**Section A**
The fields in this section are mandatory.

**Institution:** University of Chichester

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

**Title of case study:** Cutting carbon emissions through smart management of renewable energy and electric vehicles

**Period when the underpinning research was undertaken:** 01/12/2016-31/12/2020

**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: |
|---|---|---|
| Dr Yue Wang | Senior Lecturer for Electronics and Electrical Engineering | 01/09/2019-present |

**Period when the claimed impact occurred:** 2017-present

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

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

Research in the Department of Engineering and Design (EAD) at the University of Chichester (UoC) has contributed towards positive environmental impacts by evidencing and disseminating how smart energy management (SEM) of renewable energy and electrified vehicular (EV) transportation can effectively reduce carbon emissions when used together. This was established in an innovative transnational pilot conducted across 4 EU countries, in which households saw a 5% increase in 'clean kilometres', and one of the world's largest 'smart' garages achieved a total annual carbon emissions saving of 8 tons.

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

Research in EAD at the UoC has helped to demonstrate how 'smart' energy management can increase the utilisation of renewable energy systems and EV transportation.

Since 2015, Dr Yue Wang has been leading research on SEM strategies to coordinate power flow among base demand, renewable energy generation, electric vehicles' (EVs) energy requirements and battery energy storage systems. She has developed SEM strategies related to how wind turbines, photovoltaic (PV) panels and the lithium-ion batteries used in EVs can be integrated into the smart grid. Using this expertise, she has also developed models showing how real-life projects and businesses can maximise their profits through more sophisticated SEM strategies, and how those strategies can benefit from enhanced communication flows between stakeholders.

Across 3 collaborative peer-reviewed articles, Wang has developed and disseminated these insights in various ways. In **R1**, she helped demonstrate the increased utility of SEM systems informed by smart charging and 'vehicle to everything' (V2X) systems, showing how they can be used to minimise energy costs amongst a variety of stakeholders (households, neighbourhoods, businesses), reduce battery degradation, and stabilise electricity network loading. In this and another article (**R2**), she led research into the simultaneous technical and economic benefits available to domestic stakeholders through the integration of rooftop PV panels and energy storage systems. In **R3**, Wang collaborated further on the development of innovative 'decentralised' local electricity market frameworks, and their demonstrable ability to increase the

utilisation of renewable energy. Used with EVs, these innovations can lead to increases in 'green kilometres'. Taken together, these SEM strategies reveal pathways to enhancing the integration of renewable energy and electrified transportation, and reducing carbon emissions.

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

**R1.** Das, R., Wang, Y., Putrus, G., Kotter, R., Marzband, M., Herteleer, B. and Warmerdam, J. Multi-objective techno-economic-environmental optimisation of electric vehicle for energy services. *Applied Energy*, 257, p.113965, 2020. (This is a Q1 journal with a ranking of 8/103 and an impact factor of 8.426.)

**R2.** Wang, Y., Das, R., Putrus, G. and Kotter, R., Economic Evaluation of Photovoltaic and Energy Storage Technologies for Future Domestic Energy Systems – A Case Study of the UK. *Energy*, 203, p.117826, 2020. (This is a Q1 journal with a ranking of 3/60 and an impact factor of 5.537.)

**R3.** Paladin, A., Das, R., Wang, Y., Ali, Z., Kotter, R., Putrus, G. and Turri, R., Micro market based optimisation framework for decentralised management of distributed flexibility assets. *Renewable Energy*, 163, p.1595-1611, 2021. (This is a Q1 journal with a ranking of 19/122 and an impact factor of 6.274. The article was in the public domain by the end of 2020.)

**All outputs available on request.**

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

The increasing usage of distributed generation and EVs has brought challenges as well as opportunities to the electricity and transport system. EVs, which are typically charged in the evening, can add to the electricity grid's evening demand peak. PV generation peaks, on the other hand, typically coincide with low demand periods.

Developing a sustainable urban mobility and energy plan (SUMEP) to address these problems, Wang led the technical development of SEM strategies in the EU-funded SEEV4-City project (2016-20), demonstrating the sustainable integration of renewable energy and electric transportation using real-life operational pilots from 4 different EU counties (including the UK). This project was carried out in collaboration with various industry stakeholders, authorities, and research institutions in the North Sea region, with a total of 11 partners. The operational pilots had the common objective of maximising CO2 reductions in 3 different ways: i) by optimising renewable energy (PV) utilisation, ii) by maximising the clean kilometres travelled by EVs, and iii) by using batteries for grid services. The SEM strategy developed by Wang has been adapted and implemented by the industry partners who participated in these pilots, informing their energy coordination strategies.

More specifically, the following 4 operational pilots, of different scales and conducted in different locations, have showcased the following lasting benefits that can be achieved by adopting the SEM approaches:

- **Loughborough 'Living Lab', UK:** This pilot adopted SEEV4-City SEM research in equipping a typical 3-bedroom house with 4-kWp solar panels, a 2-kWh battery storage system, a Nissan Leaf EV and a commercially available domestic vehicle-to-grid (V2G) charger. By applying the smart charging method, the EV was charged from excess solar generation and discharged to supply household demand. As a result, the clean kilometres of the EV have increased by 5% [**C1**]. According to the house's owner, "Being part of this trial has been a real eye opener and helped me see the value of the different technologies. I've really enjoyed knowing that I'm getting the most out of my PV" [**C2**].
- **Vulkan Real Estate Building, Norway:** This pilot adopted SEEV4-City SEM research in helping the most advanced EV charging garage in Norway, and one of the largest in the world (equipped with 100 smart V2G-capable chargers, 2 fast chargers and 50-kWh battery storage) to promote further EV adoption. Vulkan operates for professional users of EVs such as E-taxis, electric freight vehicles and EVs for craft & services during the day, whilst offering free residential parking for people living in the neighbourhood at night. The pilot has led to

significant ongoing equivalent CO2 emissions savings for Vulkan (amounting to 8 tons in 2017 alone), and a 20% reduction of peak electricity consumption [**C3**].

- **The Johan Cruijff ArenA, Amsterdam:** This pilot adopted SEEV4-City SEM research in further developing one of the most sustainable multi-functional stadiums in the world, capable of supplying power during major sporting events and concerts for up to 68,000 visitors. Prior to the pilot, the stadium had achieved a self-sufficiency rate of around 12% from renewable generation, due to the efficient use of 1.128 MWp rooftop solar installations. The pilot contributed towards additional CO2 emission savings of 2,012 tons by 2020, via network services provisions using stationary battery storage and V2G smart chargers [**C4, C5**]. A more detailed breakdown of these savings is given in Table 1. This impact is continuous, and (as stated on the project's website), "can serve as a development model for other stadiums worldwide".

Table 1: CO2 emission saving achieved by the Johan Cruijff ArenA from the SEEV4-City project [**C5**]

| | **Initial stage** | **End of Project** |
|---|---|---|
| | **Value** | **Value** |
| **A.1 Pilot CO2 footprint [ton CO2]** | **3,587** | **3,468** |
| A.1.1 CO2 related to baseline demand [ton CO2] | 3,987 | 3,987 |
| A.1.2 CO2 related to use of battery: EV [ton CO2] | 0 | 62 |
| A.1.3 CO2 related to use of battery: BSS [ton CO2] | 0 | 0 |
| A.1.4 CO2 savings by PV production [ton CO2] | -399 | -399 |
| A.1.5 CO2 savings by ICE to EV replacement [ton CO2] | 0 | -182 |
| **A.2 Grid services [ton CO2]** | **0** | **-1,893** |
| A.2.1 Frequency Containment Reserve [ton CO2] | 0 | -1,890 |
| A.2.2 Battery as back-up services (replacement of diesel generators) [ton CO2] | 0 | -3 |
| **Total CO2 savings from project by 2020 [ton CO2]** | **2,012** | |

- **The city depot of Kortrijk, Flanders:** This pilot adopted SEEV4-City SEM research to help the city depot of Kortrijk coordinate smart EV charging with PV energy generation, maximising the utility of their 77-kWp PV system and 24 kWh EV. As a result, clean kilometres in the pilot have shown potential increases of 4% [**C6**]. SEEV4-City's SEM research also led to a decision to replace an internal combustion engine vehicle at the Kortrijk depot with an EV for postal deliveries, which has achieved (projected) annual CO2 emission savings of 1.29 tons [**C6**]. Kortrijk strives to be the first city in Flanders to become energy neutral.

Throughout its lifespan (up to 2020) the SEEV4-City project has also organised regular webinars and seminars for audiences including industry stakeholders, policymakers and academics from different European countries [**C7**]. This has facilitated the productive dissemination of our SEM research, and wide-ranging discussions of CO2 emissions reduction practices and policies. The testimonials of the key players who adopted the proposed SEM strategy were presented at these events, highlighting the benefits of the research work undertaken.

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

This section lists the sources in the form of pilots' testimonials from the SEEV4-City project website and newsletters

**C1.** Loughborough 'Living Lab', https://www.seev4-city.eu/projects/loughborough/
**C2.** SEEV4-City: Latest project news, Vehicle-to-Home: Loughborough Living Lab, https://us5.campaign-archive.com/?u=29a8e09c1514209da0a2c9d08&id=20eeda211b
**C3.** Vulkan Real Estate Building, https://www.seev4-city.eu/projects/oslo/

**C4.** The Johan Cruijff Arena, https://www.seev4-city.eu/projects/johan-cruijff-arena/
**C5.** J. Warmerdam, J. van der Hoogt and R. Kotter, "Final report – Johan Cruijff ArenA Operational Pilot", Final Report of Interreg North Sea Region SEEV4-City project, SEEV4-City-Johan-Cruijff-ArenA-Operational-Pilot-Final-Report.pdf (seev4-city.eu)
**C6.** SEEV4-City Newsflash, Impact of smart charging, electric vehicles and relighting on energy autonomy and peak load of a city depot in Kortrijk (B), https://mailchi.mp/seev4-city.eu/seev4-city-newsflash-1201821?e=3d0c9a53a9
**C7.** SEEV4-City Closing Webinars, http://event.seev4-city.eu/#webinars

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