Research Cooperation in
Renewable Energy Technologies for Electricity Generation

(REELCOOP)

Final publishable summary report

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1 Executive summary

The REELCOOP project aimed to develop different renewable electricity generation technologies, while at the same time strengthening research cooperation between EU and MPC/MENA countries. The different renewable energy areas addressed were solar photovoltaics (PV), solar thermal, concentrated solar power (CSP) and biomass. Major objectives were the design, installation and testing of 3 different prototypes, addressing the different technologies. Other objectives were the dissemination and exploitation of the project results.

After preliminary design and small-scale testing, prototype 1 – a Building Integrated PV – system was installed in Izmir (Turkey). It has a nominal capacity of 7.4 kW$_{el}$, and has been operating for 24 months. Electrical energy generation has been higher than model predictions, and the resulting Levelised Cost of Electricity (LCoE) points to a value in the range of 0.22 €/kWh, for the particular prototype location and shading conditions, but able to go down to 0.20 €/kWh for South facing, unshaded conditions (30 years lifetime). Prototype 2 – a hybrid solar/biomass micro-cogeneration system – is installed in Benguerir (Morocco) and, in its present configuration, is able to generate 4 kW$_{el}$, although with a few improvements it may reach 6 kW$_{el}$. The biomass source is olive oil waste, and its LCoE is equal to 0.22 €/kWh (with 20 years lifetime, full time operation). Prototype 3 – a hybrid CSP/biomass system, installed in Tunis (Tunisia) – generates up to 60 kW$_{el}$, using biogas from anaerobic digestion of food waste (which however is not enough to support full operation, and will in the future be replaced by syngas from a gasification unit using olive waste). This prototype was intended as a small-scale demonstrator of a larger power plant; when considering a full-size plant of 1 MW$_{el}$, its LCoE may go down to 0.15 €/kWh (lifetime of 25 years). All 3 prototypes incorporate significant technical developments, which are detailed in section 3. Grid integration was also assessed, and found to pose no problems.

The development of the 3 prototypes also contributes to bring to the market energy efficient and sustainable electricity generation systems. The systems have the potential for exploitation/commercialization, with the resulting benefits for the partner companies and the EU. Project results have been (and will be) disseminated throughout the technical and research community, and also to a wider public.

2 Summary description of project context and objectives

The REELCOOP project aimed to develop different renewable electricity generation technologies, while at the same time strengthening research cooperation between EU and MPC/MENA countries. The different renewable energy areas addressed were solar photovoltaics (PV), solar thermal, concentrated solar power (CSP) and biomass. Major objectives were the design, installation and testing of 3 different prototypes, addressing the different technologies.

The three novel prototype systems were chosen to represent both micro-scale (distributed) and large-scale (centralised) approaches to electricity generation: prototype 1 (Building Integrated PV - BIPV) and prototype 2 (hybrid solar thermal / biomass micro-cogeneration) are representative of typical micro-generation systems, while prototype 3 (hybrid CSP/biomass) is representative of a large scale power plant on a reduced scale. Prototype 1 is schematically represented in Figure 1. Objectives for the prototype were to design an easy-to-install solution that might be adapted to building refurbishments, looking at different PV cell technologies, namelly sillicium (c-Si) and novel dye-sensitized cells (DSC). The characterisation of ventilation influence was also foreseen.

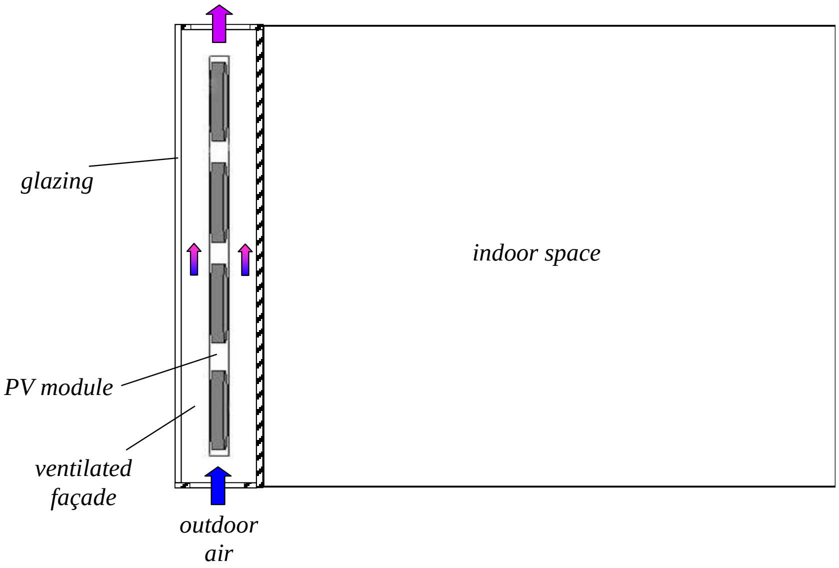


Figure 1. Schematic representation of the foreseen REELCOOP prototype 1 (BIPV).

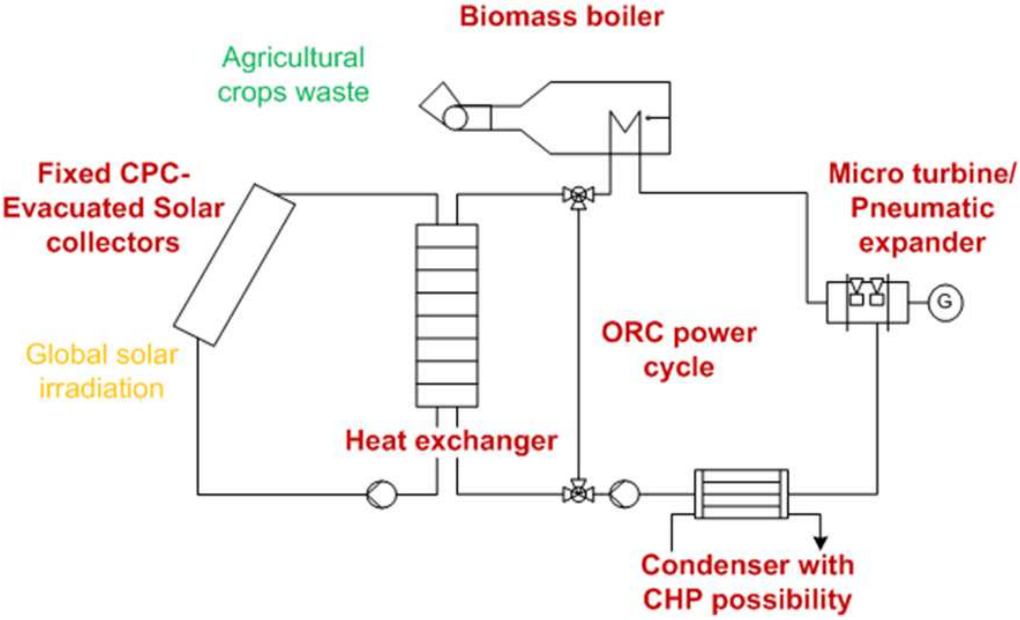


Figure 2. Schematic representation of the foreseen REELCOOP prototype 2.

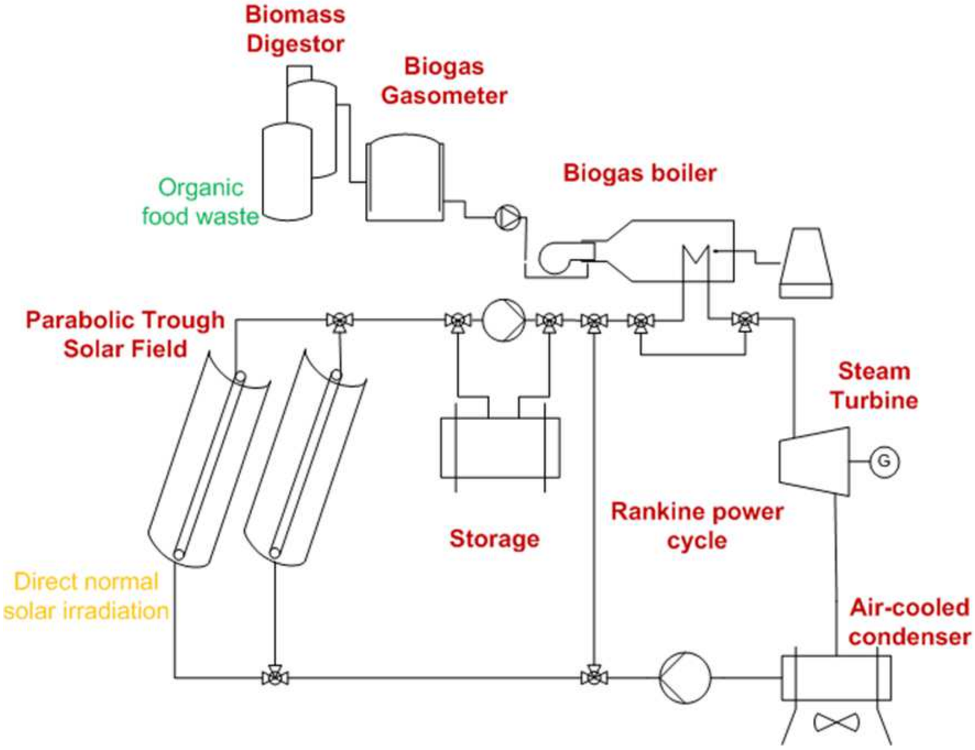


Figure 3. Schematic representation of the foreseen REELCOOP prototype 3.

Prototype 2 is schematically represented in Figure 2. The objectve was to drive the system either with (fixed) solar thermal collectors, either with a boiler burning agricultural waste, so that the system might be run during 24 hours/day, if necessary. These two renewable sources would drive a small-size Organic Rankine Cycle (ORC) power cycle, using a micro-turbine or micro-expander, coupled to an electric generator, to produce useful electricity. The cycle will also generate useful heat, by recovering the condenser output, therefore acting as a cogeneration or Combined Heat and Power (CHP) unit. This type of system is interesting in applications where electricity and useful heat are needed, such as in residential buildings.

Prototype 3 is schematically represented in Figure 3. It was intended as a small-scale demonstrator of a real-life power plant. It was also intended as a hybrid CSP/biomass driven system, using (movable) parabolic trough solar collectors and a boiler burning biogas from an anaerobic digestion process (from organic waste). The collectors would use Direct Steam Generation (DSG), and the Rankine power cycle could use either steam or an ORC fluid. A novel Phase Change Material (PCM) based storage was also to be developed.

The target characteristics for the 3 prototype systems are listed in Table 1.

Table 1: Target characteristics of REELCOOP prototype systems

Prototype system	**Energy sources**	**Electricity output**[a]	**Overall efficiency**[b]	**Levelised electricity cost**
1- BIPV	solar	6 kW	15%	0.200 €/kWh$_e$
2- CHP-ORC	solar thermal/biomass	6 kW	10%[c]	0.200 €/kWh$_e$[d]
3- CSP plant	solar/biomass	60 kW	10%	0.190 €/kWh$_e$

[a] nominal useful output

[b] average, source(s) to electricity

[c] electrical only – not including heat output

[d] only additional cost – above heat production cost

The 3 prototypes were to be developed through joint research of the involved partners, and followed by a period of testing in MPC/MENA countries. The environmental sustainability and economics of the prototype systems were to be assessed, and the results disseminated to industry and research, as proof-of-concept of REEL generation solutions. Grid integration was also to be assessed.

Specific dissemination actions were foreseen, in the form of workshops to be organised during the project duration, and in collaboration with other on-going EU projects.

3 Description of the main results/foregrounds

During the first 18 months work was mostly related to the development of prototypes and their components, aiming to achieve a final design for each of them. All components were developed as expected, and system simulation models were successfully developed and applied to predict final prototypes' performances. A final design for all 3 prototypes was defined. After that, the construction of the 3 prototypes was carried out, by manufacturing most of the components, but also buying and gathering some components from outside companies. Installation and commissioning were carried out, before testing could begin. The main achievements and results related to the prototypes are detailed in this section, separating the prototypes.

3.1 Prototype 1 (BIPV)

Concerning prototype 1 (P1), both C-Si and DSC photovoltaic cells and modules were developed and experimentally characterised. Testing in outdoor conditions with six C-Si modules (155 W_p each), carried out in Reading (UK), allowed the quantification of the ventilation effect in BIPV façades, as well as the validation of a simulation model developed with TRNSYS-TRNFLOW.

The solution chosen for REELCOOP prototype 1 combines the principle of a ventilated façade (improving PV performance) with ease of adaptation to both new and refurbished buildings. The construction solution was developed by Onyx Solar, one of the project partners. The BIPV system was installed at Yasar University, in Izmir, Turkey, in the first week of February 2016. The university campus is a modern one, and an existing building, finished in 2013, was chosen for prototype installation (Figure 4 shows the building façade, before and after prototype installation).

48 PV modules with mono-crystalline silicon solar cells were manufactured by Onyx Solar (see Figure 5). Each module has 36 6" cells, with a nominal efficiency of 17.6%, and the nominal module power is equal to 155 W. The cells are encapsulated with EVA film and 2 laminated glass sheets with a thickness of 4 mm. Each module has a total area of 1.2 m^2 and a transparency degree of 30%. This is an innovative glass-glass configuration with high mechanical stability, without the need of an aluminium frame.

Figure 4. View of prototype façade (Southeast): before and after installation of the PV modules.

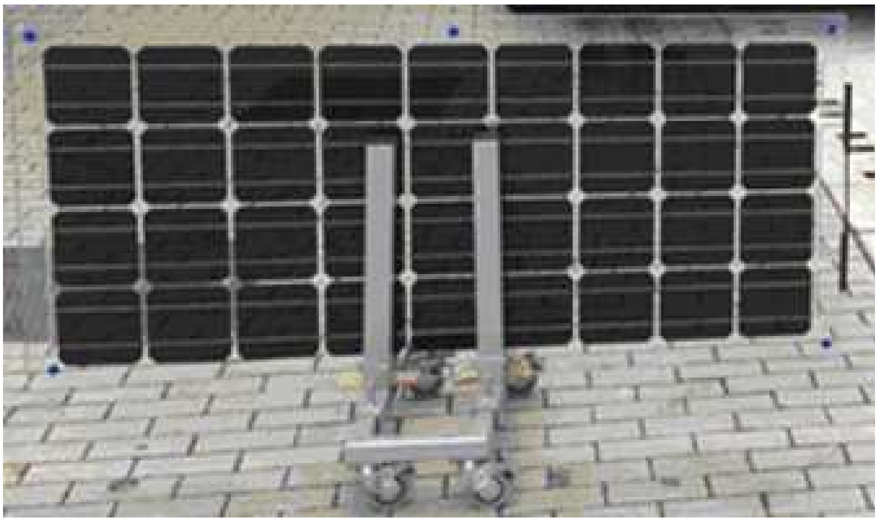


Figure 5. View of one REELCOOP prototype 1 PV module.

The PV ventilated façade is composed by the 48 modules, with a total area of 57.6 m^2 (effective PV cell area of 40.1 m^2). There is a total of 4 rows, and the gap between modules and wall is 150 mm. The PV façade nominal output power is equal to 7.44 kW.

The mounting procedure defined by Onyx Solar allowed a very quick installation time of 5 days for the whole façade and system connections. Electrical wiring and 1 junction box at each module were used, connected to one 7 kWp three-phase inverter. A monitoring device is used to monitor, control and record data from the photovoltaic system. This device is connected (RJ-485 connection) to the inverter and through Internet/Ethernet cable to a building internet port, so that the installation is monitored online.

The monthly average electricity consumption of the building is approximately 135 MWh, while the total energy consumption over a year is about 1623 MWh. This amount is significantly higher than the expected electricity generation capacity of the BIPV system, and therefore the system was not connected to the outside electrical grid.

System performance was simulated, using commercial (PVsyst) and REELCOOP developed (based on TRNSYS) computer models. The REELCOOP model, developed by the University of Reading, is able to accurately take into account the ventilation effect. As the Southeast PV façade lies on the lower part of the building, there are shading effects that were considered. This is a typical situation in urban areas. Heights and lengths of nearby buildings, as well as their distances to the PV façade were taken into account in the calculations.

Simulation results for the typical local weather conditions (Meteonorm climatic data file for Izmir) indicated a PV generated electricity of 4.2 MWh/year. After balance of system losses, these will come down to 3.8 MWh/year. The predicted average (annual) cell efficiency, based on effective cell area, is equal to 13%. As mentioned before, these results take into account shading effects, which lead to an average shading factor of about 35%. Note that with installation of a similar system in a more favourable surrounding area, without such significant shading, would increase the electrical output, with an increase due to the ventilation effect of about 7%, compared to the use of a non-ventilated façade (enclosed PV modules).

The PV system has been operating since 9 February 2016. Several climatic and output data are continuously monitored, and a summary is available online, including real-time measurements. These are available through a Sunny Portal dedicated webpage, which is accessible through the project website (http://www.reelcoop.com/project after pressing “more details”), or directly through:

https://www.sunnyportal.com/Templates/PublicPage.aspx?page=b11825cb-b706-4ca7-b717-0a11fc60f1e8. As an example, Figures 6 and 7 present monthly energy generation values during 2017, and daily values during May 2017, respectively.

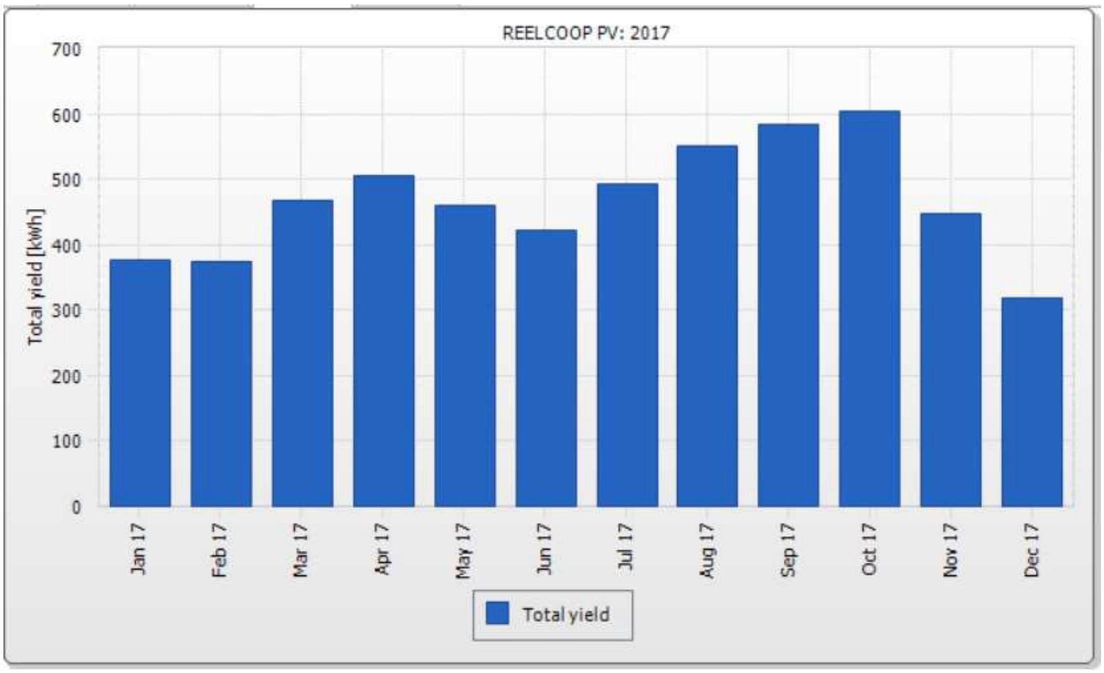


Figure 6. Monthly electricity generation in 2017.

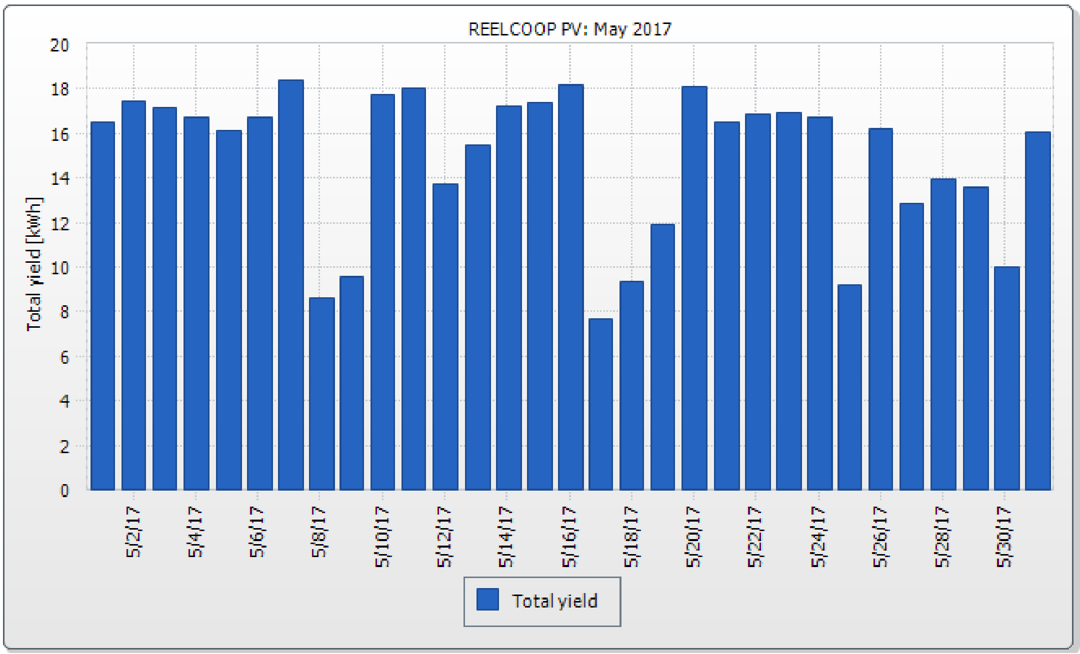


Figure 7. Daily electricity generation distribution in May 2017.

During the first 12 months the total electrical energy generated was equal to 5750 kWh and during 2017 a total of 5606 kWh was obtained. The measured values appear to be higher than the value predicted by the simulation model (4.2 MWh). Measurements of solar radiation indicated that the difference is not due to a significantly higher than average solar radiation incidence (9% higher), but more to a significant difference in the average simulated and experimental PV module (surface) temperatures. This appears to be due to a higher than predicted ventilation effect, depending on wind local conditions. The wind data used in the model were based on the Meteonorm weather conditions, and these might change due to wind unpredictability (random fluctuations) and micro-climate effects. It is well known that wind characteristics may vary significantly in urban areas when compared to typical weather station conditions. The measured average efficiency was equal to 15.8%.

An economic analysis of the prototype system was performed, based on an initial cost representing the additional cost of replacing a ceramic façade by the BIPV façade. This additional cost is equal to 148 €/m^2. Inverter and electrical installation represent an initial cost of 7000 €. Maintenance costs were estimated at 298 €/year, including the cost of replacing the inverter after 15 years. With these values, the Levelised Cost of Electricity (LCoE), for a system lifetime of 30 years, was estimated at 0.22 €/kWh using the measured annual electricity output. The LCoE could go down to 0.20 €/kWh if the prototype system was applied to a South non-shaded façade in Izmir (using simulated radiation values). This result is within the initial target (Table 1). These values assumed an annual degradation of 0.6% in the electrical output and a discount rate of 4%. Application of a similar system to other locations leads to calculated values between 0.18 €/kWh (Morocco and Tunisia) and 0.29 €/kWh (Germany and UK), also for a South non-shaded façade and 30 years lifetime.

3.2 Prototype 2 (CHP-ORC)

For prototype 2 several design options were considered, and the final configuration is schematically shown in Figure 8.

Novel solar thermal Compound Parabolic Collectors (CPC) were specifically developed for this application (Figure 9). They also possess evacuated tubes, and its position, although normally fixed, may be seasonally adjusted. After design they were manufactured by MCG Solar (Portugal) and 2 initial prototypes were tested at the University of Évora (Portugal).

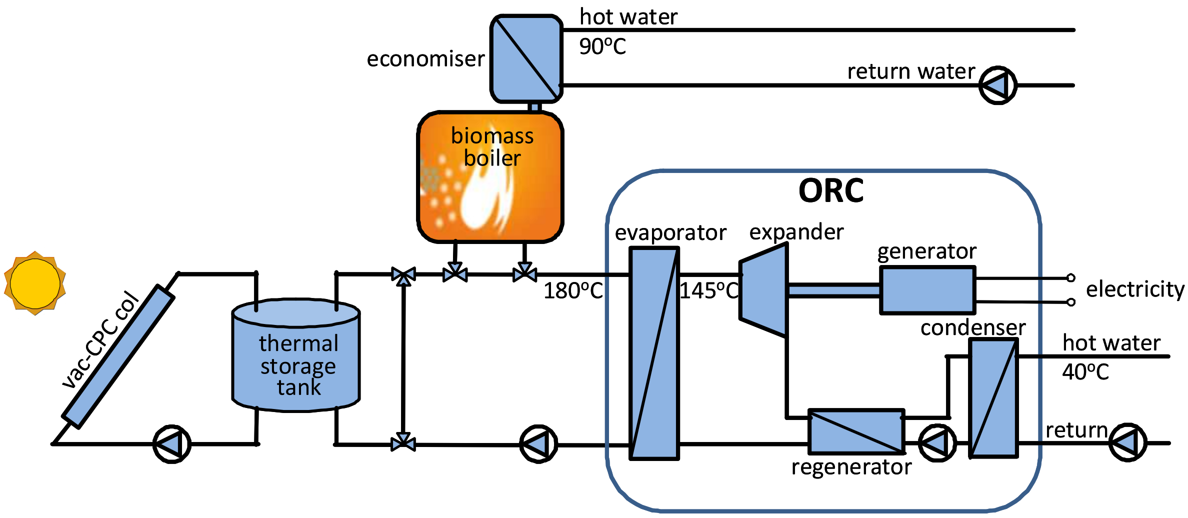


Figure 8. Schematic representation of the solar thermal-biomass CHP-ORC system (P2).

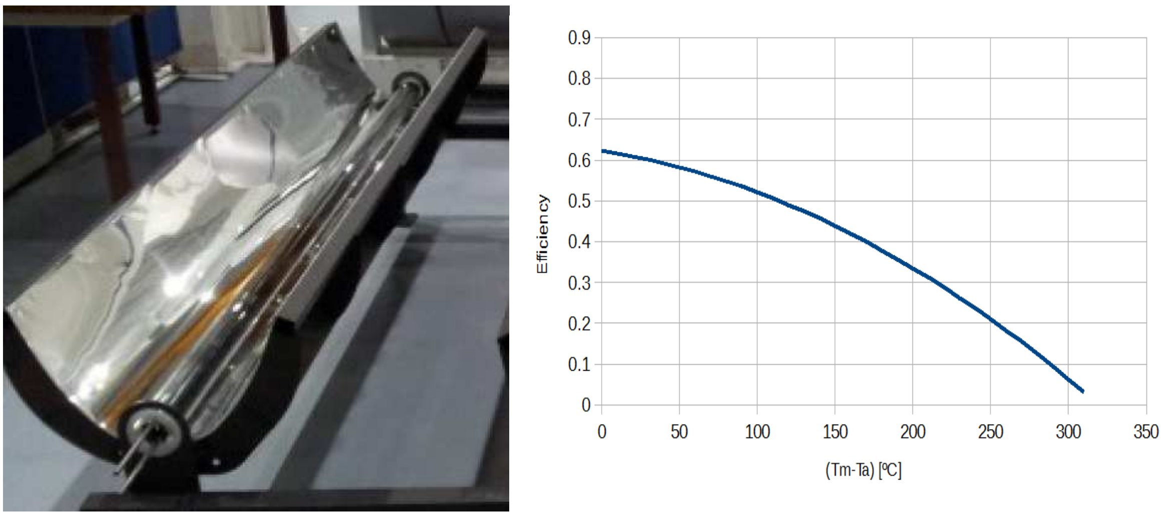


Figure 9. View of an individual CPC collector (left) and experimental efficiency curve of the collectors at 1000 W/m^2 (right).

Experimental tests showed that collector efficiency is higher than for existing collectors of the same type: even at an outlet fluid temperature as high as 177ºC, efficiency is equal to 51%, for an incident solar radiation of 1000 W/m^2. Its stagnation temperature is equal to 436ºC, for an ambient temperature of 37ºC.

32 collector modules, with a total aperture area of 146 m^2, were manufactured by MCG. The solar circuit operates with thermal oil.

For the biomass part, different biomass technologies were considered, namelly direct combustion and gasification. Tests with a dedicated gasifier were carried out at the University of Porto and tests of combustion of different olive oil process wastes were carried out in Poland. After the tests, and considering the availablity of the biomass resource in Morocco, as well as economic reasons, the direct combustion of an olive oil residue (olive oil pomace waste) was the chosen solution. The biomass boiler could also be fitted with an economiser, increasing the heat output and its temperature level.

The prototype was designed for a nominal 6 kW electrical output, using a novel rotary-lobe expander instead of a micro-turbine. The development was carried out by Termocycle, in Poland. However, due to financial problems, the partner company could not deliver the final power unit. As an alternative, the consortium decided to buy an existing unit from the market: an ENOGIA ORC unit. Its nominal power output was equal to 10 kW, but under the specific prototype conditions, without a cycle regenerator, and using an air cooler, will only deliver 4 kW, with an ORC cycle efficiency up to 8%.

After preparatory civil works carried out by IRESEN at the field test site (Green Energy Park, Benguerir, Morocco) the prototype system was installed. As mentioned, the solar field has 146 m^2 of CPC collectors (see Figure 10).

Figure 10. View of prototype 2 solar field.

Figure 11. View of biomass source (olive oil waste) and biomass storage feeder.

The biomass boiler is able to deliver 60 kW. An underground biomass storage tank was built. Figure 11 shows views of the biomass stock and feeder.

In the present stage the prototype unit does not use the heat recovery options (hot water). As mentioned, the ORC condenser is an air-cooled unit, able to operate with an outdoor air temperature up to 44.7ºC (Figure 12). The reasons for not using water cooling are related to the fact that there is no need for hot water in the facilities. However, a water condensing and delivery circuit is a standard component that poses no new engineering problems. The main novelties associated with P2 could still be tested with air cooling. The ORC cycle does not use an internal regenerator either, which could be adapted to improve system performance.

Figure 12. View of ORC power unit coupled to the air cooler.

The prototype system was tested when driven by the biomass boiler (Figure 13), due to the low availability of solar radiation during the test period. Long-term testing, covering Summer and Winter conditions, will only be accomplished in the coming months. Nevertheless, renewable electricity has already been generated.

Figure 13. View of biomass combustion in the boiler.

A simulation model was developed for the prototype system, by the University of Porto, using TRNSYS software and a dedicated ORC cycle model. The ORC model indicated that, with the modifications of using an ORC regenerator and water cooling, it would be possible to obtain a nominal electrical output of 6 kW, as initially foreseen, with a total yearly electricity generation of 52.6 MWh under the climatic conditions of Benguerir (Morocco). This output would be possible if the system operated during 24 hours/day all year round, with the boiler supplying energy when solar energy is not available. The average system electrical efficiency under these conditions would be equal to 8%, and the annual solar fraction (useful solar input in the collectors divided by the total heat input) would be equal to 19%. The biomass consumption would be equal to 71.9 tons/year. If the ORC power unit was driven by biomass only, the electrical efficiency could be equal to 14%, but in this case with an added operational cost due to the increased consumption of biomass.

An economic analysis of the prototype system was performed, assuming that the system operates with ORC regeneration and water cooling, providing a nominal 6 kW of electricity and useful heat in the condenser (water heating), and using climatic data for Benguerir. The system initial cost includes 43072 € for the collectors (specific cost of 295 €/m^2), 37131 € for the rest of the solar circuit (storage, valves, pumps, etc), 22425 € for the biomass sub-system (boiler, storage, feeding system), 22205 € for the control system, and 46000 € for the ORC unit (and cooling). With an installation cost (including foundations, civil work and services) of 37310 €, the total investment would be equal to 214143 €. For operational costs, the biomass source costs 0.038 €/kg and the electicity to drive pumps costs 0.10 €/kWh. Maintenance costs were estimated at 5000 €/year. The Levelised Cost of Electricity (LCoE) can be calculated by subtracting to the total cost the value of the useful heat obtained in the condenser (297.8 MWh/year), which would alternatively be produced in a natural gas boiler, with a natural gas cost of 0.049 €/kWh (in Morocco). With an operation of 24 hours/day, with the boiler as backup only, and considering a system lifetime of 20 years, the calculated LCoE is equal to 0.22 €/kWh, considering a discount rate of 4%, which is close to the initial target of Table 1.

3.3 Prototype 3 (CSP-biomass)

Prototype 3 corresponds to the mini power plant concept, driven by concentrated solar energy and biomass. The development and design stage, led by DLR and carried out by all involved partners, included solar collector simulation, with and without shading, and circuit thermal and hydraulic design. It led to the configuration shown in Figure 14. The solar field has a design aperture area of 979 m^2, and allows direct steam generation. The solar circuit uses the recirculation concept, to avoid collector tube dryout. Steam is separated from the liquid water in a steam drum, and supplies heat to a heat exchanger that vaporises the ORC working fluid, which is then expanded in the turbine. A dry air-cooler releases the excess heat to the ambient air.

The Parabolic Trough Collectors (PTC) were manufactured by Soltigua. They are an improved model, able to support high pressure inside the evacuated tubes. The novel ORC power unit was manufactured by Zuccato Energia, and has a rated nominal efficiency of 14%, operating at a maximum turbine inlet temperature of 160ºC with a nominal power output of 60 kW_{el}. The turbine and electric generator were designed and manufactured to be adaptable to time varying conditions in the solar field. Other components (gas boiler, air cooler, etc) were ordered from outside companies by ENIT.

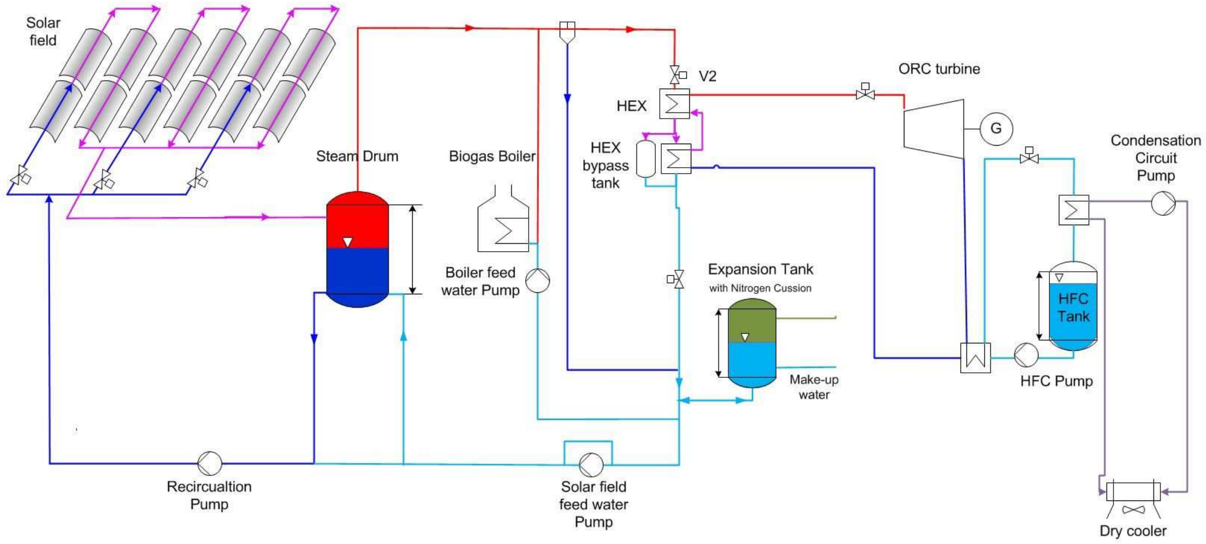


Figure 14. Schematic representation of the CSP-biomass prototype system (P3).

ENIT was also in charge of designing and building the biogas digestion sub-system. The biogas is obtained by anaerobic digestion of canteen food waste, although biogas production is limited and will be complemented by other biogas sources or natural gas (for testing purposes). The biomass digestion sub-system is composed of a digester, a water mixing tank and a decanter. The digester has a volume of $3m^3$ and uses a heat exchanger to maintain a constant temperature for the anaerobic digestion process. The mixing tank has a volume of $1m^3$ and will be used to mix water with organic waste to obtain a homogeneous substrate. The fermenter will be mechanically stirred. The decanter has a volume of $1m^3$. In this decanter, the digestate will be fed from the top and then it will pass through a sieve system, where the solid part will go down of the decanter, while the liquid part goes up and exits through a valve.

Due to the size and cost of a PCM storage unit, it was decided not to include it in P3. Alternatively, a small-scale installation was built by CIEMAT at PSA (Almería, Spain), to test a possible solution. In the end, a feasible solution was not found that may be used in practice.

P3 components were assembled and the system installed in Tunis (Tunisia), under the responsibility of ENIT. AES assisted in several tasks, including overall system control. DLR, Soltigua and Zuccato also provided their know-how. Figures 15 to 17 show different system components and views.

Figure 15. View of the P3 solar field after collector installation.

Figure 16. View of ORC power unit (left) and auxiliary building with machine room (right).

Figure 17. View of biomass boiler (left) and biomass digestion sub-system units (right).

P3 system simulations were performed by the University of Porto and DLR, using Greenius for solar-only operation, and Ebsilon for both solar-only and solar/biomass modes. Results showed a poor performance of the solar-only (without storage) operation, especially in Winter months. Hybrid operation significantly enhances operating time and system efficiency. Results for the typical local weather conditions (Meteonorm climatic data file for Tunis) indicated the capacity to generate 515 MWh of electricity per year, if the system operates during 24 hours per day. Under those circumstances, combining CSP and a 530 kW biomass boiler, the average (annual) system efficiency (electrical output divided by total input) is equal to about 10%. Note that a similar micro-CSP-only plant (without the biomass input) would produce 63 MWh/year, with an average efficiency of about 4%.

Testing of the system was carried out during a limited period of time. As an example, Figure 18 shows the generated power during a period of about 1 hour. More than the nominal 60 kW were generated. Figure 19 shows output results with solar-only mode, using 2 of the 3 collector loops, resulting in a power output up to 45 kW. Figure 20 shows a view of the steam generated during the test of Figure 19, after the collector outlet.

Long-term testing, covering Summer and Winter conditions, will only be accomplished in the coming months. Nevertheless, renewable electricity has already been supplied to the grid.

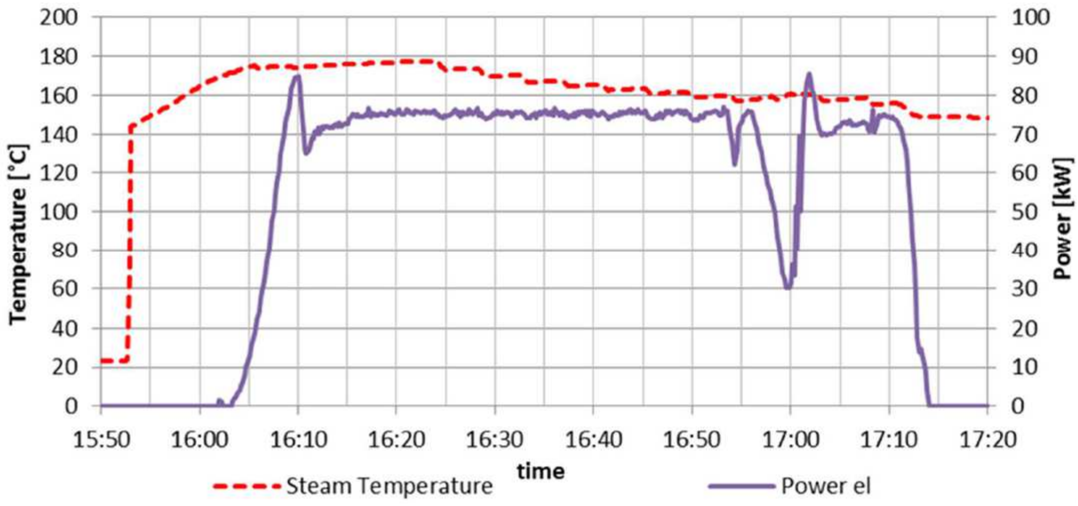


Figure 18. Power output and steam temperature during one test.

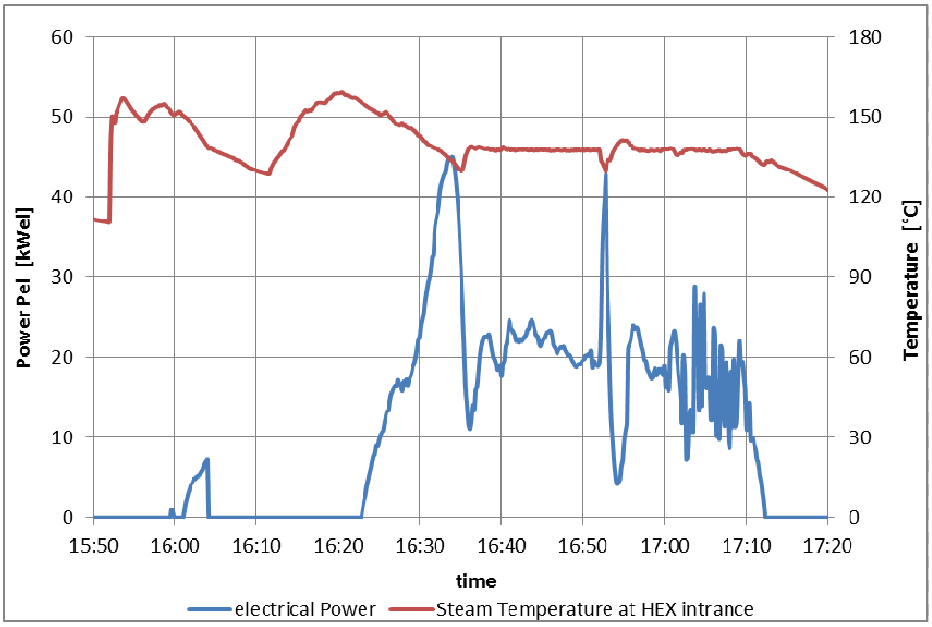


Figure 19. Power output and steam temperature during a test with 2 solar collector loops.

Figure 20. View of the steam generated with solar-only mode, after the collector outlet.

An economic analysis of this type of system was performed. However, as mentioned before, prototype 3 was intended as a small-scale demonstrator of the CSP-biomass concept, applicable to larger-scale centralised electricity generation. Therefore, the analysis was carried out for a scaled-up prototype, more representative of a real-life application. The conditions for the analysed plant are: use of direct steam generation (as in P3) and a steam turbine (instead of ORC), with an output power of 1 MW_{el}, operating from 6:00 to 22:00 everyday; the solar field has an area of 10000 m^2, reaching 350ºC; the biogas boiler has a nominal output of 5 MW_{th}, using biogas produced by anaerobic digestion of food waste, with a lower heating value of 24.34 MJ/m^3. Under these conditions, simulations for Tunis indicated an average solar field efficiency of 40%, an average biomass consumption of 9500 m^3/day, a solar share of 27.5%, and an electrical energy generation of 5840 MWh/year, with average power block efficiency of 21.3% and system efficiency of 13.7%. Note the improvements compared to the small-scale P3.

The up-scaled system has a total initial cost of 9.477 M€, of which 4.020 M€ are due to the solar field, 0.800 M€ to the power circuit, and 3.427 M€ to the biogas/biomass sub-system. The operational cost is equal to 283 k€/year. With these values and the simulated outputs, we will obtain a LCoE of 0.15 €/kWh with a discount rate of 4%, for a system lifetime of 25 years. This is a very interesting value, below the target of Table 1.

4 Potential impact

The potential impact of the project is addressed in this section. It includes the socio-economic impact and societal implications of the project so far. Cooperation among the project partners and the impact of their future cooperation will be discussed. The main dissemination activities and exploitation of the results will also be reported.

4.1 Socio-economic impact

The socio-economic external impacts that may be generated from the development of the 3 project prototypes will be addressed in the next section. This section refers to the direct impact on the partner/consortium companies and research organisations.

Partner companies are the main recipients of the technical developments achieved in REELCOOP, as they manufactured and improved most of the prototypes components. Regarding prototype 1 (BIPV), ONYX developed and tested their first c-Si based BIPV ventilated façade. ONYX also developed and consolidated BIPV installation procedures, besides gaining know-how on BIPV application to different climates. MCG developed and tested a novel CPC solar collector which can now be sold to clients, also for other applications such as industrial heat. Soltigua improved the control software of PTC solar collectors (tracking /standby/stow, initial angle setting, alarm diagnosis), and the DNI sensor. Soltigua also gained knowledge on the application and installation of PTCs in hot and desert climates, and is now commercializing a “desert ready” line of products. Zuccato Energia developed a new turbine for ORC units using superheated water (novel model ZE-75-LT) and a new ORC unit (novel model ZE-60-DSG) to be driven by superheated steam, now offered to clients. Therefore, partner companies increased their competitiveness in the market, which also has an impact on the creation of internal jobs.

Research organisations benefited from raising their research profile on renewable electricity generation systems. They developed software tools that allow them to design future systems/applications and acquired equipment that will be used for future research activities. They improved the formation of existing researchers, while at the same time forming new researchers able to tackle new challenges in renewable energy systems.

4.2 Wider societal impact

REELCOOP had an impact at different levels, which will be extended after the project termination date. Impacts outside the consortium that were identified are related to:

- creation of jobs in manufacturing companies and system installers as a result of market dissemination of prototype components/systems;
- direct and indirect impacts on the economy of the change in demand for renewable electricity systems;
- contribution to meet the EU/World targets for renewables and CO2 emissions;
- contribution to the formation of future researchers in renewable energy/electricity fields, in cooperation among EU and MPC/MENA countries.

A socio-economic study was conducted by CIEMAT to evaluate the impacts of the three REELCOOP prototypes on the economy. The parameters that were evaluated were the production of goods and services (multiplier effect), the creation of added value, and job creation. Figure 21 summarises the results.

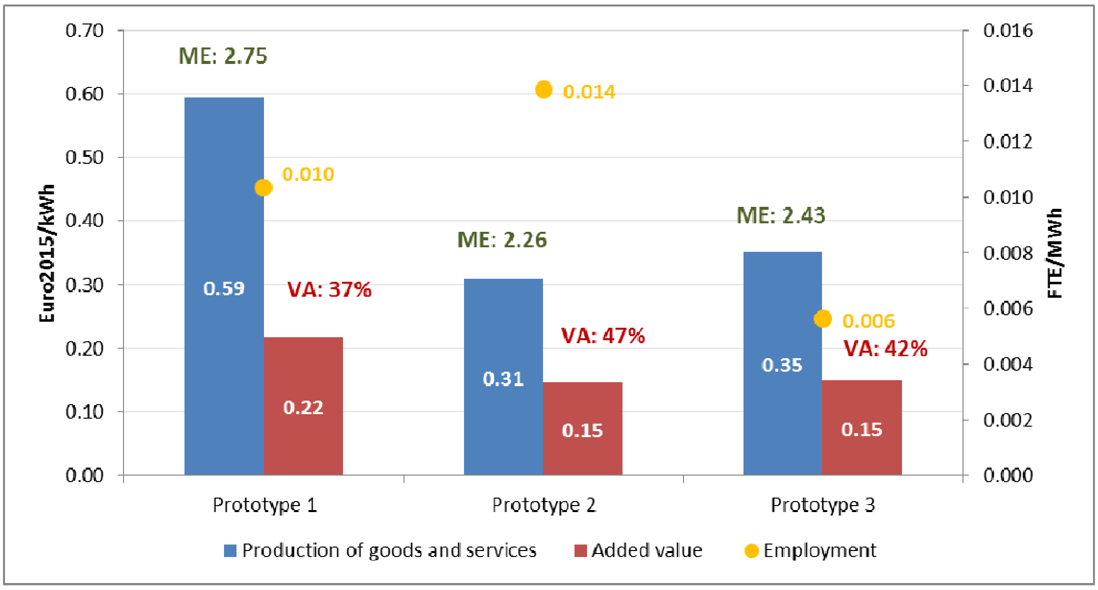


Figure 21. Socio-economic effects related to the 3 REELCOOP prototypes.

P1 (BIPV) has the highest multiplier effect (2.75) with a creation of goods and services of 0.59 €$_{2015}$/kWh; its added value is equal to 37% (0.22 €$_{2015}$/kWh); its job creation is equivalent to 1 FTE (Full Time Equivalent). P2 (CHP-ORC) has the highest added value with 47% (0.15 €$_{2015}$/kWh), the lowest multiplier effect (2.26, 0.31 €$_{2015}$/kWh), and an employement creation of 39.6 FTE. For P3, the analysis was carried out for the scaled-up 1 MW$_{el}$ system (as explained in 3.3); it has a multiplier effect of 2.43 (0.36 €$_{2015}$/kWh), an added value of 42% (0.15 €$_{2015}$/kWh) and an employement creation of 531.4 FTE (0.006 FTE/MWh). The national contents of those contributions are shown in Table 2. Prototype 2 has the highest national contributions for the 3 parameters. In order to maximize the positive socio-economic effects, the national content of the investments has to be maximized.

Table 2: Percentage of national contents for each prototype and parameter

Prototype system	Country	Goods & services	Added value	Job creation
P1- BIPV	Turkey	25%	26%	24%
P2- CHP-ORC	Morocco	52%	67%	81%
P3- CSP-biomass	Tunisia	51%	69%	66%

REELCOOP contributes to the deployment of 100% renewable electricity generation systems, and therefore, through the dissemination of similar systems, contributes to meet the EU/World energy and environmental targets. The tested systems produce no running CO2 emissions, with only small values related to manufacture of components. Calculated total emissions were 97.8 g$_{CO2}$/kWh$_{el}$ for P1, 11.8 g$_{CO2}$/kWh$_{el}$ for P2, and 18.5 g$_{CO2}$/kWh$_{el}$ for P3 (up-scaled).

REELCOOP contributed to the formation of new researchers in renewable energy/electricity fields, in cooperation among EU and MPC/MENA countries. The 3 Workshops that were held in MPC countries (Morocco, Algeria and Tunisia) were open to students and researchers not involved in REELCOOP, most of them from those countries. As a result of the workshops and also other work links, several students pursue(d) their research studies in partner universities and research centres, at graduation and post-graduation level. It is also noteworthy that the 3 prototype test facilities will continue to be used as training centres for the formation of future researchers and technicians.

The 3 REELCOOP prototypes and all related developments are the result of a joint research collaboration between EU and MENA/MPC organisations (partners). This cooperation has already been, and will be, extended throughout the coming years. A project with the objective of developing gasification units to use within the P3 concept was proposed to the ERANETMED programme, and has already started at the end of 2016 (acronym: BIOSOL, with a duration of 36 months). The units, to be developed under Tunisian and Algerian conditions, will produce syngas from olive oil residues, which will be used to complement the solar input. A gasification test facility will be added to the P3 test facility in Tunis. Most of the partners involved in REELCOOP P3 will be involved in BIOSOL. Other proposals involving other partners (P1) were recently submitted to the EC, concerning new building integrated façade systems. Actions regarding exchange of researchers and new joint post-grad courses on renewable energies were also undertaken. These new projects and actions will result in further technical and societal impacts.

Cooperation has also been extended to other EU-funded projects, namelly EUROSUNMED, ETRERA_2020, MAGHRENOV and Med-Spring. Joint workshops and actions were carried out during the project duration, and a few will continue. This cooperation extended the work network to countries that were not represented in REELCOOP, such as Norway and Egypt.

4.3 Dissemination activities and exploitation of the results

Dissemination of project concepts and results was carried out in many different ways and at different levels. This section refers the major dissemination actions that were undertaken throughout the project duration. Besides the general public, the main target groups were construction and building services companies and users, engineers and researchers working in building services and renewable energies, electrical utility companies, local/national governments and decision makers.

The first dissemination means was the project website (see section 5), which provided a clear route for the worldwide dissemination of the project concepts and results, also providing a common source of information across different disciplines and geographical boundaries within and beyond the consortium.

Three REELCOOP Workshops were organised, open to the outside community. They were dedicated to renewable electricity generation different aspects and technologies, serving as a means to disseminate project concepts and also results. Two of the workshops were organised in collaboration with the EUROSUNMED consortium, also funded under FP7. Invited speakers from outside organisations were also involved, as recognised experts in their fields. All presentations made in the workshops are available to the general public in the project website. The themes, locations and dates of the Workshops were:

- Workshop 1: State-of-the-art on Renewable Electricity Generation, Rabat (Morocco), 11 April 2014;
- Workshop 2: Renewable Electricity Generation – the distributed approach, Bou-Ismail (Algeria), 27 October 2015;
- Workshop 3: Renewable Electricity Generation – contributions & demonstrations, Tunis (Tunisia), 30 March 2017.

Another means of dissemination was the publication and distribution of REELCOOP newsletters. These were published every 6 months, with a total of 8 issues. The newsletters included information on REELCOOP developments, but also information on outside events and developments related to renewable electricity. All newsletters were and are available to the general public (for download) at the project website (under “dissemination”). They were also sent by e-mail to interested public (through previous registration). Several issues were also edited/printed in paper form, to be distributed in events such as workshops, symposiums and fairs.

The field-trial activities at the culmination of this project attracted significant interest both in the renewable energy and sustainable building communities. Visits and demonstrations were held at the 3 prototype sites. The consortium took advantage of this interest by issuing press releases and inviting journalists and publicists to attend some of the public demonstrations delivered.

Many publications were issued focussing on project concepts and findings. They may be divided into articles in scientific journals, papers in conference proceedings, academic theses/dissertations and more general texts. These publications were used to raise awareness of concepts and disseminate results, either to the renewable energy and sustainable building community, to the energy decisors, or even to the general public.

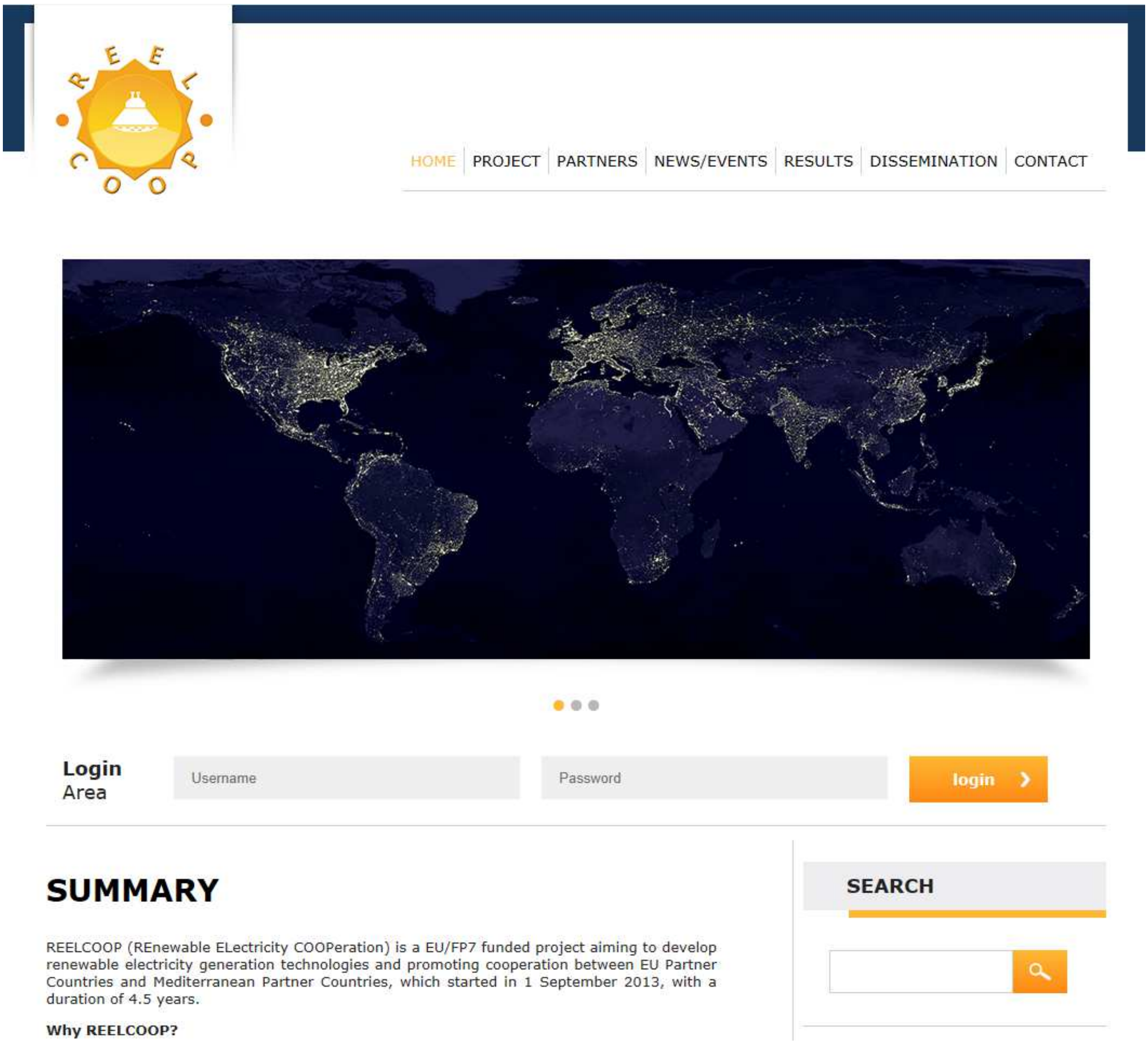
Many other dissemination activities were carried out during the project duration. These included oral presentations in conferences, presentations to wide audiences, invited lectures, poster presentations, participation in exhibitions, meetings with potential renewable electricity system manufacturers, installers and users.

Dissemination of the REELCOOP concepts, prototypes and results, will continue after the project termination. This will be mostly done through pending and future publications, as well as through future prototype results and demonstrations, since the prototypes will continue to be installed on the sites and operated after the termination date.

Concerning the exploitation of project developments/results, there was a direct exploitation by partner companies, as described in 4.1. Submission of patent applications and license agreements are also under consideration. Previously to the project start, CIEMAT held a patent on a novel PCM storage heat exchanger that could be tested during REELCOOP; unfortunately, the test results were not good for the existing PCM materials. Patents related to the novel rotary-lobe expander developed by Termocycle could not proceed, due to the company's financial problems and withdraw from the consortium. Zuccato Energia is considering submitting a patent application on the novel steam ORC unit.

5 Project public website and contacts

The project website is open to the general public, and contains project informations, results and all publications. The website address is: http://www.reelcoop.com (see Figure 22). It is linked to industry and research groups and forums, to attract interest from the renewable energy and sustainable building communities worldwide. The website has been (and will be) regularly updated with news related to renewable energy/electricity activities and also project outputs.



SUMMARY

REELCOOP (REnewable ELectricity COOPeration) is a EU/FP7 funded project aiming to develop renewable electricity generation technologies and promoting cooperation between EU Partner Countries and Mediterranean Partner Countries, which started in 1 September 2013, with a duration of 4.5 years.

Why REELCOOP?

Figure 22. Partial view of REELCOOP entry webpage.

A list of active partners and contacts of their technical responsibles follows:

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☐ University of Évora – João Marchã, P2 responsible (joaomarcha@uevora.pt)

☐ CIEMAT – Esther Rojas (esther.rojas@ciemat.es)

☐ École Nationale d'Ingénieurs de Tunis (ENIT) – Chiheb Bouden (chiheb.bouden@enit.rnu.tn)

☐ Institut de Recherche en Energie Solaire et Energies Nouvelles (IRESEN) – El Ghali Bennouna (bennouna@iresen.org)

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