**Institution:** University of Northumbria at Newcastle

**Unit of Assessment:** UoA 12 (Engineering)

**Title of case study:** Technological and commercial benefits of a micro solar combined heat and power system for domestic and small business use

**Period when the underpinning research was undertaken:** 2014 – 2020

**Details of staff conducting the underpinning research from the submitting unit:**

| Name(s): | Role(s) (e.g. job title): | Period(s) employed by submitting HEI: |
|---|---|---|
| Khamid Mahkamov | Professor | 18/04/2011 – present |
| Carolina Costa Pereira (publishes as Sol-Carolina Costa) | Senior Lecturer | 01/11/2016 – present |
| Fadi Kahwash | Research Fellow | 15/02/2017 – 14/02/2021 |
| Murat Kenisarin | Research Fellow | 15/03/2017 – 25/10/2020 |
| Irina Makhkamova | Research Fellow | 01/12/2011 – present |
| Ghanim Putrus | Professor | 01/01/1995 – present |
| Christopher Underwood | Professor | 01/09/1981 – 30/06/2018 |

**Period when the claimed impact occurred:** 2016 – 2020

**Is this case study continued from a case study submitted in 2014?** No

## 1. Summary of the impact (indicative maximum 100 words)

Solar Combined Heat and Power (CHP) is an attractive way to provide renewable energy in the domestic and small business sectors, but the large size of existing systems is not appropriate for these settings. Northumbria University has advanced technology by developing a novel system for a smaller, cost-effective, and more efficient micro CHP plant through the EUR3,999,383 *Innova MicroSolar* project. Four European industrial partners in this project gained technological and commercial benefits by developing new product lines, including the smallest Organic Rankine Cycle turbine in the world. The companies also expanded their markets, and created over 10 new jobs. As of December 2020, two micro CHP plants have been installed in Pula (Italy) and Almatret (Spain). In Almatret, the plant has been installed in a hostel that accommodates up to 45 eco-tourists per day, and provides [text removed for publication] of the hot water demand and approximately [text removed for publication] of the building's energy, reducing $CO_2$ emissions by approximately 9 tons annually. This has also enabled the local community to achieve its long-term goal of becoming a centre for eco-tourism.

## 2. Underpinning research (indicative maximum 500 words)

The European Union's (EU) strategic energy objectives identified solar energy as a feasible pathway to energy security with reduced environmental impact. Previously, a limited number of engineering solutions for solar residential and small business technologies existed, with a Combined Heat and Power (CHP) system proposed as one of the candidates. Most CHP technologies were of two types: (i) very large-scale plants, with complex solar collectors and several megawatt turbines for the production of electricity, or (ii) small-scale systems designed to satisfy only domestic hot water requirements. Hence, there was an untapped market for a novel micro CHP system that could be applied in domestic and small business sectors, and that would cover power and heat demands.

To develop the novel technology, Professor Khamid Mahkamov and his research team at Northumbria University created the conceptual design of the *Innova MicroSolar* CHP plant, rationalised separate components of the plant, and configured the whole plant as a system by means of numerical mathematical modelling. The team also participated in the experimental tests of both the individual components and the whole plant itself, including demonstrating the technical-economic advantages that could be achieved in a real environment.
In 2014, Mahkamov investigated the practicality of deploying different technologies for the provision of energy to buildings [**R1**]. Once the practicality of the technologies had been demonstrated theoretically, Mahkamov identified industrial partners to realise the concept in practice: AAVID Thermacore Europe Ltd, Enogia, Elianto CSP, and STRATEGIE SRL.

In 2016, Mahkamov's research team and the industrial partners secured a EUR3,999,383 Horizon 2020 project 'The Innovative Micro Solar Heat and Power System for Domestic and Small Business Residential Buildings' [**G1**], or *Innova MicroSolar*. The *Innova MicroSolar* plant was configured around a solar field made of Fresnel mirrors, that were used to heat thermal oil to a temperature of about 240° C. This thermal energy was then used to run a 2-kWel Organic Rankine Cycle (ORC) turbine and charge a Latent Heat Thermal Energy Storage (LHTES) unit with Phase Change Material (PCM). The LHTES extended the operational hours of the ORC turbine into the evening-time, when the sun was down. The heat rejected in the ORC condenser was used for hot water production and space heating. Finally, a smart control unit optimised the operation of the whole system with minimal user intervention [**R2**].

A series of experimental investigations were run at Northumbria to develop the PCM composite with required properties to be used in the LHTES. A wide range of organic and inorganic materials, and their combinations, were investigated [**R3**] and their thermo-physical properties were measured. Compounds made of potassium nitrate ($KNO_3$) and sodium nitrate ($NaNO_3$) salts were selected for further refining. A new compound was created (50% $KNO_3$ + 50% $NaNO_3$) to achieve the required melting point and maintain the highest possible heat of fusion (220.9° C and 98 kJ/kg). The method of enhancement of thermal conductivity of the PCMs, developed at Northumbria during the EU-funded ENTAS project [**G2**], was applied to the developed new compound [**R4**]. The enhancement was achieved by adding a particular type of expanded graphite at a specific concentration to avoid compound separation.

Advanced 3D numerical mathematical modelling of the operation of each main component was performed at Northumbria to find their rational design and optimised physical dimensions. Based on the results of simulations, design documentation was produced for the main parts of the plant and laboratory tests were run, led by the Northumbria team. For example, a combination of theoretical and experimental investigations were carried out to determine the design parameters of the LHTES with bi-directional heat pipes [**R5**].

The plant field test results were used for the analysis (mathematical simulations) of energy and carbon savings for locations across Europe with variable climates [**R6**]. The micro CHP plant proved to be highly competitive in comparison with other renewable energy technologies. The achievable energy and operational cost savings through the proposed plant with respect to traditional technologies were assessed. This analysis showed that the proposed plant could satisfy ~80% of the overall energy demand of a 100 $m^2$ dwelling in southern Europe, and could satisfy ~34% of the overall energy demand in the worst-case scenario in northern Europe. The corresponding operational cost savings amounted to 87% and 33%, respectively.

**3. References to the research** (indicative maximum of six references)

**R1.** Karmacharya*, S., **Ghanim Putrus**, **Christopher Underwood**, **Khamid Mahkamov**, McDonald*, S., and Alexakis*, A. (**2014**) 'Simulation of energy use in buildings with multiple micro generators' *Applied Thermal Engineering* **62**(2): 581 – 592 https://doi.org/10.1016/j.applthermaleng.2013.09.039

**R2.** **Khamid Mahkamov**, Pili*, P., Manca*, R., Leroux*, A., Mintsa*, A. C., Lynn*, K., Mullen*, D., Halimic*, E. Bartolini*, C., Pirro*, M., **Sol-Carolina Costa**, Cabeza*, L. F., de Gracia* Cuesto*, A., **Murat Kenisarin**, and **Irina Makhkamova** (**2018**) 'Development of a small solar thermal power plant for heat and power supply to domestic and small business buildings' *Proceedings of the ASME 12th International Conference on Energy Sustainability.* Florida, USA https://doi.org/10.1115/POWER2018-7336

**R3.** **Murat Kenisarin** and **Khamid Mahkamov** (**2016**) 'Salt hydrates as latent heat storage materials: Thermophysical properties and costs' *Solar Energy Materials and Solar Cells* **145** (part 3): 225 – 286 https://doi.org/10.1016/j.solmat.2015.10.029

**R4. Murat Kenisarin**, **Khamid Mahkamov**, **Fadi Kahwash**, and **Irina Makhkamova** (**2019**) 'Enhancing thermal conductivity of paraffin wax 53–57° C using expanded graphite' *Solar Energy Materials and Solar Cells* **200**: 110026 https://doi.org/10.1016/j.solmat.2019.110026

**R5. Sol-Carolina Costa**, **Khamid Mahkamov**, **Murat Kenisarin**, Lynn*, K., Halimic*, E., and Mullen*, D. (**2020**) 'Solar salt Latent Heat Thermal Storage for a small solar Organic Rankine Cycle plant' *ASME Journal of Energy Resources Technology* **142** (3): 031203 https://doi.org/10.1115/1.4044557

**R6.** Arteconi*, A., Del Zotto*, L., Tascioni*, R., **Khamid Mahkamov**, **Christopher Underwood**, *et al*. (**2018**) 'Multi-country analysis on energy savings in buildings by means of a micro-solar Organic Rankine Cycle system: A Simulation Study' *Environments* ***5*** (11): 119 https://doi.org/10.3390/environments5110119

*Co-authors include: industrial partners, Northumbria research students, and research partners from the University of Lleida (Spain)

**Research funding**
G1. PI, Khamid Mahkamov, European Commission, 2016-2021, EUR3,999,383 (723596), Innovative Micro Solar Heat and Power System for Domestic and Small Business Residential Buildings
G2. PI, Khamid Mahkamov, European Commission, 2014-2016, EUR309,235 (622883), Enhancing Thermal Properties of PCM Using Nano Materials

**4. Details of the impact** (indicative maximum 750 words)

Northumbria University's research in the EUR3,999,383 *Innova MicroSolar* project was used to develop, optimise, test, and install two micro CHP plants. This project enabled the four industrial partners (AAVID Thermacore Europe Ltd, Enogia, Elianto CSP, and STRATEGIE SRL) to develop new, or improve existing components manufactured for the plant [**E1**, p60-66], bringing commercial and technological benefits to these companies. The new plants led to improvements in efficiency, cost-effectiveness, and environmental advantages.

**4.1 AAVID Thermacore Europe Ltd (UK). Development of two new products: bi-directional heat pipes and 220° C PCM LHTES**
AAVID Thermacore Europe Ltd is a leading supplier of products for the thermal-management industry with a turnover of GBP5,760,357 (2017). As a result of working with Northumbria, '*Aavid Thermacore was able to create two new products, namely high-temperature bi-directional heat pipes and the LHTES accumulating and discharging the thermal energy at temperature levels of 220°C and higher'* [**E2**, see also **E1**, p12-14]. The collaboration resulted in improved components, for example the heat pipes increase the rate of charging and discharging of the thermal storage by about 30% and reduce its dimensions by 20% [**E2**]. This led to reduced thermal loss, resulting in improved efficiency. David Mullen, Project Engineering Manager at AAVID Thermacore Europe Ltd stated: *'There is a strong interest from our partners for these products, especially the developed high-temperature heat pipes, and the company increased its turnover by up to 10% over the last year as additional R&D funding was generated to adapt the new products to specific requirements of our clients'* [**E2**]. In 2019-2020, AAVID employed two new engineers and one new technician (Headcount: 3) to work specifically on new orders related to *Innova MicroSolar* products [**E2**].

**4.2 Enogia (France). Development of a new product: 2-kWel ORC Turbine package**
Enogia is an Organic Rankine Cycle (ORC) turbine manufacturer specialising in waste heat recovery. Northumbria University conducted 3D modelling of the mass and heat transfer processes and flow of the two-phase working fluid through the elements of the ORC for many combinations of configurations and design layouts with various dimensions [**E1**, p61-63]. Andre-Charles Mintsa, Enogia's Senior Project Manager stated: *'As a result of the research support from Professor Mahkamov's team, Enogia successfully developed a new product, namely 2-kWel ORC turbine – the smallest ORC turbine in the world'* [**E3**].

Enogia is now using this product in different small-scale applications. There has been strong interest from partners wanting to trial the new product and so the research and development funding of the company increased by 30% between 2018 and 2020 [text removed for publication]. Enogia also employed three additional engineers (Headcount: 3) to support this new product line [**E3**]. It has attracted interest for application not only in micro CHP plants but also in the automotive and power industries for harnessing energy from exhaust gases from engines, gas turbines, and burners. Andre-Charles Mintsa, Enogia's Senior Project Manager, reported: *'We are adapting the design of this ORC turbine for application with* [text removed for publication] *diesel engines to utilise waste energy of exhaust from engines and increase overall fuel efficiency.* [text removed for publication]*'* [**E3**].

**4.3 Elianto CSP (Italy). Optimisation of Linear Fresnel Solar Concentrating Field**
Northumbria University worked with Elianto CSP to improve the optical performance of their Fresnel mirrors, refining the outline of the solar field and geometry of mirrors to increase the concentration ratio of the optical system by 24%. This enabled the dimensions of the Fresnel mirror solar field and associated components to be reduced, while maintaining the high thermal output at a temperature of 280° C [**E4**]. This design improvement made the solar collector system more adaptable to roof mounting because of its ~25% smaller footprint and ~30% reduced weight. Moreover, the production and installation costs for the new design of the solar field were reduced by up to 32%.

This refined design has brought direct economic benefits, as Piero Pili, CEO of Elianto CSP, stated: *'The new concentrating solar collector proved to be very competitive on the market, leading to a sharp increase in product demand. In 2020, Elianto sold several thousand primary reflective mirrors of the refined design and resultant turnover has increased by 26% in 2020 in comparison to the 2016-2019 period. This innovation provided Elianto CSP with the new competitive edge on the market, with current negotiations with owners of seven new installations across Europe'* [**E4**]. As well as these direct commercial benefits, research and development income doubled from [text removed for publication] in 2018 to [text removed for publication] in 2020. To meet demand for the new product the company also employed an additional three engineers (Headcount:3) [**E4**].

**4.4 STRATEGIE SRL (Italy). New product: smart control unit**
Northumbria University's research on the optimisation of the whole plant's operation, through a strategy of dynamic interlinking of the components [**R1**, **R3**] resulted in a new product line being created by STRATEGIE SRL – a new smart control unit [**E1**, p63-65]. This product *'ensures dynamic interactions of all components through monitoring parameters of heat transfer fluids used in the plant, energy flow distributions between plant's sub-systems and measuring their performance… [The product was developed] to govern plants with the latent heat thermal storage [LHTES], and in according with customers' feedback, it increases the renewable energy utilisation factor and overall efficiency of such plants by 10-15%'* [**E5**].

The new smart control unit has attracted significant interest in the sector and was incorporated into the company's solutions for customers in the gas industry and the renewable energy technologies sector. Carlo Maria Bartolini, Chairman of STRATEGIE SRL, stated: *'The new product increased STRATEGIE SRL's turnover by 25% over the last two years [2018-2020], and the number of engineers [Headcount: more than 1] was considerably increased from 2018 to 2020 to cope with the new business… Innova MicroSolar project considerably strengthened our business contacts with other companies across the EU, which was also very beneficial for the STRATEGIE's business'* [**E5**].

**4.5 Local authorities adopted *Innova MicroSolar* plants to meet green energy goals**
As of December 2020, two *Innova MicroSolar* plants have been installed and are providing heat and power to a secondary school and the local stadium in Pula, Sardinia, Italy [**E6**], and to a hostel in Almatret, Catalonia, Spain [**E7**]. Ferro Tecnica Impianti SRL is an Italian company that builds renewable energy plants across Europe, and they used the micro CHP technology to build

the system in Pula. The cost savings and the smaller size of the *Innova MicroSolar* plant make the system extremely attractive to domestic and small business sectors and, as a result, Ferro Tecnica Impianti SRL have committed to building another plant in Ottana, Sardinia [**E6**].

In 2020, Spain passed legislation that requires clean energy sources to make up at least 70% of electricity, and requires that energy consumption is reduced by at least 35%, primarily through the renovation of buildings and homes. The municipality of Almatret decided to make the village into a destination for eco-tourism, and invested EUR40,000 from its budget to install *Innova MicroSolar* to support the energy needs of a new hostel that accommodates up to 45 eco-tourists per day. Since 2018, the plant has provided [text removed for publication] of the hot water demand and approximately [text removed for publication] of the building's total energy needs, reducing $CO_2$ emissions by approximately 9 tonnes annually [**E7**]. Jordi Tarrago Jove, Mayor President of the municipality of Almatret, stated: *'Achieving this would not have been possible without the contribution of Northumbria University. It enabled our community to achieve long-term goals of becoming a centre for eco-tourism'* [**E7**].

**5. Sources to corroborate the impact** (indicative maximum of 10 references)

| Ref. | Source of corroboration | Link to claimed impact |
|---|---|---|
| E1 | *Innova MicroSolar* technical report (March 2018 – August 2019) | Corroborates changes to all components of the *Innova MicroSolar* plant |
| E2 | Testimonial - David Mullen, Project Engineering Manager in AAVID Thermacore Europe Ltd | Corroborates creation of two new products (bi-directional heat pipes and the LHTES) and economic benefits |
| E3 | Testimonial - Andre-Charles Mintsa, Project Manager Senior in Enogia | Corroborates creation of the new product (the smallest ORC turbine in the world) and economic benefits |
| E4 | Testimonial - Piero Pili, CEO of Elianto CSP | Corroborates improved design of the linear Fresnel mirrors and economic benefits |
| E5 | Testimonial - Carlo Maria Bartolini, Chairman of STRATEGIE SRL | Corroborates development of the Smart Control Unit, economic and energy efficiency benefits |
| E6 | Testimonial - Patrizia Musca, CEO of Ferro Tecnica Impianti SRL | Confirming the *Innova MicroSolar* technology led to the installation in Pula, and a second plant planned in Sardinia |
| E7 | Testimonial - Jordi Tarrago Jove, Mayor President of the municipality of Almatret, Catalonia, Spain | Corroborating environmental, social and policy benefits of the new plant in Almaret |