

Powering trains with renewable energy

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In August 2019, Riding Sunbeams, a value-led business, demonstrated for the first time ever that it is possible to power railways directly with solar energy. Exploiting this huge transport decarbonisation potential depends on changes to policy and regulation, and interpretation thereof, to procure and value the multiple benefits of sector coupling.

Introduction

Sector convergence between transport providers and decentralised and decarbonised electricity suppliers at the grid edge is often assumed to involve big data, digital platforms and app-facilitated user-centricity. Such innovations, however, appear to be less significant for the electrification of railways. Despite over 100 years of experience, railway electrification remains difficult and costly, with few countries fully electrified and none fully decarbonised. Railway traction power currently relies on dispatchable (synchronous) energy resources. As these are mostly supplied by fossil fuels, such as gas and coal (but also biomass) or nuclear power, such electrification does not necessarily contribute to decarbonisation targets. This reflects the co-evolution of fossil energy systems and railways systems:

Both national electricity grids and the railway shadow electricity grids tend to be dominated by AC (Alternating Current) and 25kV lines to maintain the same frequency.

Both infrastructure systems support self-reinforcing carbon intensive practices which blind actors to innovations outside their siloes (Kuzemko et al. 2016).

Breaking this path-dependency requires radical innovation. Digital connectivity, however, which is driving electrification and sector convergence between decentralised and decarbonised electricity supply and individual mobility demand, plays only a minor role in this process. Converging this supply with centralised mobility demand requires more conventional technological demonstration, regulatory compliance and de-risking procurement.

Riding Sunbeams has technically proven that it is possible to match intermittent direct-wire solar energy (asynchronous) supply with the regular (synchronous) demand required for the reliable operation of railways (Nolden et al. 2020). Using the case study of Riding Sunbeams, this pa-

per explores the changes to policy and regulation required to procure and value the multiple benefits of converging decentralised and decarbonised renewable energy supply with railway traction demand.

Solar-powered trains

This section includes a sub-section providing background information on railway electrification in the UK before introducing the case study. This is followed by sub-sections exploring barriers, opportunities and solutions. The final section concludes with some regulatory implications.

Network Rail and UK railway electrification

Network Rail is a regulated public enterprise which owns and operates British railway infrastructure. It is the UK's largest single electricity purchaser (on behalf of train operating companies) with current (2018) demand of around 3.5TWh/a, representing around 1% of total UK electricity demand. It also procures around 700m litres of diesel/a as 42% of UK railway tracks are not electrified and 29% of the UK's current fleet is run solely on diesel. As a result, Network Rail is responsible for around 2.5% of transport related carbon emissions, which in turn comprise around 26% of total UK emissions (Mayers and Bamford 2019).

4,000-4,250 route km will need to be electrified using low-carbon sources to help reach the UK's zero-carbon target. Conventional electrification in the UK using grid supply points and overhead AC gantries, however, costs around two and a half times the European average (Smith 2019). To complicate matters, incremental improvements adopted in the current policy, financial and operational environment are not deemed sufficient to deliver decarbonisation "anywhere near fast enough," especially given the expected increases in demand and electrified track (RIDT 2019: 8).

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This issue has been recognised by the UK's Department for Transport. It has consequently provided several rounds of Small Business Research Initiative (SBRI) First of a Kind (FOAK) funding to support alternative decarbonisation and electrification options which support the 4Cs of Cost reduction, Carbon reduction, Capacity increase and Customer satisfaction. Supported technologies include hydrogen, batteries and direct-wire supply. While hydrogen is dependent on the development of new infrastructure and batteries still lack the energy density to power trains, direct-wire supply combines repurposed off-the-shelf technology with a high technology readiness level.

Demonstrating solar-powered trains

To this end, Riding Sunbeams' First Light project was awarded £350,000 of SBRI First of a kind funding in 2018 for the period between March and November 2019. This funding supported the installation of a 37.5kWp solar PV demonstration system at Aldershot, on a busy commuter route southwest of London, to connect solar energy directly into the traction power supply network. Several technological issues relating to signalling and harmonics needed to be overcome before the site was finally completed. In August 2019, Riding Sunbeams demonstrated the technical viability of connecting solar electricity directly into 750v DC (Direct Current) third rails found across some rail systems in the UK, Spain, South Africa and India and most metro rail systems (Murray and Bottrell 2017; Murray and Pendered 2019).

As part of the First Light project, data from data loggers was used to build digital twins using a Real Time Data Simulator at the University of Birmingham. This allowed the findings from the demonstrator site to be scaled up to prove the viability of >2MWp solar farms, using different inverters in the process. On busy Kent, Sussex and Wessex routes, around 540 substations provide connection points for trackside renewable energy developments, each of which are capable of accommodating at least a 1MWp solar farm. Due to the intermittency of both load and supply, a maximum of 15% of the total traction demand of these routes (1.38TWh/a) can be supplied by solar power without significant upgrades. This represents a £17.1m/a market at current prices (Murray and Bottrell 2017; Murray and Pendered 2019).

Commercially, Riding Sunbeams has proven that this innovation can help the UK's rail infrastructure operator Network Rail meet its business, social and environmental objectives through energy procurement and through capital sourced from outside the company. Legally, it has

identified the means for Network Rail to procure this innovation through an Innovation Partnership (Nolden et al. 2020). Both demonstration and simulation enabled Riding Sunbeams to provide evidence regarding its contribution to the SBRI First of a kind 4C business objectives:

Cost reduction: direct-wire solar traction power can be supplied at the same or at a lower price than Network Rail's current grid electricity procurement contract and without capital investment by Network Rail.

Carbon reduction: direct-wire solar traction power is the lowest carbon option available to Network Rail.

Capacity increase: direct-wire solar traction power can be provided in grid-constrained areas where bottlenecks limit the amount of electricity that can be supplied through transmission and distribution networks.

Customer satisfaction: the possibility of community and commuter co-ownership of direct-wire solar traction power supply assets provides the basis for public buy-in and democratic control of supply assets.

By enabling Network Rail to take solar traction power innovation through compliance, Riding Sunbeams' First Light project provides an opportunity for Network Rail to future-proof its business model and consolidate a bottom-up self-regulatory approach pre-empting more stringent regulation. Close collaboration with commercial and legal experts provides the basis for Network Rail to procure this innovation and facilitate convergence between decentralised renewable energy generation and traction energy demand (Nolden et al. 2020).

Barriers

Despite successful technical demonstration, simulated up-scaling and contribution to the 4C objectives, several commercial and legal barriers need to be overcome to reduce the risk and transaction costs of procuring direct-wire electricity through a Power Purchase Agreement (PPA). Compared to other sectors where PPAs have rapidly diffused as a means to procure electricity, the abovementioned path-dependency of railway systems manifests itself in distinctive regulatory institutions and shared norms, identities and missions (Kuzemko et al. 2016).

Prioritisation of safety and security of supply, together with high specificity and legacy infrastructure, do not lend themselves to innovation. Preference for single supply contracts represent a barrier to entry for innovative decentralised grid-edge solutions. These issues, together with opaque decision-making structures within Network Rail and perceived regulatory constraints, result in high (per-

ceived) risk and transaction costs. Opportunity costs result from Network Rail's long-term supply contract with EDF (Energie de France). This contract matches traction energy demand with electricity generated from EDF's eight nuclear power stations, which implies that trains mostly run on nuclear power.

While this is low carbon in principle, Network Rail recognises that direct-wire solar traction supply provides more diverse, flexible and adaptable decarbonisation and electrification opportunities. However, the EDF contract, according to Network Rail, is "put in place for the whole of Network Rail to obtain economies of scale and reduce the number of contractual meetings" (Network Rail 2017). Demonstrating this innovation at scale is considered necessary to address Network Rail's concerns regarding the consequences of large amounts of asynchronous supply for the reliable operation of railways. Overall, more evidence of the benefits of this innovation is required for Network Rail to consider procurement of this innovation alongside its electricity supply contract with EDF.

Opportunities

Aside from the benefits relating to the 4C business objectives, further social benefits of this innovation have been identified through the development of a social impact framework. This framework, which was also supported by the SBRI First of a kind funding, identified benefits which can help Network Rail fulfil the requirements of the UK Public Services (Social Value) Act 2012 (UK Government 2012). Relevant to this innovation are requirements to diversify supply chains, especially towards small and medium-size enterprises (SMEs), social enterprises and not-for-profit organisations. As Riding Sunbeams falls under the first category, and its parent companies Possible and Community Energy South fall under all three categories, procuring their direct wire solar traction power can contribute to the fulfilment of these requirements, again without capital investment by Network Rail.

The Utilities Contracts Regulation 2016 provides Network Rail with a framework to engage in alternative procurement arrangements (UK Government 2016). Rather than a strict dichotomy between pre-commercial R&D procurement and commercial procurement, it enables the establishment of Innovation Partnerships. Such partnerships provide utilities such as Network Rail with the mechanism to award contracts based on the assessment of qualitative, environmental and social aspects alongside price and cost (Regulations 82, 83 and 86 of the Utilities Contracts Regulation 2016). To enable procurement that

takes such values into consideration, the governance of Network Rail's business model needs to evolve accordingly.

Network Rail's business model is primarily regulated through the Office of Rail and Road (ORR), the Department for Transport (DfT), the Minister for Rail and the UK's devolved governments. ORR is responsible for ensuring a punctual and reliable service and the delivery of enhancement projects according to budget. For the current financial and regulatory Control Period 6 (CP6 – 2019-2014), ORR has devolved budget and responsibility towards Network Rail's eight geographical routes. This enables the routes to buy goods and services locally rather than centrally if they offer better value for money. Although this devolution does not explicitly include the possibility of procuring energy locally, ORR stresses that "routes have a choice over their own procurement, unless there is evidence this is inconsistent with Network Rail's other obligations in the network licence" (ORR 2018: 36).

Discussion

Combined, the Public Services (Social Value) Act 2012, the Utilities Contracts Regulation 2016 and the devolution of procurement responsibilities provide the means for Network Rail to directly procure solar traction power through one or multiple PPAs without challenging or breaching the long-term nuclear traction power supply contract with EDF. Innovation Partnerships at the scale of routes, rather than the whole of Network Rail, provide 'incubation space' to experiment and provide evidence as a blueprint to scale up and embed social and environmental criteria in open-market tendering once Innovation Partnerships have been terminated.

This provides the basis for long-term engagement with innovators with non-traditional business models, unfamiliar constitutions and unconventional trading histories, such as social enterprises and value-led businesses like Riding Sunbeams. Such changes help plant the seeds of change which are necessary for structural transformation through sector coupling to achieve net-zero carbon emissions. They also provide railway system with innovative solutions for more efficient public services which create public value beyond the single bottom line of cost efficiency. Rather than just technological diffusion, the procurement of direct-wire solar traction power can therefore set a precedent for recognising the inherent public value that can be created and supported through the procurement of sector-coupling grid-edge innovation. Innovation finance has been crucial in demonstrating the viability of this innovation. Another £400,000 of at-risk finance has been made available through the third round of SBRI First of a kind fund-

ing for Riding Sunbeams' Daybreak project in 2020. This project seeks to demonstrate a direct connection between renewable energy generation and more widely diffused AC overhead line powered rail traction systems. It presents a much greater electrification, decarbonisation and market opportunity compared to First Light's DC solution. A further £2.5m have been provided through the UK government's Getting Building Fund to demonstrate the DC solutions at scale. Both the tested DC solution and the emerging AC solution require procurement at scale to encourage their diffusion. It also needs to be recognised that innovations of this kind are likely to emerge through further and continual engagement with nimble SMEs, social enterprises and value-led businesses with unfamiliar trading histories.

Conclusion

Catalysing solar-powered trains through innovation procurement provides an opportunity for Network Rail to electrify and decarbonise UK rail services through capital sourced from outside the company. By facilitating the inclusion of public value requirements relating to the 4Cs and societal and environmental objectives, together with the diversification of supply chains in open-market tendering procedures, regulators have the capacity to contribute to a just energy transition through transport electrification and decarbonisation. To enable rapid and nationwide roll-out of this sector-coupling innovation in line with Ofgem's Decarbonisation Action Plan and the UK government's net-zero emissions target, grid code, distribution code and railway electrical connection compliance should be revisited to help overcome the complication of integrating renewable energy into distribution networks through railway power infrastructure supply points.

Community and commuter co-ownership of solar power supply assets increases the legitimacy of converging decentralised and decarbonised renewable energy supply with railway traction demand while facilitating local revenue recycling. Procurement in this context needs to be reframed as value-added. This allows railway infrastructure providers such as Network Rail to shift from regulatory compliance towards innovation procurement to create public value and maximise multiple benefits while creating a route to market for non-traditional electricity suppliers and their innovative sector-coupling solutions.

References

Kuzemko, C., Lockwood, M., Mitchell, C. and Hogggett, R. (2016), 'Governing for sustainable energy system change: Politics, contexts and contingency,' *Energy Research & Social Science*, 12: 96-105.

Mayers, M. and Bamford, D. (2019), Decarbonising Britain's railways demands urgent action – here's how it could be done, *The Conversation*, <https://theconversation.com/decarbonising-britains-railways-demands-urgent-action-heres-how-it-could-be-done-124905>, accessed, 13 August 2020.

Murray, L. and Bottrell, N. (2017), *Riding Sunbeams: Powering our railways with solar PV* (London: 10:10 Climate Action, Imperial College London, Community Energy South, Turbo Power Systems, Innovate UK).

Murray, L. and Pendered, O. (2019), *Riding Sunbeams – Before Dawn* (London: 10:10 Climate Action, Community Energy South, The Rural Community Energy Fund).

Network Rail (2017), *Safety Central – Energy Purchasing*, <https://safety.networkrail.co.uk/home-2/environment-and-sustainable-development/energy-and-carbon-management/energy-purchasing/>, accessed 13 August 2020.

ORR (2018), *2018 periodic review final determination – Overview of approach and decisions* (London: Office of Rail and Road).

Nolden, C., Sanchez-Graells, A., Murray, L., Pendered, O., Stone, I. and Wilkins, J. (2020), Riding Sunbeams: Powering our trains with solar PV. *PolicyBristol*, Policy Briefing 79: December 2019.

RIDT (2019), *Final Report to the Minister for Rail* (London: Rail Safety and Standards Board).

Smith, A. (2019), On track for carbon-free rail traction, *Ricardo Quarterly*, Q2 2019, <https://d1v9sz08rbysvx.cloudfront.net/rail/media/resources-downloads/carbon-free-rail-traction-june-2019.pdf>, accessed 10 August 2020.

UK Government (2012), *The Public Services (Social Value) Act 2012*, <http://www.legislation.gov.uk/ukpga/2012/3/enacted>, accessed 13 August 2020.

UK Government (2016), *The Utilities Contracts Regulation 2016*, http://www.legislation.gov.uk/uksi/2016/274/pdfs/uksi_20160274_en.pdf, accessed 13 August 2020.