

The Challenge of Sustainable Innovation through Digitalisation in the UK Railway Sector

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Summary

Sustainability and innovation are nothing new across all industries within the UK. Organisations are looking for more efficient ways to work, and with the added pressure of climate change and sustainability goals, innovation becomes a key success enabler. The UK railway sector in particular is facing consistent challenges when it comes to innovation and sustainability. With the UK being the landlord to the oldest documented railway infrastructure network in history, makes new technology and innovations harder to implement due to the bespoke nature of the infrastructure, which has further implications on cost. Sustainability and innovation implementation is managed through a variety of different strategies that guide infrastructure owners and service providers to achieve the same goal. Aligning with the UN's sustainable development goals ensures that Network Rail are dedicated to adding social, economic, and environmental value, as well as aiming for net-zero carbon, on the global stage. This paper studies how sustainability and innovation is considered within the UK railway sector, and critically appraise the current strategic plans in place to guide the industry in the UK. Digitalisation is a huge driver that is being implemented in conjunction with sustainability but requires innovation as an enabler. The suggestion is that sustainability and innovation should be considered as one, the question is why, and the result is the maximised outputs of value creation.

Keywords: innovation, sustainability, railway, digitalisation

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Introduction

Innovation and sustainability are conspiring topics when considering today's railway infrastructure. In the UK, railway infrastructure owners are at the forefront of pushing the agenda for more sustainable developments to enhance the performance, resilience, and reliability of the services that are on offer to the public.

Network Rail owns most of the UK mainline infrastructure, with London Underground owning the underground network infrastructure in London, and Strathclyde Partnership for Transport owning the underground infrastructure in Glasgow. For light rail and tram network infrastructure, there are many different owning bodies throughout the UK with examples being West Midlands Metro, Nottingham Express Transit, Manchester Metrolink, just to name a few. For the purpose of this paper, only Network Rail are going to be considered as they are the largest infrastructure owner in the UK railway sector.

Sustainability is an objective of most, if not all strategies that railway infrastructure owners are applying in current times. Sustainability can be dissected into three different elements: social, economic, and environmental. The social element is the impact that sustainability has on society and recognising positive impact gains, which in turn links directly with economic, which represents economic growth within society but also for the project in consideration. The environmental element is the most well-known and instils the main goal of sustainability which is to conserve and protect our surrounding environment and the species that live within.

Since privatisation of the UK railway infrastructure, innovation has been at the forefront of everyone's mind and has been viewed as a way to create value (Lovell and Nightingale, 2016). Innovation on the railway is finding ways to make a product, process, service, or technology better (Monitgel, 2013), enabling continuous improvement and value creation by implementing cost effective solutions for a sustainable future.

The known difficulties with sustainability and innovation make it a longer and harder process due to the extensive assurance and value-added realisation that needs to take place. Innovations can be costly so infrastructure owners can often be blinded by cost, further disabling the realisation of a value that an innovation could add for the future. The railway infrastructure, specifically mainline, is amongst the oldest recorded in the world, with many components and processes being bespoke to its nature, which means implementing innovations can be extremely difficult due to their being multiple scenarios and it conditions it must cater for, e.g. the European train control system (ETCS). ETCS is a good example of a good innovation with difficult implementation, due to its initial costs, residual costs, time it takes to implement, and the requirement to be compatible with all rolling stock types on the network, and ensuring the network infrastructure is covered in its entirety with GSM-R (Global System for Mobile Communications-Railway).

The digitalisation of railway infrastructure requires sustainability and innovation to be successful. Making processes and products digital can enhance the performance of a railway network, allowing for additional passenger capability by using more efficient technology further becoming even more cost effective.

Research Gap

It is rarely noted that innovation has a direct link with sustainability. It is also not well-known whether by linking innovation with sustainability, can add value to innovation projects, decision-making, and development of innovations. Many strategies include a combination of innovation and sustainable development but there is no direct connection made between them.

There are numerous developments where innovation is concerned across all industries throughout the world. Organisations and individuals have new ideas to support a more efficient working practice or process all the time. It is imperative that the UK railway sector ensures that no time is wasted in identifying the innovations that are going to have the greatest impact, and to maximise the benefits, sustainability needs to be considered.

Published research on sustainability and innovation as one, is almost non-existent for the UK railway sector. There is an ethical requirement to commence creating a link between the two for the purpose of research and development and can be beneficial to the industry should research be undertaken in detail.

The aim of this paper is to demonstrate the unclear links between innovation and sustainability and why working with innovation and sustainability hand in hand can have a positive impact in the way the railway trains, upskills, strategises, and evolves through digitalisation.

The following objectives have been developed to enable a structured approach towards understanding the links between innovation and sustainability:

1. Understand how sustainability is integrated into the UK Railway Sector.
2. Understand how innovation and digitalisation is integrated into the UK Railway Sector.
3. Investigate the challenges of implementing innovations and sustainability strategies.
4. Explore the links between innovation and sustainability.
5. Develop a strategy for linking and realising sustainable innovation for digitalisation.

The main limitation of this paper is that all research is based on available publications and articles.

Methodology

Reviewing available literature on these topics was complete systematically using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement to meet the objectives as mentioned in the previous section.

A preliminary search was conducted across various electronic library databases to firstly identify a suite of published research to be considered for use. The platforms identified and used for the review are: ScienceDirect, ICE Virtual Library, and University of Wolverhampton Library. Key terms used in the searches are: “railway innovation” OR “railway sustainability” OR “sustainable innovation” OR “digital railway innovation” OR “digital railway sustainability” OR “railway innovation strategies” OR “railway sustainability strategies”.

Any additional material was sourced through various articles and reports due to the lack of relevant literature. It is evident that this type of material can be biased, so a careful approach had to be taken and the purpose of the use of this type of research material had to be limited to information retrieval. Other sources include the likes of Network Rail, ORR, RSSB, United Nations, and HM Government.

To ensure this paper was focused on relevant material, and inclusion and exclusion criteria was adhered to as shown in Table 1.

Table 1 - Inclusion and Exclusion Criteria

	Inclusion Criteria	Exclusion Criteria
Date	2010 – Present	Prior to 2010
Geographic location	United Kingdom – Contribution from the United Kingdom	Not in the United Kingdom or no direct contribution from the United Kingdom
Language	English	Papers other than English

Type	Research Papers, Reports, Published Articles	Book reviews, research notes, dissertations
Publications	Peer Reviewed Articles, Organisational Reports and Publications, Government Reports, Published Textbooks, Conference Proceeding, Industry Specific Articles	Papers focusing on other infrastructure sectors besides the Railway, Discussion Forums
Participants	Organisations (Public or Private) and Researchers contributing to the analysis and information of digitising asset management in the UK specific to the Railway	Non-UK Based Organisations and Researchers
Design	Qualitative, Quantitative, Case Study, Survey, Studies that used a validated methodology	Papers and articles that are not backed by evidence or data
Focus	Is the information relevant to innovation and sustainability on the UK railway? Does the information contribute to the study of digitalisation, innovation, and sustainability strategies?	Information with no relationship to the UK railway sector or innovation and sustainability.

By using advanced filters, it was possible to narrow down any search for published material ensuring only possible relevant material was considered. The year 2010 was used to ensure a suitable cut off in line with the most recent development of sustainable and innovative solutions and strategies, further filtered to be of UK origin or contribution, dedicating research for the UK railway sector only.

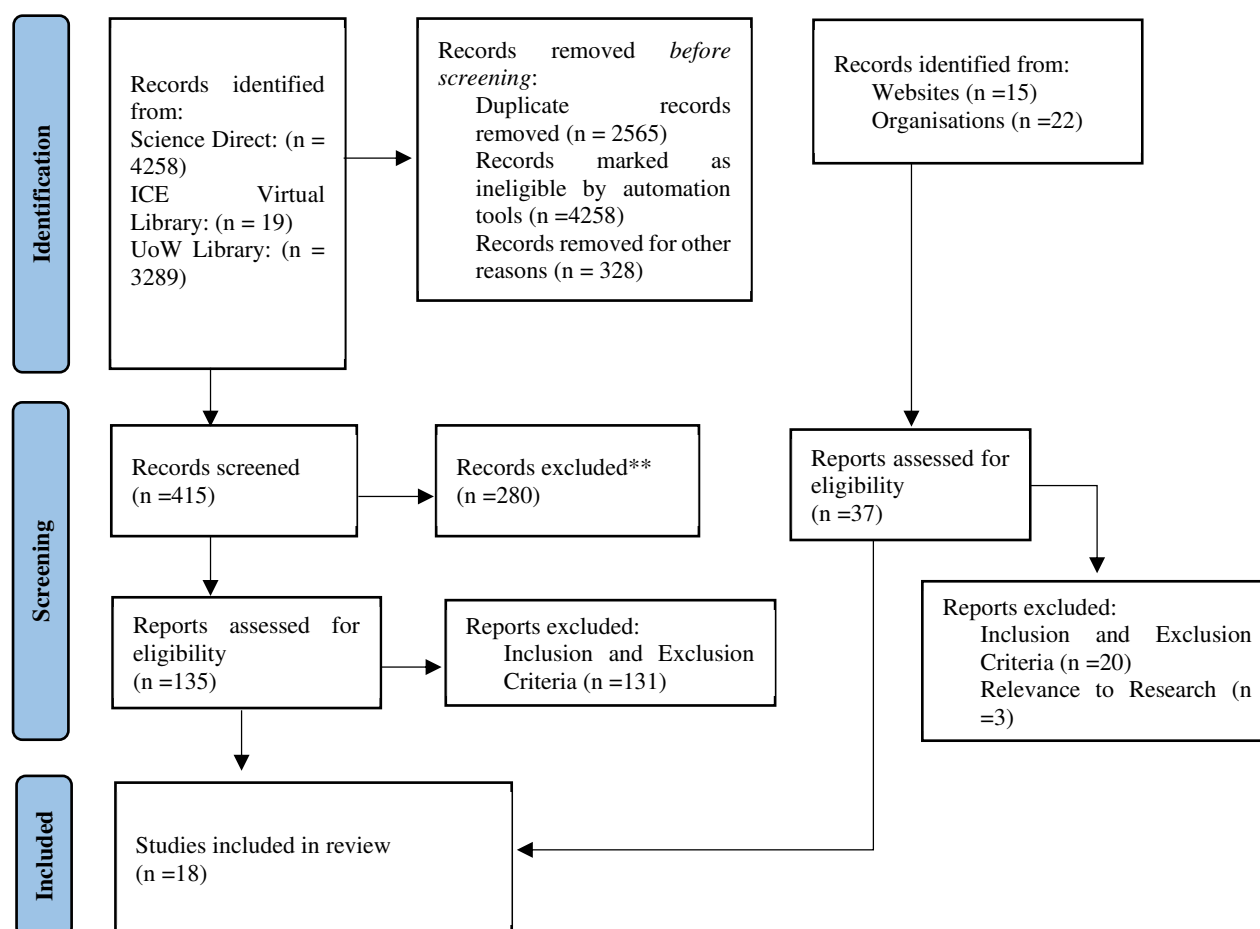


Figure 1 - PRISMA Article Screening Process

Findings

Sustainability

Network Rail are well under-way integrating sustainability into the infrastructure. Using the Environmental Sustainability Strategy (2020), and the Social Value Framework (2021), Network Rail are steering a culture of forward-thinking to future proof the infrastructure. As part of the environmental strategy, Network Rail have four main priorities to deliver their vision of being sustainable (Network Rail, 2020):

1. A low-emission railway
2. A reliable railway service that is resilient to climate change
3. Improved biodiversity of plants and wildlife
4. Minimal waste and sustainable use of materials

In line with the UK Governments target of net zero carbon emission by 2050 (HM Government, 2021), Network Rails Environmental Sustainability Strategy (2020) outlines a road map and key milestones to measure progress against.

For a low-emission railway, Network Rail have two road maps to achieve this objective: greener trains and greener assets (Network Rail, 2020). The Traction Decarbonisation Network Strategy aims to outline efficient and cost-effective selection of alternative power for rolling stock across the network, detailing recommendations for electric, hydrogen, and battery powered services when thinking of decarbonising a route from diesel to something more efficient, providing a case for each alternative power selection and how suitable it is for different purposes (Network Rail, 2020). The need for significant investment into electrifying all main line routes has also been identifying in the Environmental Sustainability Strategy, with decision on the investment expected to be final by 2029, which is a big statement and bolster Network Rail commitment to sustainability (Network Rail, 2020). Implementation of embodied carbon assessments, dust suppression and air quality assessments at all worksites and depots, and 100% renewable energy to be used, are just some of the smaller commitments that can have a huge impact on the net zero carbon goal that Network Rail have set (Network Rail, 2020). This objective has been identified as supporting 4 of the 17 sustainable development goals within the strategy in the following areas; affordable and clean energy, industry innovation and infrastructure, sustainable cities and communities, and climate action (UN, 2023).

Adapting to climate change is a critical factor in Network Rail's commitment to sustainability, with the aim to be able to operate safely without disruption under extreme weather circumstances. The infrastructure is already in place to manage this and has been since 2017, but the need to continue upgrading and future proofing assets is an ever-present theme in sustainability (Network Rail, 2020). Potential impacts of climate change have been identified with major risks including buckling of the track and flooding causing instability of the formation, but the scale of the impact is the biggest unknown which is the main barrier and challenge to being fully adaptive to climate change (Armstrong, Preston and Hood, 2017). Due to the uncertainty around extreme weather, part of the Environmental Sustainability Strategy (2020), is to agree a level of service in extreme weather conditions with various stakeholders to ensure the business can be proactive rather than reactive in service that can be provided to passengers (Network Rail, 2020).

On track with the Environmental Sustainability Strategy (2020), Network Rail released a biodiversity standard, NR/L2/ENV/122, which guides the organisation and supply chain to be compliant with legislation such as, but not limited to, The Conservation of Habitats and Species Regulations 2017, and manage land and activities sustainably. The biodiversity standard is split

into two parts covering the management of biodiversity and habit management, to ensure that the planning process along with requires plans and permits are in place and sustainable. There is also an aim to map out biodiversity along the railway corridor which could enhance the planning process in providing Network Rail with the ability to again be proactive in its approach to sustainable maintenance and construction management (Network Rail, 2020).

Minimising waste and reusing materials is an initiative that Network Rail have identified as a major sustainability objective in the Environmental Sustainability Strategy to help create a circular economy (Network Rail, 2020). In 2017/18, Network Rail managed to divert 98% of waste from landfill utilising the waste materials by recycling and re-using elsewhere on the infrastructure (Network Rail, 2020). This objective also enables the reduction of carbon footprint, further supporting the goal to reach net zero carbon by 2050. Making the most of the materials they have, Network Rail also share surplus material across the different regions using an innovative smart app which helps to reduce abortive cost by using what material is available instead of buying new material constantly (Network Rail, 2020).

The social value framework aligns with Network Rail's mantra to "put passengers first" and strategizes how to maximise the social value creation proactively and positively (Network Rail, 2021). The framework has been built to comply with relevant legislation and regulation such as: Equality Act 2010, Modern Slavery Act 2015, and Public Contracts Regulations 2015, to name a few (Network Rail, 2021). The commitment to comply with legislation and regulation, as well as being in direct alignment with the Environmental Sustainability Strategy, enables social value creation in safety, wellbeing, accessibility, and environmental management, keeping the public and workers safe and healthy whilst providing opportunities for work and better quality of life (Network Rail, 2021). The social value framework also considers the recovery from COVID-19, aligning with the UK governments social value model which details the important of economic prosperity, equal opportunity, and wellbeing, to improve educational attainment, workforce diversity, and physical and mental wellbeing which are all main factors in the social value recovery from COVID-19 (Network Rail, 2021). An important economic goal to note is Network Rail's identification of the importance in helping SME's and VCSE's, as creating a diverse supply chain will increase their ability to broaden the available expertise whilst creating nearly 16 million jobs nationwide (Network Rail, 2020). Many Network Rail strategies have a tangential connection with social value with the aim of creating social value in everything associated with the management and maintenance of railway infrastructure, from suicide prevention to codes of practice which makes it clear that Network Rail want their involvement with all things railway to breed and create social value.

The Environmental Sustainability Strategy (2020) and Social Value Framework (2021) have adopted nearly all of the sustainable development goals to demonstrate the social, economic, and environmental impact the strategies aim to have in the grand scheme of aiming for net zero carbon and sustainable development. The only sustainable development goal not identified within the strategies is number 17, partnership for the goals which aims to "Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development" (UN, 2023) however, this goal being an overarching objective is more of a secondary impact with the strategies due to Network Rail demonstrating how they are supporting sustainable development which feeds into global partnerships by representing the UK railway sector on the global stage.

Innovation

The latest of strategies considering innovation is the Rail Technical Strategy which provides a holistic overview and maps out focus points for innovation throughout the railway sector, from passenger experience innovation to frontline worker innovation (RTS Working Group, 2022).

The RTS Working Group (2022), have established five functional priorities to categorise and break down innovation focus for ease of use.

Easy to use for all is the first of five functional priorities which puts public use of railway services into the spotlight, adopting the “put passengers first” mantra and aligning with sustainability goals (RTS Working Group, 2022). The aim of this priority is to innovate for the purpose of providing accurate real-time information, fare management using smart technology, improved accessibility, on-board connectivity, and personalised experience (RTS Working Group, 2022). Setting these goals will enable the UK railway sector to have a clear understanding of the industry innovation needs under this priority and further bolster development of technology and systems through efficient filtration and selection of innovations. There is a direct link between this priority and the Social Value Framework (2021), as innovation focus will aim improve the passenger experience.

Low emissions, aligning with the Environmental Sustainability Strategy (2020), supports innovation by creating a focus on net zero carbon innovations, helping to create efficient services in terms of cost and pollution (RTS Working Group, 2022). The Traction Decarbonisation Strategy (2020) is an ongoing strategic plan to reduce carbon emissions using energy efficient powered rolling stock, which can benefit from industry concern with the Rail Technical Strategy (RTS Working Group, 2022).

The operational railway has always been a challenge when considering management and efficiency improvements due to the sheer scale and capacity of the network infrastructure. Optimising train operations has become an important part of innovation research and development, more so since the Secretary of State for Transport, Rt Hon Chris Grayling, set the goal of transforming operational management of services through digitalisation (Network Rail, 2018). The functional priority of optimising train operations comes with a list of goals that aim to improve real time operations and decisions and creating a flexible but reliable planning system, but this also requires upgraded signalling and train capabilities which will also increase capacity on the network (RTS Working Group, 2022). Digitalisation of these types of systems require a holistic approach from innovation to installation, maintenance, systems integration, and collaboration, due to signalling systems being an integral interdependency within a standard rail systems operation.

Reliability is a very common theme throughout the railway industry as it is a key success factor. The fourth functional priority, reliable and easy to maintain, expresses the need for better performing assets that are efficient throughout its whole life cycle (RTS Working Group, 2022). Drawing a direct link to the Environmental Sustainability Strategy (2020), the need for reliable assets is apparent with the climate changing year on year and innovation through digitalisation is the way forward as the benefits that can be realised through decision making tools, sustainable product development, and whole life cost analysis will greatly improve assets performance, availability, and maintenance (RTS Working Group, 2022).

The impact of digitalisation means that the railway sector is becoming more and more data driven, which is the fifth functional priority of the Rail Technical Strategy (2022). Digitising processes, and the collection and analysis of data sets new challenges for the railway sector. The goals of this priority focus on robust governance, cyber security, accessibility and use of data, and improved exploitation (RTS Working Group, 2022). Data needs to be made more accessible for the traditional methods of data use and analysis to be modified for more modern techniques, enabling the workforce to make efficient use of the collected data (RTS Working Group, 2022). Capabilities of data driven innovation are endless, and this strategy identifies some capabilities such as artificial intelligence, machine learning, and digital twin technology

for the management of the network infrastructure and services, with added benefits of remotely and efficiently assessing performance indicators (RTS Working Group, 2022).

Challenges with the Implementation of Sustainability and Innovation Strategies

To enable a holistic view on this matter, it is paramount that links are made as challenges with sustainability are often linked with innovation.

One of the most pertinent challenges lies with electrification. The benefits are great but so is the cost, which is why Network Rail are strategically placing electrification in many different objective areas, as discussed within the Environmental Sustainability Strategy (2020) and the Rail Technical Strategy (2022). Discontinuous electrification is a hot topic throughout sustainability and innovation on the railway as it has the potential to provide the same benefits but saving cost on the parts of the network which require major infrastructure changes to facilitate the overhead lines however, this requires a level of battery capacity onboard rolling stock to enable services to still run between any strategic gaps in overheads (IPEX, 2019). Considering reduced costs, low emission services, and a streamlined programme to enable electrification is a solid link between sustainability and innovation.

An area where innovation could positively impact is reducing polluting emissions as there is currently a limited amount of industry knowledge on this topic and although overall emissions are low, locally the emissions are significantly high (RTS Working Group, 2022). Supporting the Environmental Sustainability Strategy (2020), innovation on reducing air quality could be done through various SME's and VCSE's creating social value, even in the preliminary stages of study and research. Network Rail haven't identified any technology that could benefit this issue in their strategy (RTS Working Group, 2022), and only have short term plan to implement intelligent air quality monitoring however, it is known that stop-start technology has found a 50% reduction on the class 66 locomotives (Lo, 2020). With research focusing on innovation and air quality improvement, a sustainable and innovative solution could be achieved, but is currently not part of any strategy.

Social, economic, and environmental value can be added through optimising train operations by improving the reliability, accuracy and performance of services and timetables however, challenges remain in the manual intensive operation of updating and changing routes and times with no technology to update based on actual running times of services (RTS Working Group, 2022). Machine learning has been identified as an innovation that can improve overall efficiency by helping to streamline performance based on real-time data analytics further increasing the effectiveness of decision making (RSSB, 2018), but this technology has not been specifically identified in the Rail Technical Strategy (2022).

Accessibility of data and data driven systems is a growing topic within the railway sector in the UK, but it's full potential hasn't yet been realised, or at least utilised. A skills gap is evident based on the requirements of the Rail Technical Strategy (2022) however, work is underway to fill the gaps and make data more accessible and implemented through the sector. This presents a challenge for all aspects of sustainability on the infrastructure and requires consistent innovation research and studies to enable a solution fit for purpose. With accessibility requiring improvement cyber security presents further risks and more must be done to protect data which is in the interests of the public and organisations. Cyber security is a hot topic across multiple industries, in particular the railway due to the current era of digitalisation and the Office of Rail and Road (ORR) are upping their efforts in their ability to regulate and provide guidance to the rail sector on cyber security and recommend the IET Code of Practice on cyber security for guidance and expansion of knowledge (Appleton, 2022). This enforces the need for safe and

secure connectivity and can support sustainable development through efficient innovation and implementation.

Conclusions and Recommendations

The challenges the railway sector faces with innovation is apparent through the objectives set within strategies. The bespoke nature of the world's oldest railway network, means that innovation is the best way to create efficient technologies, working practices, and processes. But with the aims and objectives of various social, economic, and environmental strategies becoming more crucial year-on-year worldwide, the most efficient way to implement these innovations, would be to have a more robust strategy that sets out aims and objectives for innovation and sustainability as one.

There is a lot of detail to capture within the strategies which can be appreciated, as long as the end-users of these strategies have knowledge of the interdependencies. A simple example of this is the use of smart technology to replace the need for paperwork on site, which on the face of it is a brilliant innovation becoming paperless, but in order to procure smart technology requires mining natural resources and further inducing carbon emissions, so it needs to be looked at from more than just one view. Is the procurement of said smart technology less harmful from a social, economic, and environmental point of view? This is a heavy debate which interdependencies can sometimes get overlooked, as the Institute for Sustainable Communication (2023) suggests neither paper nor digital is more sustainable, it is more a matter of perception, but also that sustainability should be looked at as more of a balance between social, economic, and environmental impact. Based on this, the balancing act of sustainability must form a critical stage of assessing an innovation, so should be included as part of an innovation strategy.

One of the most critical challenges on the railway for sustainable innovation is electrification. Its evidential costly implementation is off-putting to infrastructure owners with an ever-decreasing budget, and a solution has already been identified but it is unknown whether it has been put into practice nationwide yet. Research suggests that discontinuous electrification can add social, economic, and environmental value, whilst requiring innovation to implement particularly with the battery capacity required to power rolling stock between electrified sections. This could be an incredibly advantageous sustainable innovation and it is recommended that this continues to be considered as an efficient option for electrification.

Research suggests innovation and sustainability work hand in hand, but they are not thought of holistically. Network Rail have multiple strategies for innovation, and multiple strategies dedicated to sustainability which are both separated by the distance of thought and coincidentally aim to achieve a better performing railway infrastructure and services. Efficiency is key as demonstrated within the strategies, efficiency forms the basis of everything sustainable and innovative, whether it be cost, workload, performance, time, material, and the list goes on. If efficiency is key, then it begs the question as to why Network Rail have not formally recognised the strategic requirement for guidance and cultural behaviour towards innovation and sustainability as one. There is a strategy for anything that requires a guided, and structured approach to be demonstrated and put into practice. The strategies are also an indirect enabler for cultural change, but different disciplines may focus on specific sustainability areas or innovation areas without the added benefit of a holistic approach.

It is recommended that although innovation and sustainability are spoken of in the same sentence, that this be strategized as one in the form of a Sustainable Innovation Strategy to

focus on main goals of sustainability through innovation. This could further act as an enabler for SME's and VCSE's to narrow down their production and development of solutions with clear positive implications for the railway sector.

It is important to maintain consistency with upskilling and recruitment. The requirement for digitally minded and talented individuals remains crucial to the success of achieving net-zero carbon by 2050. The reason for this is the industry is heading through digitalisation, and being 27 years away from net-zero carbon, with major milestones to be achieved along the way, the next generation must be prepared for a transitional handover from the generation that has begun the transformation and maintain the ideology, but improve how we strategically plan for the future. It is recommended that the current upskilling and recruitment drive be consistently undertaken over the next decade, with a clearer advertisement on the requirements for digital, sustainable, and innovation roles.

To enable a focused approach towards sustainable innovation, the approach should firstly come from what sustainable goal needs to be achieved, then identifying the innovation. Once the innovation has been identified, and preliminary studies have been completed, it must be evidenced how this innovation contributes to value creation in sustainability. If possible, weaker areas of added value should then be improved as much as possible to maximise the sustainable output of the innovation being developed. The flow chart shown in Figure 2 should be used as supporting guidance within a sustainable innovation strategy.

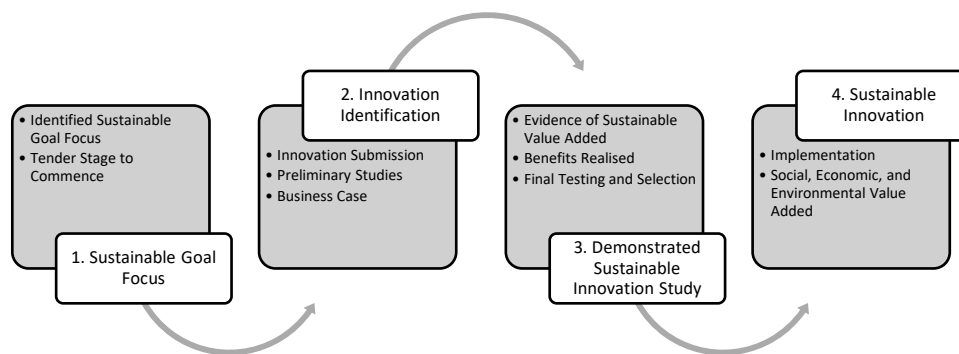


Figure 2 - Sustainable Innovation Flowchart

Using Figure 2 as a very high-level process flowchart, can streamline the process and programme timescales by enabling a more focused approach to innovation. When innovation competitions and tenders are made available to organisations, there is a wide range of ideas that are put forward and every single one of them could be beneficial in their own way but some more relevant than others to the goal that is being considered. By breaking down the requirements into sustainability requirements, this could give more opportunity for ideas to be put forward that are all relevant on the same level and enable a niche type focus for sustainable innovation. Where multiple sustainability goals are attempted to be achieved by a single innovation, it should be evidenced that value added has been maximised for the benefit of the infrastructure and services available. Previously mentioned, is the importance of getting the right sustainable balance, this must be considered at each stage within the flowchart process. With industry input, the process flowchart can be expanded within each stage to suit the needs of the business and would not be limited to the UK railway sector.

References

Appleton, P. (2022) Keeping Britain's railway safe from cyber threats . Available at: <https://www.orr.gov.uk/search-news/keeping-britains-railway-safe-cyber-threats> (Accessed: 03/03/2023).

Armstrong, J., Preston, J. and Hood, I. (2017) 'Adapting railways to provide resilience and sustainability', Proceedings of the Institution of Civil Engineers. Engineering sustainability, 170(4), pp. 225-234. doi: 10.1680/jensu.15.00017.

HM Government (2021) Net Zero Strategy: Build Back Greener Dandy Booksellers.

Institute for Sustainable Communication (2023) Which Medium Is More Sustainable? Paper or digital? Available at: <https://www.sustainablecommunication.org/which-medium-is-more-sustainable-paper-or-digital/#:~:text=Paper%20or%20digital%3F%20The%20simple%20answer%20is%20%28neither.%20The,computers%20don%27t%2C%20so%20digital%20media%20must%20be%20greener.> (Accessed: 06/03/2023).

IPEX (2019) Discontinuous Electrification - Majority Electrification. Available at: <https://www.ipexconsulting.com/insights/thought-leadership/discontinuous-electrification-majority/#:~:text=One%20way%20to%20reduce%20infrastructure%20clearance%20costs%20is,as%20%28discontinuous%20electrification%20%29.Examples%20of%20discontinuous%20electrification%20schemes> (Accessed: 03/03/2023).

Lo, C. (2020) Clearing the air: UK rail's new air quality strategy. Available at: <https://www.railway-technology.com/features/uk-rail-air-quality/> (Accessed: 03/03/2023).

Lovell, K. and Nightingale, P. (2016) 'Business models in rail infrastructure: explaining innovation', Proceedings of the Institution of Civil Engineers. Transport, 169(5), pp. 262-271. doi: 10.1680/jtran.16.00024.

Monitgel, M. (2013) Why is innovation so difficult in railways? Available at: <https://www.railengineer.co.uk/why-is-innovation-so-difficult-in-railways/#:~:text=It%20is%20however%20apparent%20that%20the%20scale%20%28size%29,in%20other%20contexts%20where%20localised%20innovation%20is%20possible.> (Accessed: 24/02/2023).

Network Rail (2021) Network Rail Social Value Framework. London: Network Rail. Available at: <https://www.networkrail.co.uk/wp-content/uploads/2021/09/Network-Rail-Social-Value-Framework-August-2021.pdf> (Accessed: 28/10/2021).

Network Rail (2020a) Environmental Sustainability Strategy. London: Network Rail. Available at: <https://www.networkrail.co.uk/wp-content/uploads/2020/09/NR-Environmental-Strategy-FINAL-web.pdf> (Accessed: 28/10/2021).

Network Rail (2020b) Traction Decarbonisation Network Strategy: Interim Programme Business Case. London: Network Rail. Available at: (Accessed: 26/02/2023).

Network Rail (2020c) Working better with SME's. Available at: <https://www.networkrail.co.uk/stories/working-better-with-smes/> (Accessed: 01/03/2023).

Network Rail (2019) What is the Digital Railway?. Available at: <https://www.networkrail.co.uk/stories/what-is-the-digital-railway/> (Accessed: 24/02/2023).

Network Rail (2018) Digital Railway Strategy. UK: Network Rail. Available at: <chrome-extension://oemmnndcbldboiebfnladdacbfmadadm/https://www.networkrail.co.uk/wp-content/uploads/2018/05/Digital-Railway-Strategy.pdf> (Accessed: 13/11/2021).

Oxford Economics (2021) The Economic Contribution of UK Rail. London: Oxford Economics Ltd. Available at: (Accessed: 28/10/2021).

RSSB (2018) Can Machine Learning Improve Railway Operational Performance? Available at: <https://www.rssb.co.uk/en/what-we-do/insights-and-news/blogs/can-machine-learning-improve-railway-operational-performance> (Accessed: 03/03/2023).

RTS Working Group (2022) Rail Technical Strategy: Innovation Across Britain's Railway RSSB.

UN (2023) Sustainable Development Goals. Available at: <https://sdgs.un.org/goals> (Accessed: 27/02/2023).