is the ones related with spatial qualities like demographic needs and consultation plan (qualitative), proximity to amenities and public space (qualitative) KPIs. And for economy ZEN project is looking at Life Cycle Cost of the interventions, solutions.

The ZEN Research Centre has nine pilot projects spread over Norway. They are test areas that aim at reducing their greenhouse gas emissions towards zero within their life cycle.

Serving as innovation hubs, the tests for new solutions for developing zero emission neighbourhoods are made. The pilot projects reflect the interdisciplinarity of the center as different parties are working together: building professionals, property developers, public authorities, energy companies, building owners and users, and of course our researchers.

They include both new and well-established areas that will be upgraded and developed further, involve more than 30.000 people, and cover more than 1 million m^2. Campus-Evenstad; Furuset-Oslo, Zero Village-Bergen, Knowledge Axis-Trondheim, Ydalir-Elverum, Airport re-development-Bodø, Mære agricultural school-Steinkjer and Fornebu-Bærum.

The publications from each test bed provide insight for Norway to develop zero emission neighbourhoods (Fmezen, 2021). The publications are mostly about the technical work done, the performance results, lessons learned from different aspects of the work done in the areas. According to the context of the demo areas the KPIs do not cover all the seven categories for each area. For example; Campus Evanstad focuses on energy, power and innovation while Fruset Oslo focuses on energy, power and economy.

4.4 ZERO PLUS

The aim of ZERO-PLUS (Acronym of "Achieving near Zero and Positive Energy Settlements in Europe using Advanced Energy Technology") research project is to search for buildings design for new highly energy performing buildings (H2020-EE-2015-1-PPP). In this project, a comprehensive, cost-effective modular system for Net Zero Energy (NZE) settlements is trying to be developed and implemented in a series of case studies across the EU (Zero Plus, 2021).

In ZERO-PLUS, the challenge of significantly reducing the costs of NZE settlements will be achieved through the implementation of three parallel strategies:

Increasing the efficiency of the components directly providing the energy conservation and energy generation in the NZE settlement.

Reducing initial costs through efficient production and installation processes and use of less material and space for energy conservation and energy production.

Reducing operational costs through better management of the loads and resources on a district scale rather than on the scale of a single building.

There is a smart lab in Dalmine, Italy is a unique facility where the most pioneering technologies are experimented, researched and simulated. The lab demonstrates the integrated operation of a vast range of products and systems for electricity transmission and distribution and for industry, made in ABB. Thanks to different types of installed and interconnected components, technicians can simulate the behaviour of radial, meshed and rural electric distribution networks, the components and systems in home automation installations, data centers, management of installed systems and energy efficiency.

There is also a Robotic Lab where a number of ZERO-PLUS technology products were considered for mock-ups to offer a good visual representation of how would real installation system look like, to demonstrate the assembly strategy and to give the opportunity to practice the assembly procedure while learning from it. In addition, the mock-ups can help the architects and installation engineer to understand the installation procedure of these technologies for real construction projects.

The monitoring and evaluation framework of ZERO PLUS supports the following activities (Gobakis, 2016); Assessment of the performance of the involved systems and technologies and also the global energy and environmental performance of the ZERO PLUS settlements.

- In depth analysis of the results of the monitoring and generation of proper technical information for future feasibility analyses and design.

- Development of the ZERO PLUS monitoring platform based upon the monitoring protocols for the energy production technologies and subsystems developed for building and for settlement level.

Web-GIS platform is being developed for the gathering and sharing of the collected data from all the case studies so that the information flows are easily managed and interpreted, by means of spatial thematic maps related to specific levels of information within the case studies. Smart interoperable sensor networks installed in the four case studies' buildings, districts and energy subsystems will formulate the physical layer of the monitoring platform. The Web-GIS platform is designed in the following levels for each case study:

- Level 1: Indoor Environmental Quality of Buildings' Users. This includes thermal comfort (assessed by Predicted Mean Vote (PMV) and Percentage of People Dissatisfied (PDD) indices), visual comfort and indoor air quality.
- Level 2: Energy demand profiles for buildings and district (public lighting). The measured energy demand and consumption profiles are collected in this level.
- Level 3: Energy production technologies monitoring level. In this level the energy flows within the energy production subsystems for each case study will be monitored. The electrical and thermal parameters of each technology will be gathered and analyzed.
- Level 4: The Case Studies Integrated Resources Management Level and Dashboard. The design of this level will be such as to allow the monitoring of the overall district/case study following smart grid's configurations. The specific level allows the effective management of energy demand and production profiles in order to achieve the ZERO-PLUS objectives.

5. Review of Replication Strategies Of Different Projects, Peds, Ped Labs

When we talk about the replication of best practices, we mean the implementation of a project that has been done in another city. This city qualifies as a *best practice* if it is a manifestation of a combination of superior ideas, excellent strategies, commanding performance and optimal utility of the best practice in the life of the individual or the nation as a whole.' (DELGOSEA project)
According to the EC reports (Ferrer 2017), Innovations in general face a day of reckoning, the moment where the costs of entering the market and upscaling simply cannot be overcome. Lack of venture capital, market failures and other barriers can bring the process to a halt. This is not only a reality for smart city solutions, but because of their nature, the number of barriers is often far higher than in many other areas of innovation.
Overcoming barriers in terms of financial and economic, technological, administrative and regulatory, social and stakeholder uptake factors, is difficult in different EU contexts. Fulfilling the gaps for identifying technologies and innovations need substantial support directly aiming at producing plans and arrangements or designs for new, altered or improved products, processes or services. For this purpose, innovations include prototyping, testing, demonstrating, piloting, large-scale product validation and market replication (EC, 2021)
The Smart Cities Information System (SCIS) experience outlines four main clusters that need to be taken into systematic consideration when approaching a replication project:

- Technical
- Financial & Economic
- Regulatory & Administrative
- Social (with specific attention to stakeholders' uptake issues).

The replication strategy of DELGOSEA project is grouped into three topics: preparations, replication, and enabling environment. All these topics contain subcategories. While the second topic discusses the actual replication process and monitoring, the other two form the framework of a successful best practice replication, namely: preparations and sustainability. The steps and tools used mentioned here have been applied in the process of the DELGOSEA project. All 16 pilot cities, which replicated best practices from different countries under the DELGOSEA umbrella, followed these step-by-step instructions. Experts with from various areas within local governance and project management assisted in creating this holistic approach. Due to the transnational character of the project, best practices from one legal, cultural and political setting have been replicated in a completely different one. This document, therefore, has been created as a general-purpose tool for replicating best practices for good local governance.

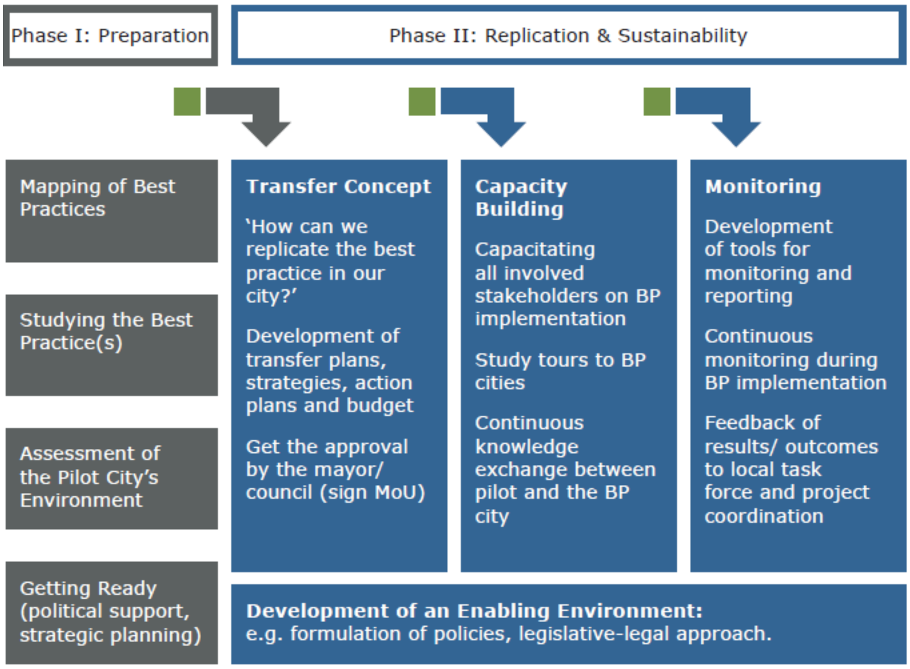

Figure 7: Replication at a glance for DELGOSEA Project, 2012

Method for reviewing replication strategies of different projects, PEDs, PED LABs for this COST Action 19126 – WG3 comprises the domains below:

- PED Design methodologies
- Methodologies for Technology Selections
- Business Models
- Governance of PEDs & PED Labs
- Standardization / Certification of PEDs

Only a few PED projects have published their replication frameworks which makes it harder to have an in depth analysis. Making City, +CityxChange and Sparcs replication strategies are summarised in the sections below. Although some of the PED Labs are working closely with cities there is not much evidence that they have structured strategies to replicate the tested technologies.

5.1 Making City

The main objective of MAKING-CITY is the development of new integrated strategies to address the urban energy system transformation towards low carbon cities, with the PED approach as the core of the urban energy transition pathway. Aligned with this aim, a harmonized energy and urban planning methodology is developed for PED design in cities. PED Methodology will be early adopted by FWCs to identify PED boundaries and select proper technologies collectively and co-design PED in their cities.

Cities must have a holistic approach on harmonizing energy and urban planning for energy transitions. Urban developments must evolve from single, unintegrated, simple "building" based interventions into Positive Energy Districts and Neighbourhoods concepts in order to reach energy and climate targets which will lead to an integrated energy planning. Proposed PED Methodology in this report provides cities considerations and guidelines to plan and design PEDs not only technically but also socially, economically, politically and spatially aligned with sustainable urbanization domains. Phases of the proposed methodology analyses main characteristics and priorities of cities by evaluating city indicators, a deep research on existing national/regional/local level city plans and implementation areas of these plans, analysing city components (e.g. resources, urban macro-form, energy infrastructure and services, social aspects), and energy demand. Once PED concept boundary is defined by these analyses, cities start social, economic and technical processes for selection of solutions to achieve PEDs. The outcome of the PED methodology is the detail cards (SPECs) of all technical and nontechnical solutions collected in solution catalogue (PEDBoard) The following figure describes in a schematic way the phases of the Methodology for PED Design.

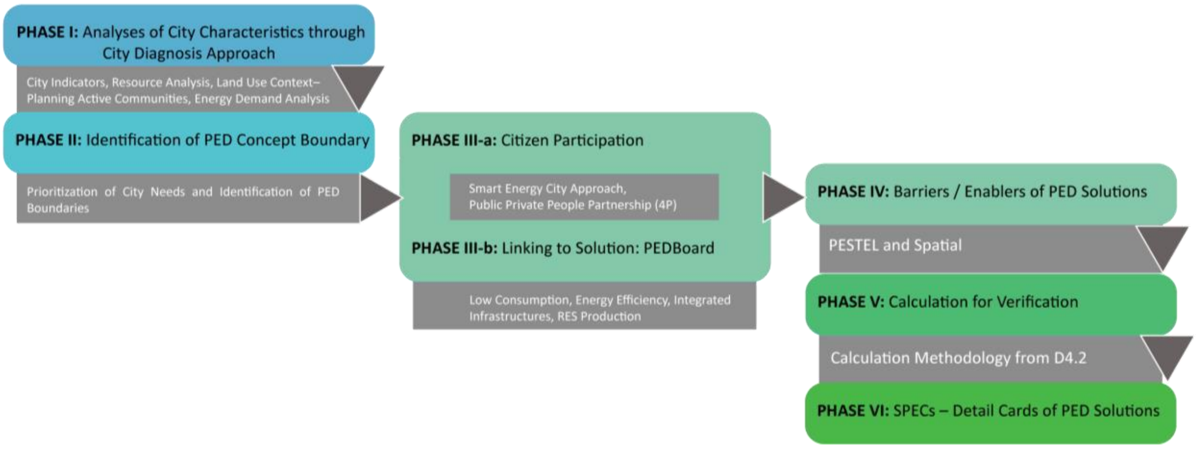

Figure 8: Phases of the MAKING-CITY PED Methodology, 2020

Thanks to proposed PED Methodology, aspects related with the specificities of the cities, regions and even countries, is considered, in order to have a standardized concept valid to be the core of specific urban energy transitions planning processes. As this incipient PED concept is a valid pathway towards an Energy transition, this must be aligned with the long-term and mid-term vision of the city plans. For the specific design of PED, technical and social barriers, and regulatory framework conditions will be identified for ensuring that technical and non-technical solutions are properly accompanied by a solid transferability perspective. In addition, in the demonstrations tested in Oulu and Groningen, a set of solutions (can be considered as a 'catalogue') and their associated benefits to reach PEDs is carried out, establishing the basis to document any other suitable solution.

Furthermore, a set of guidelines according to the different application scenarios will be carried out to facilitate designers the identification and combination of the solutions to transform a district in positive energy in the final version of this deliverable.

5.2 +CityXChange

+CityXChange project has a few attempts on defining replication strategies in a diverse set of topics. One of which is generating a "Positive Energy Champion Network" by campaigns to run in +CityxChange cities. Positive Energy Champions are individuals who embrace Positive Energy Concepts, take Positive Energy Actions and foster Positive Energy Communities by sharing their knowledge and experience with their fellow citizens. (CityxChange, D3.5, 2020)

The *Positive Energy Champion Network* will comprise a network of local influencers – building owners and occupiers, institutions and others – who can help translate the ideas, plans and innovations associated with +CityxChange implementation and the clean energy transition into local knowledge and actions – see Section 4 for details. The *Network' s* objectives are to raise awareness of *Positive Energy Concepts* and build capacity for *Positive Energy Actions* amongst citizens and communities through enabling the creation and replication of

Distributed Positive Energy Blocks (DPEBs) and Positive Energy Districts (PEDs) as part of a city's clean energy transition. A range of campaigns can be implemented using the framework which can be adapted to suit the particular needs and resources of each city.

Within this framework:

- *Positive Energy Concepts* are ideas, innovations or plans which contribute to the creation and replication of DPEBs and PEDs and the clean energy transition of a city.
- *Positive Energy Actions* are actions which make a *Positive Energy Concept* readily perceived or easily understood.
- *Positive Energy Communities* occur when citizens collaborate to initiate and sustain *Positive Energy Actions.*
- *Positive Energy Advice* refers to expert input and mentoring arranged for *Positive Energy Champions* during a *Positive Energy Champion Campaign.*
- *A Positive Energy Champion Network* is a team of *Positive Energy Champions.*

Besides that, CityXchange also introduces DPEB LABs which is defined as a dedicated centre for digital innovation within a city focused on the creation and replication of DPEBs. It comprises a *Programme*

and virtual and physical locations, or a network of locations, where implementation of the

+CityxChange Innovation Playground can become manifest. (CityxChange, D3.6, 2020)

A +CityxChange DPEB Innovation Lab is a dedicated centre for digital innovation within a city. Data and visualisation tools including the +CityxChange Decision Support Tool (DST) are available to stakeholders using the DPEB Innovation Lab – citizens, business, academia and government agencies – to support competition and innovation. I t has a collaborative operating structure and supports an Open Innovation 2.0 ecosystem for entrepreneurs and start-ups. Located i n the Innovation Playground, the DPEB Innovation Lab hosts open challenges to develop solutions to progress the creation of DPEBs and provides a place where the design and operation of DPEBs are visualised and analysed. The DPEB Innovation Lab can include a mini prototyping lab where DIT (Do-It-Together) RES projects are designed, piloted and delivered. In summary, the objective of DPEB innovation Labs is to:

- Initiate new collaborative operating structures.
- Cultivate an Open Innovation 2.0 ecosystem for entrepreneurs and start-ups.
- Support competition and innovation in the creation and replication of DPEBs.
- Enable a permeable culture of co-creation in the city.

5.3 SPARCs

Replication framework of SPARCs is basically based on *'LC proving the urban energy transformation while FC demonstrates the smooth transferability of this transformation model'* (Calzada, I., 2020).

Including all these parameters, defining a holistic approach requires, apart from adjusting the impact indicators already identified, to take in addition under consideration specific Interventions Indicators, as well as Replication Indicators. In that way, accurate projection of the intervention impacts will be enabled, allowing targeted and efficient deployment of similar interventions at different districts and building blocks of the Lighthouse, Fellow or other cities.

Building the holistic SPARCS assessment framework, technical partners as well as the City representatives of Leipzig and Espoo need to be consulted, contributing with specific knowhow on the enhancement of available KPIs and with the identification of additional indicators. Several forms of feedback collection will be utilized to obtain the necessary information such as:

- Workshop sessions
- Live consultation/clarification sessions
- Offline reviews

It is crucial for the targets of the projects that all technical and city partners will contribute to the best of their abilities to cover all aspects of the holistic methodology, to clarify open points and to build a common understanding on the purpose of each indicator in the context of the planned city implementations.

5.4 POCITYF

The replication roadmap of Pocityf project is divided into 4 phases. This roadmap is planned for the follower cities of the project but can be applied to other cities as well. There are lists of activities to be performed and information on which WP, Task, tools or deliverables can be of help for each activity.

Phase 1 is the preliminary phase and consists in defining the state of the art of the situation at the beginning of the project: baseline, objectives are defined, researches on regulation framework and potential barriers are investigated and a first approach to the stakeholders and ISs/IEs is performed.

Phase 2 is divided into 2 phases: Phase 2a and Phase 2b. All actions to be performed are strongly connected and complementary and very often, activities will have to be performed in a parallel or in a cyclical way. Phase 2a focuses on the stakeholder's engagement and ISs/IEs determination when Phase 2b concerns the economic aspects (funding research and BMs elaboration). Activities in Phase 2a are to be started before those of Phase 2b but at a certain point, activities in Phase 2b will be needed to validate/invalidate choices of solutions performed in Phase 2a. For example: in Phase 2a when evaluating a solution, researches on possible funding and BMs will be needed to validate the choice with the stakeholders.

Phase 3 is related to the finalization of the previous activities and to the planning of the implementation.

Phase 4 is related to the implementation and monitoring that will occur after the previous phases

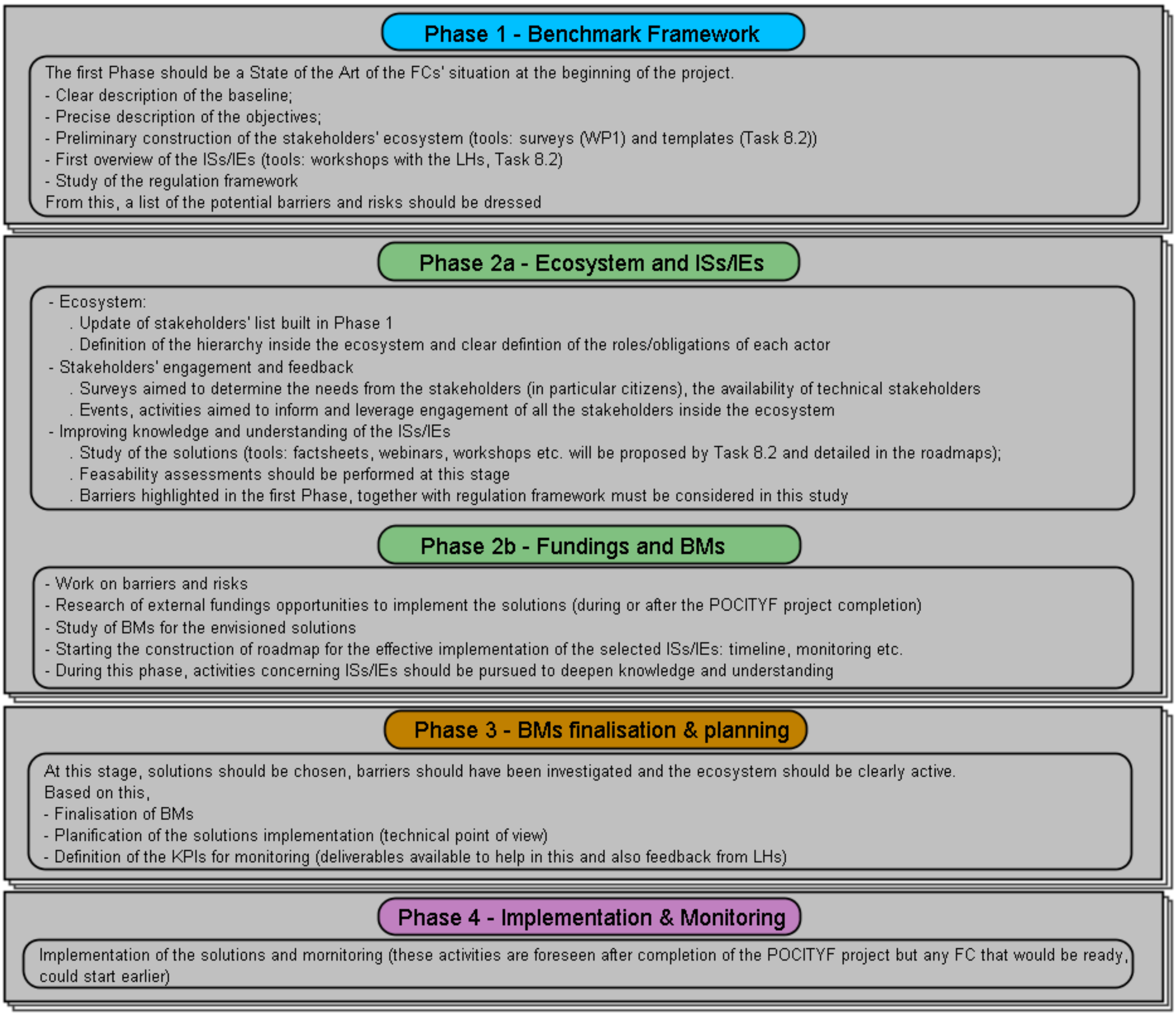

Figure 9: List of activities for each replication phase of Pocityf project

Source: WP8 Replication Plans and 2050 Vision by Fellow Cities presentation provided by Consortium

*IS: Integrated solution IE: Innovative Element

5. Conclusion

Monitoring and Evaluation Frameworks

The monitoring and evaluation plans have been prepared for PED projects in order to measure and assess the project activities at both city and project level considering the indicator categories defined by SCIS, CITYkeys, CIVITAS, and other relevant reference frameworks (previous smart city projects, etc.). The objective of almost all the projects is to select a set of Key Performance Indicators (KPIs) and data collection procedures for the common and transparent monitoring as well as the evaluation of smart city actions across the cities.

The project level evaluation framework consists of key performance indicators selected for evaluating the actions made in the demo areas on short- and medium-term. The project level can be considered as more technical than the city level concentrating not only assessing the level of sustainable energy planning but also the execution of the interventions in the PED areas and social aspects. The evaluation procedure describes the methodology to assess project actions with the defined indicators.

The methodologies developed are used as guides for the evaluation procedure step by step on a general level. It aims to describe the process for post-intervention evaluation concentrating on the project level actions and indicators (KPIs) that have been established and aligned in cooperation with the Lighthouse cities. KPIs are the main tools for the evaluation frameworks for tracking the progress, assessing the impacts in the demonstration areas and focusing on monitoring the evolution of a city district towards a smarter city as a whole.

Although some of the projects emphasized the process evaluation, it seems the focus is on the final evaluation. Evaluations after certain period would have given the opportunity to change certain procedures or the way doing things.

The monitoring and evaluation are particularly more challenging for PED Labs. For the PED or PED relevant projects there are certain targets that the consortium or team need to achieve so they need to have clear plan to evaluate if they achieved the targets. Most of the PED Labs are used as test beds for new technologies. Still, it is even more important to develop a monitoring and evaluation framework since the stakeholders are more diverse depending on the technologies used, the target groups, etc. The ZEN project of Norwegian University of Science and Technology has labs in different cities. In order to be able to control the developments they have s specific framework for monitoring and evaluation.

Replication

Developing replication and upscaling plans for Smart City Projects and Project Innovation LABs is complicated in terms of project timelines to figure out lessons learnt and measure the impact for generating a framework to transfer this knowledge and experience to follower/fellow cities. Since PED projects are pioneer, starting at 2018 under SCC Lighthouse Projects, most the projects and Innovation LABs still could not provide plans / methods/ tool for replication activities. For this reason, only a few projects could be presented in this report.

On the other hand, PED Labs are mostly in test / experiment / research phase that replicating the results of the experiments still are not ready. In the following years, more mature products, that are “ready to implement” in the market will be updated in this document and their replication frameworks and strategies will be shared.

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ANNEX 1: Key Performance Indicators

ENERGY INDICATORS		
KPI	**Explanation**	**Unit**
Common KPIs		
Energy Consumption	Final energy consumption divided for all uses and forms of energy (electricity/thermal/gas). Usually calculated at building level, aggregated to district level. Transportation and public lighting are usually calculated separately	kWh/month; kWh/a; kWh/(m2month); kWh/(m2a)
Primary Energy Demand and Consumption	Primary energy consumed inside the PED boundaries. All energy forms which have to be converted (often with subsequent losses) to useable forms of energy. Some of the projects does not have it as a KPI.	kWh/month; kWh/a; kWh/(m2month); kWh/(m2a)
Energy Savings	Total annual saved primary energy (some projects have it as demand or consumption) in the PED compared to baseline situation. The baseline calculations methods can vary depending on the characteristics of the interventions and areas (explained in other sections)	kWh/(m2a); %
Renewable energy production	Amount of RES production inside PED boundaries, and share (compared to final energy consumption in the area.) Can be divided into electricity and thermal energy.	kWh/month; kWh/a; % of final energy consumption
Exported energy outside the PED	The amount of electricity and thermal energy exported outside the PED boundaries from the demo area. Some projects have separate KPIs identified for electricity and thermal energy.	kWh/15min(/day); kWh/month; kWh/a; kWh/(m2month); kWh/(m2a)
Percentage of peak load reduction	Comparing the peak energy demand of baseline and after interventions (per final consumer, per feeder, per network).	%; # of peaks (congestion), duration of peaks and size of peaks; MHDx maximum hourly deficit
Energy storage capacity	Local storage capacity for energy balancing within the PEDs.	%; kWh
PED Energy Balance Self Sufficiency Ratio (P)	The overall primary energy balance of the PED area considering demand-consumption, energy flows, storage, RES.	kWh/month; kWh/a; (surplus + or deficit -); %
Energy imported to PED	The amount of electricity and thermal energy (district heating, gas and other sources) imported to the PED area from outside the PED boundaries.	kWh/15min(/day); kWh/month; kWh/a; kWh/(m2month); kWh/(m2a)
Project Specific KPIs		
Reduced energy curtailment of RES and DER (POCITFY, SParcs)	Reduction of energy curtailment due to technical and operational problems such as over voltage, over frequency, local congestion, etc.	%
System flexibility for energy players (Making City)	The indicator determines the increased system flexibility for the energy utilities as an effective way to exploit all resources to respond to a set of diversions (e.g. demand changes in a specific time interval) and maintain the power balance in terms of load or cost.	%, MW/€

ENERGY INDICATORS		
KPI	**Explanation**	**Unit**
kWp photovoltaic installed per 100 inhabitants	Installed capacity of photovoltaic interpolated to 100 inhabitants to be assessed per sector (residential, tertiary, industrial and public)	kWp/100 inhabitants,

ENVIRONMENT INDICATORS		
KPI	**Explanation**	**Unit**
Common KPIs		
Energy-related greenhouse gas emissions	Greenhouse gas emissions savings resulting from interventions in PED.	kgCO2-eq/ (m2month); kgCO2-eq/ (m2a), kgCO2-eq/ (kWh a)
Energy-related greenhouse gas emissions reduction	Reduction of CO2-eq. emissions in the PED area achieved by the project actions and interventions.	kgCO2-eq/a; %
Project Specific KPIs		
Life cycle greenhouse gas emissions, environmental footprint (Atelier)	Quantify the increase due to the emissions of greenhouse gases caused by PED, due to consumption of materials and provision of services within PEDs. The impact categories chosen are: life cycle greenhouse gas emissions, ozone layer depletion, human toxicity, fine particulate matter, ionizing radiation, photochemical ozone formation, acidification, terrestrial-, freshwater- and marine-eutrophication, freshwater ecotoxicity, land use, water use as well as fossil, mineral and metal resources.	
Water consumption onsite (Atelier)	Measures the reduced water consumption	m3/y
Onsite noise levels, outdoor noise levels (Atelier, Pocityf)	Implementation of heat pumps and electric vehicles will have influence on the onsite noise levels, while on the other hand, good sound insulation material will reduce the noise received by the users of the buildings.	decibels
Indoor humidity (hourly), Indoor Temperature (hourly), Outdoor Temperature (hourly)	These indicators are for monitoring the well-being of residents and building users	
Municipal Solid Waste (Pocityf)	Provides a measure of how much waste a city is producing and the level of service a city is providing for collection.	ton
Recycling Rate of Solid Waste (Pocityf)	Estimates the percentage of city's solid waste that is recycled, calculated as the total amount of the city's solid waste that is recycled in tons divided by the total amount of solid waste produced	%
Climate Resilience Strategy (Pocityf)	Assesses to what extent the city has a resilience strategy and action plan.	Likert Scale 1-7

MOBILITY INDICATORS		
KPI	**Explanation**	**Unit**
Common KPIs		
Annual energy demand by charging infrastructure	The total energy consumption of EVs in the PED	kWh/month; kWh/year/charging station; Annual kWh
Relative modal shift from fossil-fuel vehicles to electric mobility in the PED area.	Relative modal shift from fossil-fuel vehicles to electric mobility in the PED area	km/vehicle/y # of trips/vehicle/y km/year # of trips/year
Relative share/contribution of Vehicle to Grid (V2G) to the total energy system performance of the PED	Measures the total amount of energy (kWh) that is charged from Vehicle to Grid (V2G). This technological solution is currently widely explored to benefit both the EV charging demands as well as the flexibility of local energy systems.	kWh/y
Relative share of EV demand covered by local RES	Relative share of EV demand covered by local RES in the PED energy system	%
Number of EV charging points, Energy delivered for EV charging in PED,	Number of EV charging station inside the PED that are available for the public use, Energy consumption (energy delivered) by the EV charging stations in PED, and if available, the total number of charges, or the total charging time.	# of installed stations, kWh/month; kWh/a; charging time; # of charges
Project Specific KPIs		
EV car sharing rate (SPARCS)	Total number of citizens (#), citizens sharing an EV (#)	%
Share of EV in local transportation	Total number of vehicles in local transportation (#), Electric vehicles in local transportation (#), EVs available for sharing (#), EV car charging stations (#), Bicycles in local transportation mode (#), EV bus charging stations (#)	%
Parkin laces (car & bike)	Car parking places (#), Bicycle parking places (#)	%
Utilization of charging stations	Charging EV stations Utilization	hours used per day/month/year
Reduction of CO2, NOx, particulate matter emissions (PM2.5)	Emitted CO2 measurements/calculations, Values for Tropospheric NOx , Values for small particulates (ppm), Values for tHC Volatile hydrocarbons (ppm)	Tones/year, ppm

ECONOMIC INDICATORS		
KPI	**Explanation**	**Unit**
Common KPIs		
Simple Payback Period	Economic payback period of investments. Some of the interventions aim is to increase flexibility of the system so there is no pay back for those.	Years
Total Investments	The amount of money is invested in total to PED interventions. Subdivision of the sources (EU funding, (local) government funding, private investment by companies and other private investment.	€/m2; €/kW(h)
Total annual costs	The total annual costs are defined as the sum of capital-related annual costs (e.g. interests and repairs caused by the investment), requirement-related costs (e.g. power costs), operation related costs (e.g. costs of using the installation, i.e. maintenance) and other costs (e.g. insurance). These costs (can) vary for each year. Although not selected as a KPI for some of the projects it is an important variable to calculate payback period.	€/a
EC.4 Return on Investment (ROI)	The ratio between the total incomes/net profit and the total investment of the project/product etc.	%
Project Specific KPIs		
Average CO2 abatement cost	Estimates the costs in euros per ton of CO2 saved per year. This KPI can be estimated by capitalizing on information already available in other KPIs: carbon dioxide emission reduction	€/ton CO2eq
Local Job Creation (Pocityf)	Assesses the creation of direct jobs from the implementation and operation of smart city project solutions	number
New Business Creation (Pocityf)	Assesses the number of new businesses created (including start-ups) as one point of overall business climate in a jurisdiction and entrepreneurship.	number
Energy Poverty (Making City)	Percentage of households by definition (described further in the Annex), or energy bill as % of total household disposable income.	% of households, or % share of income
Average Electricity Price for Companies and Consumers (Pocityf)	Represents the average minimum cost at which electricity must be sold, so as to balance the costs with profits.	€/kWh
Percentage of the Total Distributed Energy Resources Capacity Traded (Pocityf)	Measures the amount of Distributed Energy Resources (DERs) capacity traded as a percentage of the total DERs capacity available.	%

SOCIAL INDICATORS		
KPI	**Explanation**	**Unit**
Common KPIs		
People Reached	Percentage of people in the target group that have been reached and/or are activated by the project	%
Local community involvement in the implementation and planning phase	The extent to which residents/users have been involved in the implementation process.	Likert Scale 1-5
Degree of satisfaction	The level of satisfaction and acceptance of people affected by the actions in the project, from a technical point of view; perceived adequateness, benefit (e.g. comfort), usefulness, ease of use, aesthetics; economic point of view; cost, risk, benefit.	Likert Scale 1-5
Resident engagement /empowerment to climate conscious actions	Increased consciousness of residents of the area on the defined issues (project interventions, energy, environment, climate, personal/communal consumption, carbon footprint and handprint, etc	Likert Scale
Number of community participation events and actions	Open-door events, community meetings, co-design workshops, consultation and desgin processes.	Number of events hosted by the cities
Number of new jobs created	Number of direct or indirect jobs created through the project activities and replication.	Number of jobs created
Project Specific KPIs		
Number of citizen observatories established (Cityxchange)	Observatories are platforms where stakeholders can interact and raise awareness. It is a physical space.	Number
Number of innovation labs/playground contributing to the creation of DPEBs (Cityxchange)	Dedicated physical spaces for innovation where stakeholders, entrepreneurs and start-ups can engage to develop innovative solutions	Number in cities
Number of Positive Energy Champions trained (cityxchange)	It is a campaign where participants are invited to incorporate positive energy concepts in their daily lives and helping others to do the same	Number
Replication Strategy (SPARCS)	Social compatibility, Ease of use for professional stakeholders, Trialability, Technical compatibility, Visibility of Results, Advantages for end users, Ease of use for end users of the solution, Solution(s) to development issues, Advantages for stakeholders	Likert Scale 1-5

ANNEX 2: Key Performance Indicator Definition Template

This template is prepared taking into account the common features of different projects. Some of them have more detail some less.

Name			
KPI Type		KPI Owner	
Level/Spatial Scale		Data Owner	
Unit		Data Year	
Description		Associated Demo	
Calculation/Formula			
Data Sources			
Calculation Frequency			
Beseline			
Monitoring			
Quality Assurance			
Stakeholders			
Type of Indicator	Input	Outcome	Impact
	Output	Process	
References			