Institution: Oxford Brookes University

Unit of Assessment: 12, Engineering

Title of case study: Transitioning to the 'new normal' of electric vehicles

Period when the underpinning research was undertaken: 2004 to present

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:
Prof A Hutchinson	Head of Sustainable Vehicle Engineering Centre (SVEC)	[text removed for publication]
Prof D Morrey	ECM Research Lead	
Dr M Raugei	Senior Research Fellow	
Dr S Savage	Research Fellow (SVEC)	
Dr P Winfield	Deputy Head (SVEC)	

Period when the claimed impact occurred: 1 August 2013 to 31 Dec 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

The need for more sustainable transport solutions has never been more pressing. Enabling the shift to electric vehicles globally requires both innovative engineering, and detailed understanding of driver expectations and behaviours. Multi-disciplinary research at Oxford Brookes University's Sustainable Vehicle Engineering Centre (SVEC) since 2004 has uniquely addressed the economic, technical, social and environmental aspects of electric vehicles and personal mobility. Through collaborations with the industry, local government and public-private partnerships, SVEC has had impact in two distinct areas:

- Substantial commercial gain for a major automotive manufacturer, BMW, who used SVEC's research to inform the technical development of their electric cars, and benefitted from guidance on building wider acceptance of electric vehicles in their markets globally.
- Influencing UK transport policy on electric vehicle adoption as a result of trials, and influencing policy on powered light vehicles through collaboration with the Low Carbon Vehicle Partnership.

2. Underpinning research

For individual transport to become more sustainable it must become smaller, lighter, energy-efficient, recyclable and use renewable energy sources. Future light duty vehicles (cars and vans) must use fewer primary material resources. Since launching the Engineering and Physical Sciences Research Council (EPSRC)-funded *DRIVENet: Network for the design for dismantling, reuse & recycling in road vehicles* in 2004 (GR/S87577/01, 2004–2007, PI: Hutchinson), Oxford Brookes University's (OBU) Sustainable Vehicle Engineering Centre (SVEC) has produced world-leading research on energy, emissions and materials resource challenges facing the international automotive industry. This has included important work on: lightweight vehicles that could be designed for dismantling and materials recovery; electric powertrains and battery technologies whose component parts can be recycled; and vehicles with a reduced use phase energy consumption that is derived from renewable energy sources.

Further, electric transport is inextricably linked to the electricity grid, both in terms of direct energy use and energy storage in vehicle batteries that can be used to deliver energy *into* the grid during times of peak demand. A thorough understanding and modelling of this new energy and transport nexus was required to deliver a new robust, low carbon approach.

SVEC's research in electric vehicle (EV) introduction and e-mobility provides a fundamental and detailed understanding of these energy requirements through unique modelling and analysis **[3.1]**.

SVEC created a new methodology for sustainable vehicle design, to enable detailed evaluation of the whole life energy and economic implications of combining different forms of powertrain, components, materials, processes and recycling techniques **[3.2]**. This was achieved by combining database information with detailed Life Cycle Assessment (LCA) models in a multi-partner EPSRC-funded project entitled *Towards Affordable, Closed Loop Recyclable Future Low Carbon Vehicle Structures* (TARF-LCV) (EP/I038616/1, 2011–2016, Co-PI: Hutchinson) and incorporating whole lifecycle energy analyses with predictions of the market growth of electric and hybrid vehicles **[3.3]**.

As a long-standing collaborator with OBU, BMW Group chose SVEC in 2009 to lead the technical and psychological research elements of the flagship Technology Strategy Board (TSB)-supported *MINI E* project in the UK (TP11/LCV/6/I/BF045J, GBP3,360,724 plus up to 50% contribution from industry, 2009-2011, PI: Hutchinson). The project included electric vehicle trials in Oxfordshire as part of *Project i* (BMW's holistic approach to future personal transport). Project partners included Scottish and Southern Energy who supplied the home/public charging technology and electricity, Oxford City Council and Oxfordshire County Council who provided infrastructure support, and the South East England Development Agency (SEEDA) who brokered local partnerships to facilitate vehicle trials. Key deliverables of OBU were demographics of potential customers, an in-depth understanding of their mobility needs and an analysis of underlying motivations relating to the attractiveness of driving EVs. This involved two six-month trials of 40 vehicles (effectively 'beta test' MINI-Es) with 138 private and fleet drivers, combining objective data-logger information with subjective driver data. Data-loggers analyzed the energy drawn from the grid for both home and public charging, and the energy consumed directly by the cars. This determined the effects of temperature on battery performance during winter weather, the energy used by the vehicles' ancillary systems, patterns of driver charging and locations of charging, charging efficiency and overall energy use.

SVEC was supported by OBU's Department of Psychology who analysed the social and psychological aspects of driving electric cars through questionnaire design, diary development, focus groups and interviews with drivers to analyse attitudes and experiences over time. This enabled OBU to reveal critical factors underpinning customer motivation, covering initial attitudes, adaptation to new technologies and behavioural change. It became clear that what drives consumers is convenience, emphasizing the vital role that home-charging would play in the future uptake of EVs. Additionally, SVEC developed new business models for BMW to quantify the scale and market potential for EVs in the vital UK business fleet context **[3.4]**; this sector accounts for 60% of new UK sales and is therefore fundamental to understanding a viable business proposition. At BMW's request, SVEC surveyed 10% of this market via BMW's premium fleet customers and developed business models comprising volumes, market sectors, pricing stances and routes to market **[3.5]**. This confirmed the opportunity for new vehicle sales volumes.

3. References to the research

[3.1] Sweeting, WJ, Hutchinson, AR and Savage, SD (2011). 'Factors affecting electric vehicle energy consumption'. *Sustainable Engineering* 4(3):192-201.
DOI: 10.1080/19397038.2011.592956

[3.2] Sweeting, WJ and Winfield, PH (2012). 'Future transportation: Lifetime considerations and framework for sustainability assessment', *Energy Policy* 51:927-938.
DOI: 10.1016/j.enpol.2012.09.055

[3.3] Raugei, M, Morrey, D, Hutchinson, AR and Winfield, PH (2015). 'A coherent life cycle assessment of a range of light-weighting strategies for compact vehicles', *Cleaner Production* 108 Part A:1168-1176. DOI: 10.1016/j.jclepro.2015.05.100

[3.4]* 'New Business Model Opportunities: Potential for Electric Vehicles in the UK'. Confidential project report, MINI E Project UK, SVEC, Oxford Brookes University, April 2011.

[3.5]* 'New Business Model Opportunities: UK Fleet Market Potential for Alternatively-Fuelled Vehicles'. Confidential project report, MINI E Project UK, SVEC, Oxford Brookes University, August 2011.

*can be supplied by OBU Research Business & Development Office on request

4. Details of the impact

Sustainable personal travel solutions for individuals, families and business are a critical element of future transport strategies in the UK and internationally. SVEC's cross-sector, multi-disciplinary, research into the economic, technical, social and environmental aspects of electric vehicles, including battery pack manufacture and recycling, have had significant impact on automotive manufacturers and those planning future transport policy. As noted by Andrew Smith MP in 2015, Higher Education Innovation Fund support was used to set up the Sustainable Vehicle Engineering Centre at Oxford Brookes University: *"That has been used by BMW and all the major automotive companies in the development of electric vehicles. The university has just launched an innovative new undergraduate degree in business and automotive management, in partnership with BMW. That is university innovation in the lead in a crucial national industry"* **[5.1]**.

Impact on development of the BMWi3 and general market acceptance of EVs

The MINI E project was designed by BMW Group as a path-breaking field trial in the early days of electro-mobility. It aimed to gain insights into real life usage and customer expectations of Electric Vehicles (EVs) prior to any vehicles coming to market. There were six trials in total across Europe, Asia and the USA, and SVEC was the lead scientific partner in its UK trials (2009-11). Oxford City was an early major beneficiary of the electric vehicle trials, with around 80 public charging points installed or planned around the city. In 2019, Head of Government Affairs, BMW Group (UK) wrote to Professor Hutchinson, Head of SVEC, confirming that the company "*highly value the output of the research performed by your team at Oxford Brookes University, and the way in which it has benefitted all 'BMW i" projects after the 'MINI E*'" **[5.2]**. Specifically, the BMW Group highlighted that the results of the MINI E UK project had direct influence on their electrification strategy, the developments of the BMW *i*3 and ultimately the MINI Electric, and helped to inform policy-making decisions as well as other EV market stakeholders **[5.2]**.

SVEC's key contribution to the MINI E UK project was the collation and analysis of vehicle energy use and electricity grid data, plus strategic market analysis, to inform BMW developments in battery management, optimised cabin heating, grid connectivity and business segments for future marketing policy. Furthermore, SVEC worked together with colleagues from the Department of Psychology (OBU) who analysed the social and psychological aspects of driving electric cars, over time. These findings helped to inform BMW's vehicle cabin design and vehicle interfaces. It also allowed BMW Group to understand how drivers respond to electric cars in terms of expectations, behaviours and opinions. Head of Government Affairs, BMW Group (UK) stated: *"…the results proved the vital role charging at home has as a key argument to win potential customers. This strongly shaped public decision making for charging infrastructure as well as BMW Group's activities in offering installation services as a part of the vehicle purchase process. Results achieved by Oxford Brookes on the MINI E's characteristics in respect to the enjoyment level in the strong dynamics of electric vehicles also strongly influenced the future BMW "i" strategy"* **[5.2]**. OBU research findings were reviewed at project meetings and workshops in UK and Germany and influenced designers, engineers and business decision-makers. The company also emphasised that *"the customer data and insight, in which Oxford Brookes were so instrumental in delivering has proved immensely useful too, especially in political conversations throughout the world"* **[5.2]**.

The MINI E UK project proved to be a strong basis for development of the BMW "*i*" brand. The early project findings informed development of the 2011 BMW Active E, an electric derivative of the BMW 1 Series Coupe used to validate future powertrain developments, in preparation for the 2013 BMW *i*3, the first purpose-built EV from the BMW Group **[5.2]**. The *i*3 EV production began in September 2013 and it has been a highly successful model with more than 200,000 units sold worldwide by October 2020 **[5.3]** (sales value ~GBP6billion). It is now in its third evolution, with a larger battery pack and two performance versions.

The BMW Group has fully committed itself to electrification since the inaugural *i*3. By the end of 2019 BMW had sold over 500,000 electrified vehicles **[5.4]**. In September 2019, the MINI Electric made its public debut at the Frankfurt motor show and the first UK cars were delivered in March 2020. BMW Group said: "*MINI Electric is probably the best local success story, as what set out as a British applied research project many years ago has come full circle with the local production of*

the MINI Electric in the Oxford plant" **[5.2]**. The firm's Oxford plant built more than 11,000 units by the end of July 2020 – more than 3,000 of which found homes on UK driveways, making Britain the EV's second largest market **[5.5]**. The Managing Director of MINI's Plant Oxford noted: "*Everyone at Plant Oxford is immensely proud that our hard work integrating MINI Electric into the production line is paying off, with the car proving so popular with customers in the UK and around the world. As the home of the brand, it gives us huge satisfaction to build the first fully-electric car in the MINI product line-up here in Oxford, for global export*" **[5.5]**. By 2021, BMW Group will have five all-electric models, including MINI Electric and BMW *i*3, *i*X3, *i*4 and *i*NEXT. Additionally, they are committed to bring 25 electrified vehicles to the market by 2023 **[5.2, 5.4]**.

Further influence on general acceptance of, and implementation strategies for, electric vehicles was enabled through collaboration with the UK Centre of Excellence for Low Carbon and Fuel Cell Technologies (CENEX). Together, OBU and CENEX combined information on driver adaptation, infrastructure requirements, cost barriers, EV charging behaviour and energy use, from all eight of the UK Ultra Low Carbon Vehicle (ULCV) trials to provide a national picture for the Technology Strategy Board (TSB) and Office for Low Emission Vehicles (OLEV) **[5.6]**. CENEX later reported: "*The programme outcomes identified infrastructure and cost barriers that influenced subsequent Government policy and actions such as further funding for EV deployments, learning activities, Plugged-in-Places funding to help urban regions with infrastructure installation … and undoubtedly influenced OEM EV developments and UK government policy"* **[5.7]**. This is evidenced in the government's continuing commitment to electrification through subsidies for EV purchase and home charging installation, zero road tax, provision of public charging infrastructure and unification of charge point access and payment for customers.

Impact on transport policy

Professor Hutchinson was an influential member of the Board of the Low Carbon Vehicle Partnership (LowCVP) 2014-16. This public-private partnership, part-funded by the Department for Transport (DfT), exists to accelerate a sustainable shift to lower carbon vehicles and fuels. SVEC's whole life cycle research outputs, brought to the Board by Hutchinson, focused attention on energy and emissions of different vehicle types. The Managing Director of LowCVP stated: *"…the work Oxford Brookes carried out, on the applications and on Life Cycle Analysis of the sector, represented a unique assessment of the broad full life GHG impact potential of the PLV (Powered Light Vehicle) relative to the existing body of work for conventional vehicles"* **[5.8]**. SVEC's research emphasized the need for small urban EVs and our life cycle assessment data and analysis were included in reports and supporting recommendations for adoption of future urban transport, such as '*Micro Vehicles - Opportunities for L-Category Vehicles in the UK'* (LowCVP, 2019) **[5.9]**. *"The valuable work Oxford Brookes helped deliver within a unique collaboration of academic institutions in support of the LowCVP PLV initiative. The work LowCVP and the group have developed on PLV has been referenced within our subsequent activity on commercial vehicle applications, the 'Future of Mobility' consultations and within the overall Transport Decarbonisation plan due to be published by DfT* (in Spring 2021). *We fundamentally believe, based on the original work from our academic PLV interest group, that there is a huge opportunity for this vehicle category to contribute to both UK industrial strength and to the decarbonisation of UK transport in pursuit of our Net Zero targets".* **[5.8, 5.10]**.

In summary, SVEC's multi-disciplinary and cross-sector approach to analysing and addressing the technical and social elements around the transition to electric vehicles, has benefitted the automotive industry, consumers and transport policy-makers. It has played an important part in enabling the shift to the 'new normal' of electric vehicles, which has environmental benefits for us all. Further, our life cycle assessment model outputs are informing policy debate and strategic investment in UK battery manufacturing and recycling. Our work since 2011 has addressed the circular economy for electric vehicle traction batteries with a TSB pilot project, followed by a multi-partner EU Framework 7 project. We are now a partner in the Faraday Institution, EPSRC-funded, multi-partner GBP9,354,458 Reuse and Recycling of Lithium Ion Batteries (ReLIB) project (FIRG005, 2018-2021, Co-PI: Hutchinson).

5. Sources to corroborate the impact

[5.1] A Smith MP (Oxford East (Lab)). Hansard, 24th June 2015.

[5.2] Head of Government Affairs, BMW Group (UK). Letter to Oxford Brookes University, 14th November 2019.

[5.3] Press releases by BMW Group: i) *Six years of BMW i3: Electric vehicle pioneers drive over 200,000 km in their BMW i3* (02.01.2020) and ii) *First of its kind and innovation driver for sustainable mobility: 200 000 BMW i3 produced to date* (16.10.2020).

[5.4] BMW Sustainable Value Report 2019. Available at: https://www.bmwgroup.com/content/dam/grpw/websites/bmwgroup_com/responsibility/downloads/en/2020/2020-BMW-Group-SVR-2019-Englisch.pdf

[5.5] Examples of news items about MINI Electric: i) Autocar, *New Mini Electric revealed as affordable Brit-built* EV (09.07.2019) and ii) Auto Express, *MINI Electric production passes 11,000 unit milestone* (30.07.2020).

[5.6] S Carroll et al (2013). 'Assessing the viability of EVs in daily life', Final Report, CENEX and Oxford Brookes University, September.

[5.7] Head of Transport, CENEX. Letter to Oxford Brookes University, 11th December 2019.

[5.8] Managing Director, Low Carbon Vehicle Partnership. Letter to Oxford Brookes, 14th October 2020.

[5.9] LowCVP (2019) 'Micro Vehicles – Opportunities for Low Carbon L-Category Vehicles in the UK'.

[5.10] MCIA (2019) 'The Route to Tomorrow's Journeys: Powered Light Vehicles – Practical, Efficient & Safe Transport for All'. Available at: https://mcia.co.uk/en/the-route