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The District Energy-Efficient Retrofitting of Torrelago (Laguna de Duero – Spain)

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Abstract. The urban growth is estimated to reach up the 66 % by 2050 and consequently the need of resources within the cities will increase significantly. This, combined with the 40 % of energy consumption and 36 % of CO_2 emissions of the building sector, makes necessary to accelerate the transition towards more sustainable cities. The CITyFiED project contributes to this transition, aiming to develop an innovative and holistic methodological approach for energy-efficient district renovation and deliver three large scale demonstration cases in the cities of Lund (Sweden), Laguna de Duero (Spain) and Soma (Turkey). CITyFiED methodology consists of several phases that ease the decision-making tasks towards the district renovation, considering the energy efficiency as the main pillar and local authorities as clients. For the case of Torrelago district (Spain) the intervention consists of a set of energy conservative measures including the façade retrofitting of 143.025 m^2 of living space in 31 twelve-storey buildings; the renovation of the district heating network with a new biomass thermal plant; the integration of renewable energy sources, including a micro-cogeneration system, and the installation of individual smart meters. After the renovation action, one-year monitoring campaign is ongoing. The CITyFiED monitoring platform will collect information from the energy systems and deliver environmental, technical, economic and social key performance indicators by March 2019. At the end of the project the achievement of the predefined goals will be verified: up to 36 % of energy saving and 3,429 tons-CO2/yr emissions saving covering the 59,4 % of the energy consumption with renewable sources

1. Introduction. The CITyFiED project

CITyFiED is a project based on a mix of demonstration, renewable energy technologies and sound business models towards the sustainable development of cities. CITyFiED aims to enhance the energy efficiency of the city districts and provide a high quality of life to its inhabitants through a better management of its resources. An extensive demonstration action, involving the necessary technological and municipal stakeholders, has been carried out as part of CITyFiED in the cities of Laguna de Duero (Spain), Soma (Turkey) and Lund (Sweden), with the aim of maximizing the impact and replication potential. This study focuses on the demonstration case located in Laguna de Duero, i.e. the Torrelago district, which means the retrofitting of 143,025 m^2 of living space, involving 31 buildings with 1,488 dwellings and around 4,000 citizens.

2. The methodology for city renovation at district scale

Sustainable urban renovation is characterized by multiple factors, different spatial scales and a number of administrative structures that should address the evaluation of alternative scenarios or solutions. This defines a complex decision problem that includes different stakeholders where several aspects need to be considered simultaneously. A methodology based on a KPI-driven approach for urban renovation at district level is delivered by the project [1], with the energy efficiency as main pillar and the local authorities as clients. It is composed of 7 phases to facilitate the decision-making process, which contribute to an effective dialogue among all the stakeholders, aiming to understand the objectives and needs of the city to deliver a customized Strategy for Sustainable Urban Renovation.

2.1. Stakeholders of the Methodology

The methodology addresses the roles and responsibilities of the stakeholders involved along the application phases. The foresight of an *External Consultancy Group* (ECG) to closely cooperate with the local authorities is one of the key innovative aspects. This multidisciplinary group collaborates when understanding the city and setting up the most suitable strategy for the sustainable renovation, facilitating consequently the decision-making process. The stakeholders are sorted in three different groups as shown in Figure 1.

Figure 1. Stakeholders defined in the Methodology

2.2. Phases of the Methodology

The Methodology is deployed in seven phases as can be seen in Figure 2. Each phase establishes a collaborative procedure among all the stakeholders and considers ways to strengthen confidence in decision-making processes. It combines both district and city scales, starting with the urban and district analysis, proposing initiatives at district level and pursuing the impact of the renovation and the accomplishment with the initial objectives at both scales.

- *Phase I. Understanding the city objectives:* The main objective of this phase is to make a first approach to the city understanding in order to better know its initial situation and current problems. This analysis, combined with a definition of the long-term city vision, will enable the identification of the transition pathway of the city within its Strategic Urban Planning and the definition of the general objectives that will guide this transformation.
- *Phase II. Diagnosis of the city at district level:* The city is understood as an aggregation of districts. The main target of this Phase is to define the specific objectives for the district selected through different analysis.
- *Phase III. Analysis of the measures and scenarios:* This phase will define the renovation scenarios to be considered for being implemented in the district. Energy simulation tools and others are

considered to study the impact of different energy conservation measures that may define the corresponding scenarios, in order to facilitate the decision making process.

- *Phase IV. Prioritization and selection of the intervention scenario*: The main objective of this phase is to select the most suitable solution from the potential scenarios based on a multi-criteria analysis.
- *Phase V. Strategy for Sustainable Urban Renovation (SSUR):* This phase aims at defining the Strategies for Sustainable Urban Renovation and its integration within the Strategic Urban Planning.
- *Phase VI. Strategy Implementation Plan and Execution:* The definition of the specific plans for the realization of the actions defined in the Strategy for Sustainable Urban Renovation document is the target of this phase.
- *Phase VII: Monitoring and impact assessment evaluation:* Transforming European cities into Smart Cities not only requires comprehensive approaches to energy efficiency and environment by focusing on citizens' needs and interests, but also suitable integrated monitoring and evaluation procedures and correction actions for future interventions. Therefore, a Sustainable Evaluation Plan is defined in this phase.

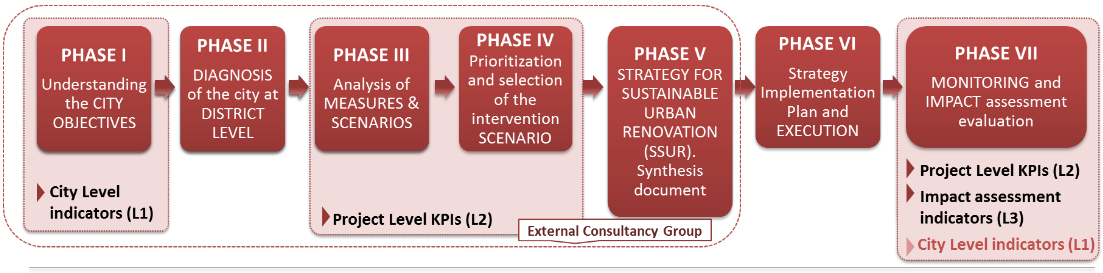

Figure 2. The CITyFiED methodological approach

2.3. *Key Performance Indicators (KPIs)*

In order to provide guidance and quantitative criteria, three levels of indicators are defined: *City Level Indicators* (L1) to understand and diagnose the urban area at city and district scales; *Project Level KPIs* (L2) to perform the analysis and selection of the solutions; and *Impact Assessment Indicators at city and district level* (L3) for the final evaluation of results and impacts achieved.

The *Project Level KPIs* play a key role in the project assessment at district level and serve as a tool for a detailed evaluation to determine the most relevant factors affecting the state and performance of a district, as well as to evaluate the actions that correspond to the objectives previously set for the city. The set of KPIs have been classified in 4 areas: Social, Environmental, Technical and Economic indicators (see Table 1). They are calculated for each demo site of the CITyFiED project and will enable to achieve a more accurate knowledge to improve the decision-making process as well as to transfer the CITyFiED project results into the technical database of Smart Cities Information System (SCIS) [2].

3. The monitoring strategy

After a large renovation action, one full year monitoring campaign is in progress from April 2018 and the CITyFiED monitoring platform is ready to collect information from the new energy systems and deliver the environmental, technical, economic and social key performance indicators by March 2019.

The monitoring of interventions is a key aspect of the project. One of CITyFiED's objectives is to provide ICT solutions so the different agents involved in the project can explorer and evaluate interventions. With these tools stakeholders can know and evaluate energy consumption, associating it with its economic cost and environmental impact.

Table 1. Project Level KPIs

Technical	Economic
Peak load of electricity consumption	Investments per conditioned area
Load profile of electricity consumption	Investments per power installed
Peak load of thermal (heating and cooling)	Grants
energy consumption	Cost Savings
Load profile of thermal (heating and cooling) energy	Internal Rate of Return
consumption	Return On Investment
Degree of congruence of calculated annual final	Total Annual Costs before and after the interventions
energy demand and monitored consumption	Total Annual Costs before and after the interventions
Degree of energetic self-supply based on RES	Net Present Value
Degree of energetic self-supply based on CHP	Static Payback Period
Net fossil energy consumed	
Net RES energy consumed	
Environmental	**Social**
Energy demand and consumption	The extent to which citizens are involved in the
Energy savings	decision-making process
Primary energy demand and consumption	Trust in decision-makers and stakeholders
Greenhouse gas emissions	Overall evaluation of costs
Greenhouse gas emission reduction	Awareness of climate change and clean technologies

Together with the retrofitting measures implemented in Torrelago district, a set of systems have been installed at district, building and dwelling level to monitor the energy consumption and visualise it in the CITyFiED monitoring platform (Figure 3).

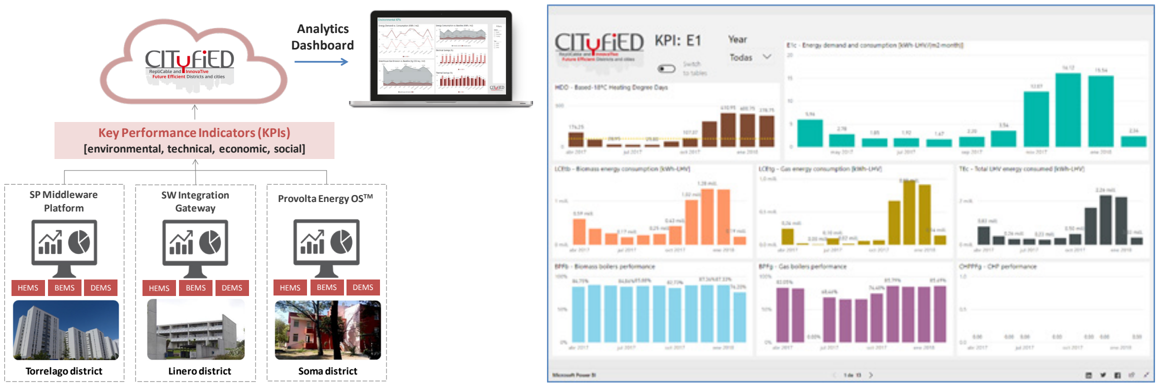

Figure 3. The CITyFiED monitoring platform and KPI visualisation

The data stored in the platform allow the creation of tools to satisfy the needs of different stakeholders involved in the project with different perspectives. In order to implement the ICT solutions, a procedure based on User-Centered Design (UCD) has been taken [3], adjusting this approach to the needs and requirements of the CITyFiED project. UCD is a method that defines the design of a solution on the needs, limitations and preferences of the end user, who is placed at the centre of the whole development. The approach developed in CITyFiED is available in [4] and includes four phases: concept, design, development and deployment. In the application of the procedure a number of tools have been delivered to facilitate the development of solutions, such as workshops, brainstorming sessions and user tests where stakeholders have actively participated. The methodology takes into account not only technological aspects but also communication issues and user behavior.

The visualization tool developed for the Torrelago district (Figure 4) is a responsive web application where residents can monitor their energy consumption and get recommendations. The objective of the application is to empower residents on their consumption habits and to help them in making decisions.

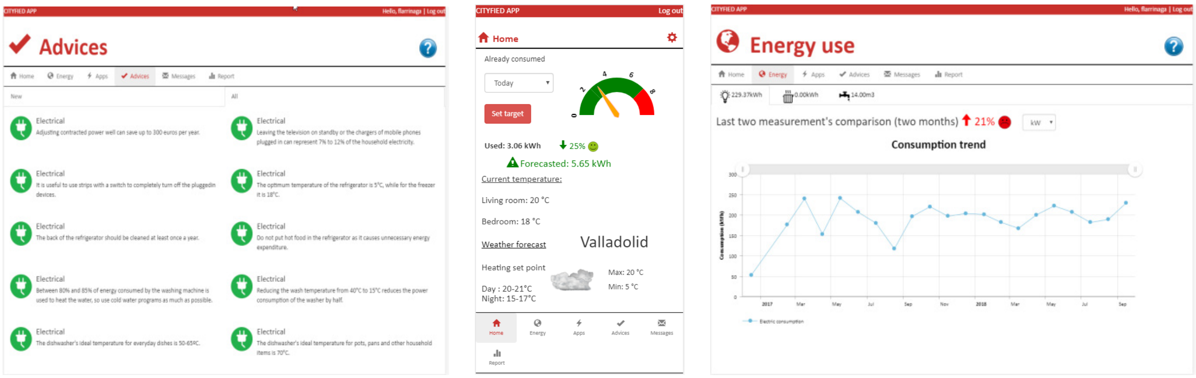

Figure 4. Visualization-recommendation tools

4. Deep retrofitting in the residential district of Torrelago

In a truly cooperative approach, CITyFiED has embraced the Torrelago district residents in a democratic process to take part and decide on the renovation actions. At the same time, a sound ESCo business model has ensured that the retrofitting investments all made economic sense to the residents so they can benefit from them. All of the main economic and technological aspects in terms of building retrofitting, district heating system upgrade, integration of renewable energy sources and monitoring have been addressed by means of a systemic approach in order to achieve not only significant energy savings and very low CO_2 emissions but also remarkable improvements in the residents' comfort conditions.

4.1. Energy-efficient building retrofitting

Before CITyFiED, the lack of insulation in the building envelopes made their residents suffer significant indoor heat losses and poor comfort levels. Improving the inhabitants comfort has been one of the main goals of CITyFiED.

The original façades in Torrelago buildings were made of brick cavity walls with a thickness of 25.5 cm and closed by ceramic lattices in the natural ventilation area of the kitchen. The brick cavity walls had no insulation layer with a U-value of 1.36 W/m^2·°C, resulting in a high demand of thermal energy. The solution adopted consisted of the retrofitting of the 31 buildings, i.e. 143.025 m^2 of living space, with an external thermal insulation composite system (ETICS), which meets the Spanish Technical Building Code requirement in terms of U-value $\leq$ 0.66 W/m^2·°C in the climatic zone of Laguna de Duero (i.e. D2). The system is composed by 8 cm expanded polystyrene (EPS) sheet for insulation, fixed by adhesive mortar and mechanical anchors, mortar layer, cement mortar, fibreglass mesh and white finishing mortar. The resulting wall has a width of 35 cm and a U-value of 0.339 W/m^2·°C. Not only a more energy efficient district has been achieved thanks to the building retrofitting, but also the inhabitants' benefit of higher levels of comfort and quality of life.

Figure 5. Torrelago district: Original buildings (left) and retrofitting process (right)

4.2. District heating upgrade based on renewable energy sources

In parallel to the building renovation action, the old energy system composed of two independent gas-based district heating networks were upgraded. One of the old gas boiler rooms was dismantled and replaced by a new biomass boiler room of 3.5 MW with a biomass silo of 400 m^3 (Figure 6). In addition, the two existing networks were connected with a new pipe line to build a new multi-source (biomass and natural gas) district heating system that covers 80 % of the thermal demand with renewable energy sources.

The thermal energy is produced by three renewable energy biomass boilers, two of them of 1,250 kW and one of 950 kW. These boilers have a triple heat exchanger to achieve maximum heat transfer and efficiency. Using a digital control system and modulating regulation, the boilers reach a performance of 90 %. Additionally, the existing gas-based boilers are kept to be used in case of demand peaks, biomass boilers breakdowns or lack of biomass supply. Two inertia tanks of 12,500 liters capacity each were installed to increase the return temperature to the boilers and to stratify the water mixture, so the heating water can be supplied at the highest possible temperature.

On the other hand, new variable flow pumps, heat exchange substations, individual smart meters and thermostats were installed, together with a micro-cogeneration system to generate 33 kW of power and 73.4 kW of useful thermal energy. The main goal of the CHP facility is to compensate the electricity overrun of the biomass boilers and to supply part of the DHW demand.

Figure 6. New biomass boiler room and silo

4.3. Smart metering

A completely new control system to manage the district heating system was installed. This is based in two main strategies. The first one i) is related to the temperature of the inertia tanks, which controls the pumping load, reducing it when the temperature is lower than 73ºC. This strategy avoids that the return temperature to the boilers decrease bellow a minimum value, in order to protect them. The other strategy ii) is related to the heating supply temperatures. These are controlled by a 2-way valve through the outdoor temperature, reducing the heat loses when this temperature is not very demanding.

In order to measure residents' heat consumption, individual smart energy meters have been installed in each dwelling. By knowing the consumption of each dwelling, the community of owners is now in a position to implement individual billing. Each dwelling has a new thermostat provided with a cut-off valve, which avoids energy consumption once the comfort temperature (set by the resident in the thermostat) has been reached.

The whole district heating network was modeled in TRNSYS, a dynamic modeling tool, which enables to easily simulate modifications and analyse the resulting impact on the overall performance of the system. Such simulations have contributed to optimize the system, develop new control strategies and other improvements resulting in a better and most efficient system.

5. Impact analysis

5.1. Energy-environmental assessment

In order to assess the energy performance of the retrofitting project, the International Performance Measurement and Verification Protocol (IPMVP) has been taken as a reference. A mathematical model based on the measured energy consumption from 2009 to 2014 with $R^2 = 97.5\%$ has been defined (Figure 7).

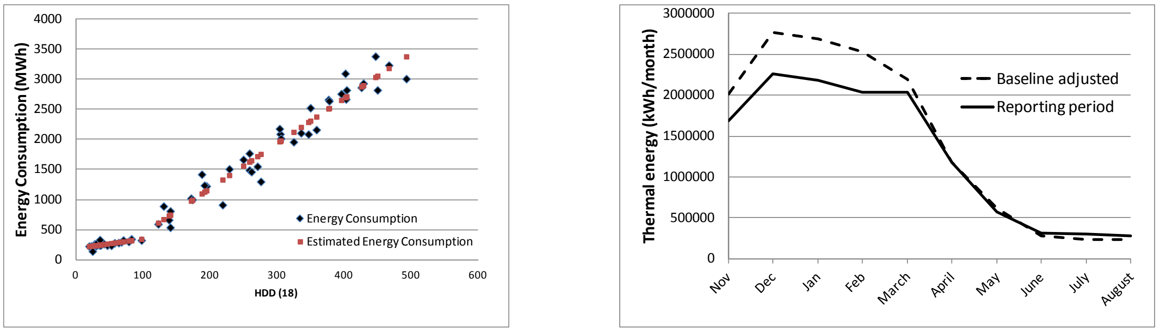

Figure 7. Mathematical model comparison (left) and baseline adjusted vs reporting period (right)

$$E\ [MWh] = -305.44 + 7.47 \cdot HDD + 498.72 \cdot M - 5.92 \cdot M \cdot HDD + \varepsilon \qquad (1)$$

Where M = 0 in winter season and M = 1 in summer season, HDD = Heating Degree Days.

Analysing the data collected so far, the consumption of primary energy has been reduced by 20 % while the CO_2 emissions have been reduced by 56 % (Figure 8). It should be noticed that the building retrofitting action was finished in March 2018 and one full year monitoring campaign is in progress from April 2018 to March 2019. These preliminary results show a positive trend in line with the expected energy savings, i.e. around 40–50 %.

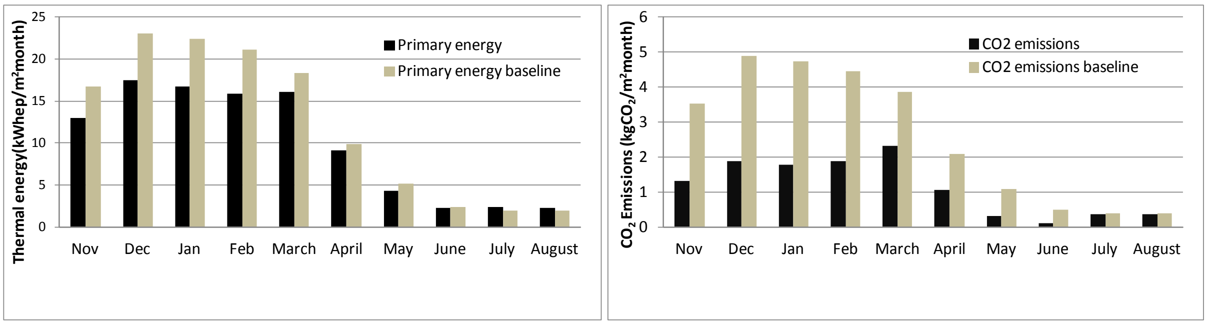

Figure 8. Energy performance (left) and CO_2 emissions (right)

CITyFiED project has also included a simplified environmental assessment of the renovation actions through a Life Cycle Assessment (LCA) study, one of the most internationally recognized and accepted methods to investigate the environmental benefits of the life cycle of products, processes and services. The project has included therefore a study to characterize the environmental impacts related to the energy measures taken in Torrelago demonstration site, and to reveal these impacts from different life cycle stages. The LCA covers both emissions from the manufacturing of materials and the operation for the buildings over a reference study period. This means that the reduction of the operational energy achieved, due to CITyFiED actions, in comparison with no intervention has been assessed considering a life cycle approach.

As defined by ISO, LCA is a multiphase process with four interrelated steps: i) goal and scope definition; ii) Life Cycle Inventory (LCI); iii) Life Cycle Impact Assessment (LCIA), and iv) interpretation. The functional unit (FU) to carry out the assessment has been defined as "1 m^2 of heated or cooled living space with a reference study period of 50 years (A_{temp})". Regarding the scope, a "cradle to grave" approach has been followed, including several life cycle stages of the buildings (not all of them because their selection was limited by data availability) according to the European Standard EN15978.

The environmental impact analysis was focused on the comparison between the LCA results with and without CITyFiED retrofitting actions. The environmental results that correspond with the collected data for the LCIs show that project scenario reduces the Cumulative Energy Demand (CED) indicator in 65 % and the Global Warming Potential (GWP) by more than 70 %. More specifically with respect to this last indicator, the impact avoided in the project scenario is 2.4 tCO_2eq/FU in regard to the baseline. The energy use during the operation stage of the buildings is the most influential aspect regarding environmental impact, and its relative impact with the whole life-cycle is higher than 95 % for both indicators, but decreases more than 65 % in the project scenario compared to the baseline.

As a summary conclusion, this study has demonstrated that, considering a life cycle approach, district retrofitting actions have effectively reduced the environmental impact associated with the baseline because significant energy savings are achieved. The other life-cycle phases considered in the project scenario are less important and the production (A1–A3), transport (A4), maintenance, replacement (B2–B4) and end of life (C1–C3) phases represent less than 3 % of life-cycle environmental impacts. It is clear, therefore, that CITyFiED intervention has had a direct and positive environmental effect on the most influence phase for the buildings, the operational energy.

5.2. Socio-economic assessment

Citizens, as main users of the city environment, have clear benefits in their daily lives: raising the economic activity in the city, which has led to a reduction of unemployment with 50 new jobs created in the CITyFiED context, enhancement of their environment and quality of life, and also to be on board for the transition to the concept of smart city of the future, with more technology at the service of the citizen. Even utilities and other energy providers benefit in a variety of ways from CITyFiED energy efficiency measures. Direct benefits include lower costs for energy generation, transmission and distribution, improved system reliability, dampened price volatility in wholesale markets and the possibility of delaying or deferring costly system upgrades.

The improved comfort conditions and new appearance of the buildings have been especially well received. The residents affirm that comfort has improved not only during the cold months in winter, but also in the summer due to the new insulation of the façades. Additionally, residents are now able to set the indoor temperature in their dwellings, monitor their own thermal energy consumption and live in a dry, condensation-free environment, which was an issue before the retrofitting.

Another important aspect is the environmental awareness, which rose in the district due to the project development. This awareness made some of the dwelling owners change the windows on their own.

6. Conclusions

CITyFiED actions in Laguna de Duero has reached more than 4,000 inhabitants that directly benefit from the project actions and their different testimonies on the district retrofitting actions play a key role in the deliberations of CITyFiED representatives. CITyFiED investment in Laguna de Duero, more than 16.5 M€, has provided many different benefits to citizens and other local stakeholders. Whether by directly reducing energy consumption and associated costs, which can enable investment in other goods and services, or facilitating the achievement of other objectives, e.g. making indoor environments healthier, creating new jobs or boosting industrial productivity.

Energy efficiency is taking its place as a major energy resource in Laguna de Duero city to achieve sustainability and growth targets. Reducing energy consumption and CO_2 emissions, so far 20 % and 56 % respectively, was not only about adapting new technologies, but ensuring that these technologies were also being accepted by the public. Being able to talk about real examples that have proven to be efficient allow us push forward energy retrofitting projects and solutions beyond CITyFiED.

Acknowledgments

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