PATHWAY TO 2030

Course: 2652 - Fundamentals of Environment and sustainability

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Introduction

The concept of sustainability has emerged as a critical global concern, as societies endeavor to achieve a harmonious equilibrium between economic growth, environmental conservation and energy security (European Commission, 2019). The reduction of carbon emissions and the transition to renewable energy sources represent fundamental steps in addressing and mitigating the effects of climate change. To achieve this goal, it is essential to implement projects such as the Pathway to 2030, which serve to establish the infrastructure required for integrating clean energy sources into national grids. These initiatives facilitate a reduction in reliance on fossil fuels, foster innovation, create green jobs and contribute to long-term economic and environmental stability (UNPD, 2024).

The United Kingdom has committed to ambitious climate goals, including achieving net-zero carbon emissions by 2050. A critical part of this pledge is meeting the 2030 renewable energy and climate targets set by both the UK and Scottish governments, which aim for a 68% reduction in greenhouse gas emissions compared to 1990 levels. In 2022, the UK Government outlined a strategic plan to decrease reliance on volatile global gas markets, transitioning instead to sustainable, locally sourced electricity (SSEN, 2022). Historically, the country has relied heavily on natural gas imports from nations like Qatar and Norway, with around half of its natural gas supply coming from these two countries (GOV.UK, 2023). This dependency exposes the UK to the volatility of global energy markets and geopolitical risks, as seen during the recent energy crises. The Pathway to 2030 which began in February 2023 seeks to reduce this reliance by fostering a sustainable, locally sourced energy system that can provide greater resilience and stability. This shift is essential not only for environmental goals but also for enhancing national energy security and economic autonomy.

The development of strong infrastructure is essential for realizing these objectives. A major challenge in this transition is the modernization of existing energy infrastructure to support the substantial rise in renewable energy, such as wind and solar power. To integrate these renewable sources effectively into the energy system, the power grid must be adapted to handle their inherent variability. The Pathway to 2030 project tackles this challenge head-on, upgrading and expanding the UK's transmission network to support the shift toward a more sustainable energy future.

The Pathway to 2030 represents a significant and ambitious step towards the future of renewable energy in Scotland. The wind project, situated in the north of Scotland (**Image 1**), encompasses over

500 km² of land and offshore areas and is projected to have an output capacity of 11 GW (SSEN, 2023). This would provide sufficient energy to power over 10 million homes (SSEN, 2023) in the U.K. The Pathway to 2030 involves the construction of wind farms, the upgrading of the electricity grid, and the construction 15 new 400kV substations in Scotland to transmit the power across the U.K (REGLOBAL). Scotland, with its extensive coastal areas and strong, consistent wind speeds, has emerged as a global hub for offshore wind energy. The North of Scotland offers a potential of 10% of the total carbon emission reduction required to achieve the U. K's net zero targets (SSEN, 2023). The Scottish Government has pledged to derive 50% of its energy from renewable sources by 2030 (BBC News, 2017). Offshore wind will play a pivotal role in achieving these targets. The strategic location of Scotland's offshore wind farms, particularly in the North Sea. The North Sea is characterized by favorable wind conditions, which have made it an ideal location for offshore wind farms. Consequently, the region has become a focal point for European wind energy development, attracting investment from major players in the renewable energy sector, including Siemens and BAM. To gain a deeper understanding of the success of Scotland's offshore wind industry, it is instructive to make a comparison with other leading markets, such as Denmark and the Netherlands.

The *Pathway to 2030* project is a joint venture between three major entities: SSEN Transmission, Siemens Energy and BAM**,** each bringing unique expertise and resources to the initiative.

Scottish and Southern Electricity Networks Transmission (SSEN Transmission) occupies a pivotal role within the UK energy sector. SSEN Transmission is responsible for the maintenance and development of the high-voltage electricity transmission network across the north of Scotland, an area characterized by a wealth of renewable energy resources, including wind power and energy storage (SSEN, 2022). The role of SSEN Transmission in the project is to reinforce and expand the high-voltage transmission lines across northern Scotland to facilitate the efficient transmission of the growing output from renewable sources, such as wind farms. SSEN Transmission has devised a plan to implement significant upgrades to the grid infrastructure with the objective of meeting the UK's growing demand for renewable energy and facilitating the transition to a net zero economy. SSEN Transmission is investing a sum more than £20 billion in this project (Offshore Energy, 2024), with a particular emphasis on the creation of a grid that is more resilient and efficient, capable of accommodating the growing load from renewable energy sources and ensuring energy security for the country.

Siemens Energy is a global leader in the field of energy technology, offering a range of solutions across the entire energy value chain, including power generation, transmission and storage. Siemens Energy is a global enterprise, operating in over 90 countries (Siemens Energy, n.d.). It is at the vanguard of the global energy transition, developing sustainable energy solutions. As part of the Pathway to 2030 project, Siemens Energy is constructing new substations and modernizing existing ones that are vital for regulating the flow of electricity from these sources into the national grid.

Royal BAM Group (BAM), a prominent European construction and civil engineering enterprise, has considerable expertise in the delivery of large-scale infrastructure projects. BAM has a long history, dating back to 1869, and is involved in several sectors, including energy, transport and public infrastructure. In the Pathway to 2030 project, BAM is engaged in the construction of essential physical infrastructure, including transmission towers, underground cables, and substations, with the objective of supporting the large-scale generation of renewable energy. The collective impact of these actions is to modernize the grid, increase capacity and ensure long-term sustainability and energy security for the UK. Each entity contributes its own expertise, thereby facilitating the modernization of the UK's energy infrastructure. This is intended to support the transition to renewable energy and to ensure a more sustainable and secure energy future.

In view of the considerable contribution made by the Pathway to 2030 project to the advancement of sustainability, this report will examine its impact across three pivotal environmental domains. The three fundamental elements of the natural world are water, earth and air. This research aims to provide a nuanced perspective that underscores both the far-reaching environmental and societal benefits of the project as well as its potential negative implications. The analysis of the Project Pathway 2030 is based on the principles of Life Cycle Assessment (LCA). This approach evaluates the project's impact across the sustainable dimensions of water, earth, and air, as well as its socio-economic implications throughout its entire life cycle. The assessment considers both short-term and long-term influences, comparing and weighting the identified impacts. Using the LCA framework, we will derive the relative significance of these impacts, perform a comparative analysis, and provide holistic recommendations grounded in our findings. (Finnveden et al., 2009)

Earth

To evaluate the Pathway to 2030 project’s impact on soil and land health, an in-depth analysis of the current state of Scotland’s soils will be assessed. The focus will be on the Northern Scotland, where the majority of the project will take place. This includes assessing soil and existing vulnerabilities in the peatland. Furthermore, other ecological factors that could affect or be affected by the project will also be addressed. Finally, a broader perspective on soil impact will be included to provide a comprehensive understanding of how changes in the area could contribute to or mitigate larger environmental challenges, such as carbon storage and ecosystem stability.

The Pathway to 2030 project, led by SSEN Transmission, Siemens Energy, and BAM aims to upgrade the electricity grid and transmission network to accommodate renewable energy sources. This project focuses on expanding the capacity of the grid to integrate and distribute renewable power efficiently. To accommodate this new substation will connect 220MW of renewable energy to the network, supplying enough electricity for approximately 250,000 households (BAM, 2024). By upgrading the grid, the project aims to create a more sustainable energy system.
Constructing these substations however comes with environmental impacts, especially affecting soil and land. This is concerning as peat soil is one of the most important types of soil, and vital to mitigate climate change (Scottish Wildlife Trust, n.d.). Some of the substations will be built near the Scotland's peatlands, which covers over 20% of the country's landscape. These peatlands play an important role in carbon storage, holding approximately 2,735 million tons of carbon (Jorat et al., 2020; Jorat et al., 2024). Additionally, they are crucial for providing Scotland with clean drinking water (NatureScot, n.d.). However, almost roughly 80% of the peatlands in Scotland is degraded, which causes environmental damage. Rather than storing carbon, the peatlands are estimated to release more CO_2 than they capture, intensifying climate change (Scottish Wildlife Trust, n.d.)

Short-term

Looking at the short-term impacts of the projects, disturbing peatlands is a critical factor, as disturbance of the peatlands during the construction of substations bears the risks of releasing stored carbon into the atmosphere, ultimately leading to environmental damage. Thus, especially the soil is impacted in the construction phase of pathway to 2030. Considering the fragility of peatlands, construction activities as a part of the project could damage both the ecosystem and carbon storage. Given the increased demand for renewable energy and decarbonization there is an increase in infrastructure on peatlands, which can negatively impact these areas. Therefore, it is crucial to consider the environmental consequences when building the substations in the construction phase (Jorat et al., 2024). Maintaining healthy peatlands is important as they help regulate pollutants in the atmosphere such as nitrogen and sulphur dioxide, helping to improve air quality. In addition to regulating pollutants in the atmosphere, peatlands also support biodiversity, hence emphasizing the need to preserve peatlands (NatureScot, n.d.). If the peatlands, are disturbed too much in the construction phase it can lead to negative consequences such as the causing the project to have a negative impact during the use phase.

In addition to short-term influences affecting the peatlands in Scotland, the project can also affect the ecosystems near the construction areas. According to Arvesen et al. (2014), the construction of transmission networks poses risk to local ecosystems, particularly by contributing to biodiversity loss. This impact is often driven by habitat fragmentation. Biasotto & Kindel (2018) further emphasize that these biodiversity risks are most profound during the early stages of infrastructure projects, particularly during the construction phase. However, the biodiversity loss caused by transmission networks often extend beyond the construction phase and can continue to be impacted during operation (Biasotto & Kindel, 2018) in the life cycle. Thus, building the transmission network and substations as a part of the pathway to 2030 project can result in an impact of the biodiversity short-term, but can also lead to long-term negative biodiversity consequences if strategies to mitigate biodiversity loss are not considered during the operation of the network.

Long-term

To address the long-term influences of the project a comprehensive evaluation of the earth and land will be addressed. First, the impact on peatlands and soil will be considered, as it is important for capturing carbon and biodiversity. Without careful consideration of these impacts, the project could undermine the environmental benefits of transitioning to renewable energy in this area. As SSEN Transmission, Siemens Energy, and BAM have not yet addressed how they are going to mitigate the environmental impacts of constructing substations near peatlands, it is assumed that the project may have some negative long-term effects, which goes beyond the initial stages of resources and construction but might affect earth in the use phase and even after. The project could lead to reductions in carbon storage, biodiversity loss, and ecosystem disruptions. Hence, disturbing the peatlands may release significant amount of stored carbon into the atmosphere, undermining the effort of reduced carbon emissions through renewable energy (Jorat et al., 2024).

The infrastructure project may also have negative effects on the nearby ecosystems. The construction of pipelines and substations require significant modifications of the land, including draining and building on the peatlands in the construction phase (Marín, 2023). If the disturbances of the ecosystem are too intense and common the ecosystem may not return to the initial state leading to long-term damage, which will affect the soil during the use and end of life phases (Rural 21, 2020).

Nevertheless, BAM has committed to address the biodiversity risks by embedding practices into their projects to mitigate biodiversity loss. The strategy includes designing projects to minimize disturbance, with the goal of achieving an aggregated positive impact on biodiversity by 2030. With this initiative BAM aims to support the UN's Sustainable Development Goal 15 – Life on land, by offering solutions that offers biodiversity improving to clients (BAM, n.d.). SSEN Transmissions have also committed to deliver a Biodiversity Net Gain on its projects and will in situations where avoiding disturbance is challenging restore other habitats, especially in peatlands and woodlands SSEN Transmission (n.d.b.).

Sub-conclusion

By evaluating the short-term and long-term effects on earth and soil both negative and potential positive outcomes can occur. In Scotland where the project takes place peatlands cover 20% of the landscape. In particular, the peatlands make up a large part in the Northern part of Scotland where the transmission lines and substations will be built (Jorat et al., 2020; Jorat et al., 2024). This is concerning, as the peatlands are crucial when it comes to the storage of carbon and ecosystem stability. Thus, implying that any disturbances made in the area during construction could release carbon and reduce the potential environmental benefits long-term of transitioning to renewable energy (Jorat et al., 2024). Furthermore, another short-term impact of disturbing the peatlands is the fragmentation of habits that can cause a biodiversity loss (Arvesen et al., 2014; Biasotto & Kindel, 2018). The biodiversity loss is not only limited to the initial phase as Biasotto & Kindel (2018) emphasize that the impact on biodiversity in the initial construction phase can lead to long-term environmental damage, and impact all of the stages in the life cycle. Thus, it is important that these factors are evaluated before, during and after the project. Long-term commitments have been made by BAM and SSEM Transmissions to mitigate negative ecological impacts, in particular focusing on biodiversity. Both companies have committed to deliver a Biodiversity Net Gain on projects (BAM, n.d.; SSEN Transmission, n.d.b.). This indicates awareness of the long-term environmental impacts among the companies engaged in the project.

Air

To evaluate the "Pathway to 2030" impact on air quality using the LCA-Method, we will first analyze the current air conditions in the project region, identifying weaknesses and unique circumstances. The focus will be on northern Scotland, the primary project area, with additional insights covering the rest of the UK (mainly England).

A recent National Atmospheric Emissions Inventory report highlights a significant improvement in Scotland's air quality from 2005 to 2022, with substantial reductions in key pollutants such as nitrogen oxides (NOx), sulfur dioxide (SO2), and particulate matter (PM10 and PM2.5) (Mitchell et al., 2024). These improvements are largely reflected by stricter emission standards on vehicle and industrial emissions, the shift from coal to cleaner fuels in power generation and the decreased use of fertilizers in recent years (Mitchell et al., 2024). Although Scotland's air quality is generally good, urban areas such as Glasgow, Edinburgh, and Aberdeen still face elevated levels of pollutants like nitrogen dioxide (NO2) and particulate matter (PM), but also rural areas with extensive agriculture are significant hotspots, particularly for ammonia (NH3) (Mitchel et al. 2024; Scottish Air Quality, 2024). The negative impacts on air quality are largely driven by road traffic, industrial activities and agriculture, causing up to 2700 deaths a year in Scotland attributed to long-term exposure, while contributing to environmental issues such as acidification, climate change and biodiversity loss (Mitchel et al., 2024; Rodrick, 2024; UK Health Agency, 2022).

Regarding weak spots and unique circumstances of Scotland, which are crucial for evaluating the "Pathway to 2030," the country's rich reservoir of natural carbon sinks and air-regulating ecosystems stand out as critical factors. We already highlighted the widely distributed peatlands, which are among the most efficient carbon storage systems globally, but there is a lot more. (Jorat et al., 2020; Jorat et al., 2024). Bog and moorland ecosystems also store carbon effectively due to their rich organic material (Garnett et al., 2001; NatureScot, 2024a) while retaining water, supporting biodiversity, and providing natural flood defenses (Luscombe et al., 2015; Marrs et al., 2007). Forested areas and woodlands further enhance carbon storage, holding an estimated two billion tons of carbon, and play a crucial role in regulating air quality through their ability to absorb pollutants like NOx, SO2, and particulate matter. (Forestry Commission, 2020; NatureScot, 2024b; Powe & Willis, 2004).

Scotland's blue carbon sinks, including coastal salt marshes, seagrass meadows, kelp forests, shellfish beds, and deep-sea sediments, all play a vital role in capturing and storing carbon. Each of these ecosystems also brings unique benefits: coastal salt marshes act as natural buffers against storm surges, seagrass meadows store CO_2 in sediment layers that remain undisturbed for centuries and support marine biodiversity, and kelp forests, shellfish beds, and deep-sea sediments contribute to carbon sequestration while fostering marine ecosystem health. An overview of these weak spots can be seen in **Table 1**. (Black et al., 2022; Cunningham et al., 2023; Levy & Gray, 2015; Luisetti, 2019; NatureScot, 2024b)

Short-term

Regarding the short-term impact, we have identified the primary sources of pollution and negative effects on air quality and GHG emissions, which are largely tied to the construction activities. First, we will analyze how the sourcing, transportation, and use of materials may impact air quality. Next, we will examine potential pollution directly caused by the construction itself. Finally, we will contextualize these findings with the identified weak spots to provide a comprehensive assessment.

The initial sourcing and manufacturing of elements used in the "Pathway to 2030" must be considered, particularly as their environmental impact may be more significant in the regions where these materials are extracted or produced than in the locations where the project takes place. An operation of such scale demands substantial quantities of materials such as cement, copper, aluminum, steel, and rare earth elements used in the production of components like wind turbines, subsea cables, transmission lines, and substations. (Arvesen et al., 2014; Chen et al., 2022; Jorge & Hertwich, 2013; Li, J. et al., 2020; Nassar et al., 2016; Pavel et al., 2017). Mining and manufacturing these materials can cause significant CO_2 emissions and air pollutions like NO_x and particulate matter, especially if energy-intensive methods reliant on coal or oil are used (Chen et al., 2022; Jorge & Hertwich, 2013; Li, J. et al 2020).

A report by the International Energy Agency (2022) emphasizes how the extraction and processing of these materials can take up substantial proportions of the overall lifecycle emissions of such projects. As mentioned, these impacts on air quality are not directly linked to the project regions as for example steel is mostly sourced in China, Inda or Japan (World Steel Association, 2024) while other minerals and rare earths are extracted especially in Chile, China and Indonesia (IEA, 2022).

Ultimately, the various components for the project must be transported to the specific locations where they are required. Diesel-powered trucks and other vehicles are often used to transport materials like steel, tower components, and transformers to construction sites. This adds to localized air pollution near ports, construction zones, and along transit routes, further impacting air quality. Transport-related emissions not only contribute to the project's overall carbon footprint but may also exacerbate air quality issues in areas where transportation already plays a significant role in pollution. This is particularly relevant for northern Scotland, where emissions from logistics routes are a notable concern. (Vanwoensel et al., 2001; Mitchel et al. 2024; Scottish Air Quality, 2024)
Similarly, the use of heavy machinery, such as excavators, cranes, and large marine vessels, is a major contributor to short-term local air pollution during the construction of project components like substations, transmission towers, and subsea cables. These machines, primarily powered by fossil fuels such as diesel, emit significant amounts of CO2, NOx, SO2, and particulate matter, negatively affecting local air quality (Cao, 2016; Kumar & Imam, 2013; Sandanayake, 2016).

The emission of these pollutants poses a significant health risk to local communities in the affected regions. Pollutants such as NOx, SO2, and particulate matter are linked to chronic respiratory, cardiovascular, neurological, and carcinogenic effects, contributing to increased morbidity and mortality (Buonocore et al., 2014; Costa et al., 2014; Ku et al., 2016). In northern Scotland and other emission sites, these pollutants could lead to a rise in air pollution-related diseases and deaths, especially where levels might already be critical (Scottish Air Quality, 2024; UK Health Agency, 2022).

Long-term

As discussed, the factors mentioned not only reduce air quality but also result in significant CO2 emissions during the production process, contributing to the long-term climate crisis as greenhouse gases (GHGs) (Chen et al., 2022; Kumar & Imam, 2013). However, the scale of these emissions pales in comparison to the potential damage the project's construction could inflict on the previously highlighted natural carbon sinks and air-regulating ecosystems. Building infrastructure such as onshore substations, transmission towers, access roads or subsea cables can degrade these sensitive ecosystems, including peatlands, moorlands, salt marshes, and seagrass meadows, which store vast amounts of carbon (Black et al., 2022; Forestry Commission, 2020; Garnett et al., 2001; Jorat et al., 2020). Activities like soil compaction and altered drainage in peatlands, trenching for subsea cables, or sediment disruption during offshore installations can release stored CO_2 and affect water retention and carbon cycling (Luscombe et al., 2015; Marrs et al., 2007; Environmental Protection Agency, 2024). Deforestation for transmission networks further diminishes carbon storage and air regulating capacity while releasing CO_2 through plant decomposition and soil erosion (Forestry Commission, 2020; BAM, n.d.; SSEN Transmission, n.d.a.). Recovery is often slow - for example, seagrass meadows may take decades to regenerate after disturbance (Kenworthy et al., 2018) - and in some cases, damage could be irreversible, severely impacting their climate-regulating functions.

The disturbances to vulnerable ecosystems and the air quality impacts from construction do not end with project completion. Long-term maintenance efforts, which often involve heavy machinery, are required to ensure the project's ongoing functionality. Consequently, some short-term effects on air quality may persist throughout the project’s life cycle. (Kumar & Imam, 2013)

The primary purpose of this project and its anticipated positive impact on air quality lie in the substitution of fossil-fueled energy sources with green energy. The effectiveness of wind energy as a substantial source is already evident: in 2023, gas held the largest energy share at 32%, followed by wind at 29.4%, with record achievements, including wind providing 41.2% of the nation's energy in December and recording the lowest annual carbon intensity of $27gCO_2/kWh$ (Martins, 2024). Other noteworthy shares include nuclear energy (14.2%) and imported energy (10.7%) (Martins, 2024). Looking ahead to 2030, the project aims to further enhance the use of wind energy, improve distribution efficiency, and increase the share of renewable energy to achieve net zero by 2050.

A key strategy for achieving these goals is reducing carbon emissions through infrastructure upgrades in northern Scotland, which focus on transmitting renewable energy, particularly offshore wind. This transition significantly reduces reliance on fossil fuels, a critical step as fossil fuel combustion is a primary source of air pollutants, including carbon dioxide (CO_2) and nitrogen oxides (NO_x), which contribute to climate change and degrade air quality (Shindell & Smith, 2019).

The project also increases support for offshore wind energy by enabling the connection and distribution of up to 50 GW of capacity (SSEN Transmission, n.d.c.). This directly supports the UK’s 2030 renewable energy targets and reduces greenhouse gas emissions across the energy grid (SSEN-Transmission, n.d.a.). Since wind energy generates no direct emissions during operation, its adoption significantly cuts airborne pollutants in regions dependent on energy from northern Scotland (NESO, 2022). Furthermore, the expansion of domestic renewable energy production enhances energy independence by reducing reliance on imported energy, which is often volatile and carbon-intensive

(Martins, 2024). This shift bolsters energy security while decreasing the need for high-emission backup sources such as coal or natural gas. The resulting reduction in particulate matter (PM) and sulfur dioxide (SO2) emissions benefits respiratory health and helps mitigate smog formation (SSEN Transmission, n.d.b.).

Additional benefits are expected from improved grid efficiency and interconnectedness, which should minimize energy losses. Research by Jorge and Hertwich (2013) on Norway's transmission infrastructure revealed that nearly half of the climate impact was attributable to power losses, emphasizing the importance of system optimization.

The environmental and health advantages of enhanced air quality are further supported by Li et al. (2020), who found that ultra-high voltage (UHV) lines in China delivered substantial benefits by improving air quality. The transmission of cleaner energy sources significantly reduced regional air pollution, especially in areas that relied heavily on imported energy.

Sub-conclusion

The project presents potential short- and long-term negative effects, which must be carefully weighed against its anticipated long-term benefits. While short-term negative effects are likely temporary and may be outweighed by the reduction in fossil fuel dependency, the possibility of irreversible damage to natural carbon sinks raises significant concerns. SSEN has committed to carefully assessing environmental impacts and compensating for unavoidable destruction, such as deforestation, following the principles of avoid, minimize, mitigate, and restore (SSEN Transmission, n.d.a.). However, these negative effects, could become substantial if ecosystems are irreversibly harmed, particularly in terms of carbon release, rendering compensation measures insufficient. Thus, long-term negative effects could significantly diminish the project's benefits, potentially undermining its primary goal of achieving net zero by 2050.

Water

To understand how the water is affected by BAM and Siemens Energy's infrastructural project to deliver a transmission network off- and onshore, supporting the UK's transition to Net Zero, it is important to examine both short- and long-term impacts.

Short term

A life cycle assessment approach both highlights the short- and long-term advantages and disadvantages of the of the project. Several negative short-term environmental impacts are expected to arise from the construction of an offshore grid that interconnects wind farms with onshore energy users.

According to Edgar, G., et al. (2014), these short-term influences include various forms of environmental disturbance, particularly affecting marine ecosystems. The construction phase, along with the necessary maintenance activities, involves operations such as cable laying and the extensive use of marine vessels, both of which can disrupt local habitats.

The installation of cables and underwater infrastructure can disturb the seabed, potentially displacing or damaging marine flora and fauna and releasing sediment into the water column, which may harm species sensitive to changes in water quality.

Additionally, the noise and presence of marine vessels in the area can interfere with marine wildlife, including mammals, fish, and seabirds, potentially leading to shifts in migration patterns or stress-induced behaviors (Edgar, G., et al., 2014).

In response to these anticipated impacts, SSEN Transmission has demonstrated a proactive approach by integrating environmental risk assessments early in their project development phase.

Recognizing the potential for flood risks and drainage challenges, SSEM consulted with water and flooding experts to ensure comprehensive planning for water management. Their strategy includes designing and implementing systems to control water flow around construction sites, aiming to prevent unintended alterations to natural water courses and minimize erosion. Prior to the beginning of construction, the company developed specific plans to protect both surface and groundwater sources, thereby reducing the likelihood of pollution or contamination that could result from the project's activities. This preparation reflects a commitment to mitigating immediate ecological impacts, as well as preserving the integrity of surrounding environments as construction progresses (SSEN, n.d.b).

Long-term

Our assessment identified several long-term advantages and disadvantages induced through the BAM and Simens Energy Transmission network project. As with earth and air, the transmission network will contribute to the overall goal of being CO2 neutral in 2050 ending up affecting water in a positive way as well (Environmental Protection Agency, 2024). By reducing/removing fossil fuel as an energy source, this will decrease the carbon dioxide (CO_2) in the atmosphere thereby reducing the amount of absorbed CO_2 by the ocean. This should decrease the process of 'ocean acidification', which will then create a better pH level of the seawater positively impacting marine life (Environmental Protection Agency, 2024).

Further, an article by UCSUSA states that an increase in acidic water and warmer ocean temperatures have negatively affected lots of local economies, particularly the fishing industries. They are suffering from aquatic species dying. By turning this development around shifting from fossil fuels to sustainable energy sources, the water quality should increase and thereby contribute and support to a better and healthier fishing industry (Union of Concerned Scientists, 2019).

Building a transmission network between the existing wind turbines offshore can affect the water and the marine habitats in the long term (GOV.UK, 2023). By connecting the offshore cables to each other, having a more integrated approach towards the transmission network, instead of them being connected individually to the onshore grid, can minimize the number of cables and connections. This will reduce environmental disruptions and seabed disturbance (GOV.UK, 2023). Here, seabed disturbance is referred to as the disruption or the alteration of the ocean caused by human activities (GOV.UK, 2023). In this case, this project will minimize human disturbance by connecting cables and thereby reducing the number of cables offshore.

More in depth, this project can improve the environment for aquatic species and reduce the potential risk of disruption in several ecosystems (GOV.UK, 2023). Improved water quality and minimized offshore cables could enhance the fishing industry by creating better conditions for aquatic species to thrive, restoring the environment to its previous state (Union of Concerned Scientists, 2019).

However, in the long term, Edgar, G., et al., 2014 argues that an offshore grid, which uses cables and substations with heavy metals such as copper and iron can contribute to marine water pollution as these cables can release some of these heavy metals out in the sea representing a negative impact (Edgar, G., et al., 2014).

On the other hand, SSEM Transmission is very clear about the project living up to the biodiversity net gain (BNG) that was introduced in England in 2024 as mandatory for all infrastructure projects. They state: "We also acknowledge that minimizing impacts is not enough on its own, and we have therefore committed to delivering BNG on all projects…Where our projects are unable to completely avoid irreplaceable habitats, we have also introduced a commitment to restore more habitat than we affect" (SSEN Transmission, n.d.b.).

Furthermore, the underwater transmission network currently being developed by BAM and Siemens Energy in the UK has raised concerns regarding its potential long-term impact on the marine ecosystem, especially concerning electromagnetic fields (EMF) generated by high-voltage underwater cables. These EMF emissions can have significant effects on various marine species, particularly those sensitive to electromagnetic signals, such as sharks, rays, and certain fish species. As highlighted by a report from the Institute of Marine Research, electromagnetic fields created by power cables on the seabed may interfere with the navigation abilities of marine animals that rely on natural electromagnetic cues. This interference could disrupt vital behaviors like migration and feeding, particularly in areas surrounding the cables (Institute of Marine Research, n.d.).

Furthermore, a study by NTNU emphasizes the need for additional research into the cumulative effects of EMFs on marine organisms. Sensitive species that rely on electromagnetic signals for essential life processes could face disturbances from these cables, potentially impacting their reproductive success, habitat preference, and population dynamics over time (NTNU Open, 2023). The lack of conclusive data highlights an urgent need for further studies to better understand the long-term implications of increased EMF exposure on marine biodiversity.

Additionally, magnetic fields produced by submarine cables have been reported to impact fish and larval behaviors. As the number of offshore wind farms and associated cables increases, the frequency and intensity of EMF exposure in marine environments around the UK are likely to grow. This expansion may result in broad ecological consequences for marine life in and around these sites, potentially altering ecosystem structure and function in the long term (FiskerForum.dk, 2023).

This sub-conclusion synthesizes the anticipated impacts of the BAM and Siemens Energy project on water ecosystems, illustrating both the ecological benefits and potential challenges associated with offshore transmission networks. The balance between supporting renewable energy goals and protecting marine environments remains a focal point for the project's ongoing environmental management strategies.

Sub-conclusion

The BAM and Siemens Energy transmission network project for the UK's transition to Net Zero presents complex short- and long-term impacts on marine environments, specifically in water quality and the health of underwater ecosystems. Over the long term, the transition to renewable energy and the reduction of CO_2 emissions aim to contribute to ocean health by decreasing ocean acidification, which may stabilize seawater pH levels and support marine biodiversity (Environmental Protection Agency, 2024). Shifting from fossil fuels to sustainable energy could, therefore, indirectly enhance water quality, benefiting industries like fishing, which rely on thriving marine ecosystems (Union of Concerned Scientists, 2019).

The integrated design of the transmission network seeks to minimize environmental disturbances by consolidating offshore cables, reducing seabed disruption, and lowering the impact on marine habitats (GOV.UK, 2023). However, potential risks exist, such as the release of heavy metals from cables and substations into the water, which may contribute to long-term marine pollution (Edgar et al., 2014). Moreover, concerns around electromagnetic fields (EMF) from high-voltage underwater cables suggest additional long-term effects on species sensitive to electromagnetic signals, including sharks and rays. These EMFs could disrupt natural behaviors, such as migration and feeding, which are critical to the balance of marine ecosystems (Institute of Marine Research, n.d.; NTNU Open, 2023; FiskerForum.dk, 2023).

In the short term, construction activities related to the project, such as cable laying and the use of marine vessels, may result in immediate disruptions to local habitats and increased sediment in the water column. This sediment displacement could harm marine flora and fauna, especially species sensitive to changes in water quality (Edgar et al., 2014). To mitigate these immediate impacts, SSEN Transmission has implemented proactive water management plans, including flood risk assessments and drainage systems, to protect local water sources and limit the effects of construction on the surrounding marine environment (SSEN Transmission, n.d.b.).

Socio-Economic Impact

Large-scale renewable energy projects offer socio-economic benefits while also presenting environmental, cultural and localized challenges.

On one hand, Pathway to 2030 is projected to create around 20,000 jobs nationwide, including 9,000 in Scotland (Prosper Scotland, 2024). These opportunities span construction, engineering, and maintenance, bolstering local economies, particularly in regions directly hosting the projects. Significant investments tied to this initiative are driving business activity, boosting industries linked to renewable energy, and creating opportunities for small and medium enterprises within the supply chain. Training and upskilling programs are also preparing a capable workforce to sustain future energy infrastructure.

In addition to these immediate economic benefits, investments in renewable energy infrastructure are expected to enhance economic stability by reducing dependency on external energy sources. With more reliable domestic energy production, local economies can benefit from consistent energy availability and reduced exposure to price volatility in global energy markets. Over time, increased renewable energy capacity is anticipated to lower energy costs for households and businesses, enhancing economic resilience and promoting national energy independence (Cleary, 2023). The Siemens BAM project exemplifies these advantages, demonstrating how renewable energy infrastructure can catalyze economic progress, innovation, and investment while supporting long-term sustainability goals.

However, these benefits are coupled with significant challenges. During the construction phase, noise pollution from heavy machinery, material transport, and site activities can disrupt local communities and ecosystems. Air pollution from dust and emissions generated by construction processes may pose health risks to nearby residents, especially vulnerable groups such as children and the elderly. Additionally, large-scale infrastructure development can lead to the loss of natural habitats**,** which has far-reaching impacts on the biodiversity of affected regions (WWF, 2024). The removal of vegetation, soil disruption, and habitat fragmentation can threaten local flora and fauna, particularly species already at risk due to climate change and human activities. Developers are implementing mitigation measures, including habitat restoration and wildlife corridors, to minimize biodiversity loss, but these efforts cannot entirely offset the environmental cost (SSEN, 2024).

While these short-term impacts are a concern, the transition to renewable energy promises significant long-term benefits, including better air quality (International Energy Agency, n.d.) By reducing reliance on fossil fuels and their associated emissions, renewable energy projects will contribute to cleaner air, improving public health and environmental conditions for future generations. Moreover, as renewable energy infrastructure matures, efforts to integrate ecological restoration into these projects can help offset some of the initial environmental impacts (UNEP, 2024).

The visual presence of wind turbines and large-scale infrastructure adds to localized challenges. These changes to the landscape can negatively affect tourism, particularly in areas where unspoiled natural beauty is a major attraction (Soini et al., 2011). Tourists seeking scenic experiences may be deterred by altered views, potentially reducing revenue for local businesses reliant on tourism. Property owners near such developments may also experience financial losses, as research shows wind turbines can decrease property values by up to 12% within a 2 km radius (Gibbons, 2015). These combined challenges highlight the importance of equitable planning and meaningful community engagement in renewable energy projects. The Beauly–Denny transmission line project, which faced over 20,000 objections, underscores the risks of neglecting these concerns and demonstrates the need for early and inclusive dialogue to foster public support (Tobiasson et al., 2016).

To mitigate these challenges, SSEN has emphasized proactive community engagement. Its Community Liaison Group (CLG) facilitates open communication between project teams and residents, ensuring transparency about project milestones, timelines, and potential impacts (BAM, 2024). The CLG also provides a platform for residents to raise concerns, provide feedback, and co-develop solutions to challenges such as noise, air pollution, habitat loss, and landscape changes. This inclusive approach helps build trust and ensures that projects align with community expectations and priorities.

Cultural heritage preservation is another critical consideration. Scotland's renewable energy expansion risks affecting historically and culturally significant areas, including the Heart of Neolithic Orkney, a UNESCO World Heritage Site featuring landmarks like the Maeshowe chambered cairn and the Ring of Brodgar (Marine Scotland, n.d.). Infrastructure projects such as the Orkney-Caithness Link could disrupt these landscapes, which are integral to Scotland's cultural identity and tourism economy. While mitigation measures, such as archaeological surveys and underground cabling, are being implemented to reduce disruptions, the visual and physical changes to these landscapes could still diminish their integrity and reduce their appeal to tourists (Marine Scotland, n.d.a.).

Environmental restoration is a key pillar of Scotland's renewable energy strategy. SSEN has invested nearly £250,000 in nature recovery initiatives through its support for the Projects for Nature platform (SSEN, 2024). These efforts include regenerating 24 hectares of woodland in Somerset and restoring 11 hectares of fenland near a Site of Special Scientific Interest in Oxfordshire. These projects enhance biodiversity and improve ecosystem services while engaging local communities in conservation efforts. By integrating environmental restoration with renewable energy development, SSEN demonstrates how infrastructure projects can align with ecological stewardship, contributing to long-term socio-economic resilience while addressing urgent climate and biodiversity challenges.

It is evident that the pathway to 2030 will undoubtedly contribute to socio-economic growth. However, it is imperative that the potential detriment to the environment and cultural heritage is also considered, and it is important to find a balance between these two factors. Addressing challenges during the construction phase such as noise, air pollution, health risks and biodiversity loss is crucial to ensure sustainable development. Concurrently, it is vital to remain focused on the long-term benefits of the project, including improved air quality, enhanced economic stability, and a reduced reliance on external energy sources.

Recommendations

The life cycle assessment (LCA) framework has been applied throughout this report to provide a comprehensive understanding of the project's environmental impacts across its entire lifecycle. This analysis highlights the critical importance of sustainable practices at every stage of the project, from which several recommendations can be derived.

In the material sourcing phase, prioritizing sustainable materials such as recycled steel or low-impact alternatives is essential. This could be achieved by partnering with suppliers who use renewable energy in manufacturing for example. During the construction phase, efforts should focus on minimizing short-term impacts by using low-emission construction machinery, optimizing transportation logistics, and implementing robust habitat restoration strategies post-construction to protect surrounding ecosystems.

Regarding socio-demographic impacts, early community engagement and equitable job distribution are vital to ensure local support and fairness. In the operation phase, a well-designed maintenance plan should prioritize ecosystem health, particularly around substations, peatlands, and marine habitats. Adaptive management strategies are recommended to address any unforeseen impacts effectively.

For the end-of-life phase, the development of a decommissioning strategy should begin early. This strategy should address potential challenges in dismantling infrastructure and ensure the safe disposal or recycling of materials like copper and other metals.

Across the entire LCA, adopting circular economy principles and maintaining strong relationships with stakeholders, including policymakers, is crucial. Transparency in reporting and accountability throughout the project is recommended to build trust and ensure alignment with environmental and societal goals. This holistic approach not only minimizes negative impacts but also enhances the project's sustainability and long-term success.

Another viable method to analyze the impact of Pathway 2030 is the Environmental Impact Assessment (EIA), which evaluates the potential environmental consequences of a project or action, helping to identify, mitigate, and manage adverse effects on the environment (Morgan, 2012). SSEN is already in the process of conducting an EIA for Pathway to 2030 which they committed to make accessible on their website (SSEN Transmission, n.d.a.). While these insights are not available publicly yet, SSEN has already committed to take certain environmental actions to mitigate negative effects and overcome identified challenges based on the EIA. This again highlights the importance of seizing the opportunities of advancing renewable energy while addressing key environmental challenges. The project incorporates preventive measures to mitigate its impacts, such as environmental risk assessments, biodiversity net gain (BNG) commitments, and proactive water management strategies (SSEN Transmission, n.d.a.). These measures include habitat restoration for peatlands and woodlands, flood risk controls, and sustainable drainage systems to protect ecosystems during construction. The focus on biodiversity conservation through habitat restoration, coupled with community engagement initiatives like the Community Liaison Group, addresses local concerns.

However, while important these measures might not be enough facing the severe potential drawbacks of the project we have discussed throughout this report. To address these challenges, we recommend prioritizing strict preservation of previously discussed natural carbon sinks by avoiding sensitive areas and restoring degraded sites to safeguard carbon storage and biodiversity. Consolidating offshore cables and utilizing EMF-shielded designs can minimize seabed disturbance and mitigate risks to marine species. Further, the use of low ground impact machines at construction site can enable effective building activities while avoiding damage to these ecosystems. In general, stakeholders involved in the project should strive to gather comprehensive information about potential areas of environmental impact to understand the effects their actions may have and plan the project accordingly. Contributing to this goal, we have used the insights of this report and connected the single projects of pathway to 2030 to the ecosystems they might influence which you can see in **Table 2**.

Lastly, we recommend creating a long-term monitoring programs and adaptive management strategies that can help the project meet its environmental goals while supporting the UK's transition to a net-zero energy system. These actions demonstrate the value of SSENs EIA-driven approach, ensuring environmental impacts are minimized while delivering renewable energy benefits.

Conclusion

The U.K.'s Pathway to 2030 project is a crucial step towards achieving U.K.'s net-zero emissions target by 2050, with a focus on meeting the 2030 goal of a 68% reduction in greenhouse gas emissions. This joint venture between SSEN Transmission, Siemens Energy and BAM leverages expertise from different fields. The project, located in northern Scotland, involves the construction of wind farms, upgrading the electricity grid, and building 15 new substations in Scotland to facilitate the transfer of renewable energy across Scotland. By doing so, enough power will be generated to power more than 10 million homes in the U.K., while contributing to a reduction of up to 10% of total carbon emissions required to meet U.K.'s net zero target.

To assess the impact on earth, air, and water this report analyzed the most significant impacts using the LCA tool, focusing on the short-term and long-term impacts. Short-term environmental challenges were particularly identified during the construction phase in the life cycle. The challenges include disturbances to marine ecosystem from cable installation, peatland disruption, and release of various pollutants and carbon oxide, which may temporarily harm air and water quality in the area. Besides the intended positive long-term effects of the project, the lasting negative effects mostly gathered around potentially irreversible harm to fragile ecosystems and natural carbon sinks. The destruction of these systems could lead to a significant release of CO2 further enhancing climate change, while diminishing ecosystem services and contributing to biodiversity loss.

We proposed several recommendations considering SSENs current environmental statements and concluding that project stakeholders should gather thorough environmental data to assess impacts like we did in this report and plan responsibly minimizing the environmental drawbacks of the project. Further, the socio-economic impact was examined. These were represented by challenges such as noise, health risks, and biodiversity loss concerns. Therefore, efforts to mitigate these impacts could be represented through community engagement, habitat restoration, and cultural preservation are actively being implemented.

In conclusion the project reflects a good example of how to focus on 'green growth' rather than 'no growth.' Instead of restricting energy production, this project aims to transform and optimize the UK's energy network, enabling the country to achieve both economic growth and sustainability. However, this report also highlights the tremendous environmental and socio-economic challenges of projects of this size and scope using frameworks like LCA or EIA. These results show an important tradeoff dynamic that will form the sustainable and environmental future of the UK and the globe.

References

Arvesen, A., Nes, R., Huertas-Hernando, D., & Hertwich, E. (2014). Life cycle assessment of an offshore grid interconnecting wind farms and customers across the North Sea. *The International Journal of Life Cycle Assessment, 19*, 826–837. https://doi.org/10.1007/s11367-014-0709-2

BAM. (2024). *BAM helps to deliver on UK's net-zero targets by connecting Orkney Islands with GB electricity grid*. Retrieved from https://www.bam.com/en/press/press-releases/2024/9/bam-helps-to-deliver-on-uks-net-zero-targets-by-connecting-orkney

BAM. (n.d.). *Biodiversity*. Retrieved from https://www.bam.com/en/sustainability/biodiversity

BBC News. (2017). *Scotland's ambitious renewable energy goals*. Retrieved from https://www.bbc.com/news/uk-scotland-scotland-politics-38729869

Biasotto, L. D., & Kindel, A. (2018). Power lines and impacts on biodiversity: A systematic review. *Environmental Impact Assessment Review, 71*(4).

Black, K., Smeaton, C., Turrell, W., & Austin, W. (2022). Assessing the potential vulnerability of sedimentary carbon stores to bottom trawling disturbance within the UK EEZ. *Frontiers in Marine Science, 9*. https://doi.org/10.3389/fmars.2022.892892

Buonocore, J., Dong, X., Spengler, J., Fu, J., & Levy, J. (2014). Using the Community Multiscale Air Quality (CMAQ) model to estimate public health impacts of PM2.5 from individual power plants. *Environment International, 68*, 200–208. https://doi.org/10.1016/j.envint.2014.03.031

Cao, T., Durbin, T., Russell, R., Cocker, D., Scora, G., Maldonado, H., & Johnson, K. (2016). Evaluations of in-use emission factors from off-road construction equipment. *Atmospheric Environment, 147*, 234–245. https://doi.org/10.1016/j.atmosenv.2016.09.042

Chen, Z., Kleijn, R., & Lin, H. (2022). Metal requirements for building electrical grid systems of global wind power and utility-scale solar photovoltaic until 2050. *Environmental Science & Technology, 57*, 1080–1091. https://doi.org/10.1021/acs.est.2c06496

Cleary, D. (2023). *Economic impact of SSEN Transmission's capital investment programme*. Biggar Economics.

Costa, S., Ferreira, J., Silveira, C., Costa, C., Lopes, D., Relvas, H., Borrego, C., Roebeling, P., Miranda, A., & Teixeira, J. (2014). Integrating health on air quality assessment—Review report on health risks of two major European outdoor air pollutants: PM and NO2. *Journal of Toxicology and Environmental Health, Part B, 17*, 307–340. https://doi.org/10.1080/10937404.2014.946164

Cunningham, C., & Hunt, C. (2023). *Scottish blue carbon: A literature review of the current evidence for Scotland's blue carbon habitats*. NatureScot Research Report, 1326.

Department for Business, Energy & Industrial Strategy. (2023). *Digest of UK energy statistics (DUKES) 2023* Retrieved from https://assets.publishing.service.gov.uk/media/64f1fcba9ee0f2000db7bdd8/DUKES_2023_Chapters_1-7.pdf

Edgar, G., Clarke, L., & Foster, S. (2014). Environmental impacts of offshore transmission networks in marine ecosystems. *The International Journal of Life Cycle Assessment, 19*(10), 1528–1537. https://doi.org/10.1007/s11367-014-0709-2

Energy.gov.(n.d.). *Health and safety benefits of clean energy*. Retrieved from https://www.energy.gov/eere/health-and-safety-benefits-clean-energy

Environmental Protection Agency. (2024). Ocean acidification. U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/ocean-acidification

European Commission. (2019). *Employment and social developments in Europe 2019: Chapter 2 - Sustainable growth and development in the EU: concepts and challenges*. Retrieved from https://ec.europa.eu.

Finnveden, G., Hauschild, M., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D., & Suh, S. (2009). Recent developments in Life Cycle Assessment.. *Journal of environmental management*, 91 1, 1-21 . https://doi.org/10.1016/j.jenvman.2009.06.018.

FiskerForum.dk. (2023). *Havvind: Magnetiske felter fra søkabler kan bremse eller skade fisk og larvers adfærd*. Retrieved from https://fiskerforum.dk/havvind-magnetiske-felter-fra-soekabler-kan-bremse-eller-skade-fisk-og-larvers-adfaerd

Forestry Commission. (2020). *Forestry statistics 2020—Chapter 4: Carbon*. Retrieved from https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2020/4-carbon

Institute of Marine Research. (n.d.). Hav og kyst: Havvind. Retrieved from https://www.hi.no/hi/temasider/hav-og-kyst/havvind

Garnett, M., Ineson, P., Stevenson, A., & Howard, D. (2001). Terrestrial organic carbon storage in a British moorland. *Global Change Biology, 7*. https://doi.org/10.1046/j.1365-2486.2001.00382.x

Gibbons, S. (2015). Gone with the wind: Valuing the visual impacts of wind turbines through house prices. *Journal of Environmental Economics and Management, 72*, 177–196. https://doi.org/10.1016/j.jeem.2015.04.006

GOV.UK. (2023). Offshore transmission network review: Summary of outputs. Retrieved from https://www.gov.uk/government/publications/offshore-transmission-network-review/offshore-transmission-network-review-summary-of-outputs

GOV.UK (2023). Digest of United Kingdom energy statistics (DUKES) 2023: Chapters 1-7. Retrieved from https://assets.publishing.service.gov.uk.

International Energy Agency. (n.d.). *Multiple benefits of energy efficiency: Air quality.* Retrieved from https://www.iea.org/reports/multiple-benefits-of-energy-efficiency/air-quality

International Energy Agency. (2022). *The role of critical minerals in clean energy transitions*. Retrieved from https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

Jorat, M. E., Goddard, M. A., Manning, P., Lau, H. K., Ngeow, S., Sohi, S. P., & Manning, D. A. C. (2020). Passive CO2 removal in urban soils: Evidence from brownfield sites. *Science of The Total Environment, 703*(10), 1–9.

Jorat, M. E., Minto, A., Tierney, I., & Gilmour, D. (2024). Future carbon-neutral societies: Minimising construction impact on groundwater-dependent wetlands and peatlands. *Sustainability, 16*(17), 7713. https://doi.org/10.3390/su16177713

Jorge, R., & Hertwich, E. (2013). Environmental evaluation of power transmission in Norway. *Applied Energy, 101*, 513–520. https://doi.org/10.1016/j.apenergy.2012.06.004

Kenworthy, W., Hall, M., Hammerstrom, K., Merello, M., & Schwartzschild, A. (2018). Restoration of tropical seagrass beds using wild bird fertilization and sediment regrading. Ecological Engineering, 112, 72-81. https://doi.org/10.1016/J.ECOLENG.2017.12.008.

Ku, T., Ji, X., Zhang, Y., Li, G., & Sang, N. (2016). PM2.5, SO2 and NO2 co-exposure impairs neurobehavior and induces mitochondrial injuries in the mouse brain. *Chemosphere, 163*, 27–34. https://doi.org/10.1016/j.chemosphere.2016.08.009

Kumar, P., & Imam, B. (2013). Footprints of air pollution and changing environment on the sustainability of built infrastructure. *The Science of the Total Environment, 444*, 85–101.

Levy, P., & Gray, A. (2015). Greenhouse gas balance of a semi-natural peatbog in northern Scotland. *Environmental Research Letters, 10*. https://doi.org/10.1088/1748-9326/10/9/094019

Li, J., Peng, K., Wang, P., Zhang, N., Feng, K., Guan, D., Meng, J., Wei, W., & Yang, Q. (2020). Critical rare-earth elements mismatch global wind-power ambitions. *One Earth*. https://doi.org/10.1016/j.oneear.2020.06.009

Li, Y., Yi, B., & Wang, Y. (2020). Can ultra-high voltage power transmission bring environmental and health benefits? An assessment in China. Journal of Cleaner Production, 276, 124296. https://doi.org/10.1016/J.JCLEPRO.2020.124296.

Luisetti, T., Turner, R., Andrews, J., Jickells, T., Kröger, S., Diesing, M., Paltriguera, L., Johnson, M., Parker, E., Bakker, D., & Weston, K. (2019). Quantifying and valuing carbon flows and stores in coastal and shelf ecosystems in the UK. *Ecosystem Services*. https://doi.org/10.1016/j.ecoser.2018.10.013

Luscombe, D., Anderson, K., Gatis, N., Grand-Clement, E., & Brazier, R. (2015). Using airborne thermal imaging data to measure near-surface hydrology in upland ecosystems. *Hydrological Processes, 29*, 1656–1668. https://doi.org/10.1002/hyp.10285

Marín, J. O., (2023). *How can sustainable infrastructure contribute to Protection and Enhancement of Biodiversity & the Natural Environment?* FAST-Infra sustainable Infrastructure. https://www.fastinfralabel.org/news/how-can-sustainable-infrastructure-contribute-to-protection-and-enhancement-of-biodiversity-the-natural-environment

Marine Scotland. (n.d.). *Chapter 20: Onshore cultural heritage.* Retrieved from https://marine.gov.scot/sites/default/files/chapter_20_onshore_cultural_heritage.pdf

Marine Scotland. (n.d.a.). *SHE Orkney to Caithness: Volume 1 Main Report.* Retrieved from https://marine.gov.scot/datafiles/lot/SHE_Orkney%20to%20Caithness/1%20Volume%201_Main%20Report.pdf

Marrs, R., Galtress, K., Tong, C., Cox, E., Blackbird, S., Heyes, T., Pakeman, R., & Duc, L. (2007). Competing conservation goals, biodiversity or ecosystem services: Element losses and species recruitment in a managed moorland-bracken model system. *Journal of Environmental Management, 85*(4), 1034–1047. https://doi.org/10.1016/j.jenvman.2006.11.011

Martins, L. D. (2024, January 8). Britain's 2023 electricity mix in review. *Current*. Retrieved from https://www.current-news.co.uk/britains-2023-electricity-mix-in-review

Mitchell, J., Gu, Y., Cottey, R., Chalmers-Arnold, I., Zhang, H., Thornton, A., Hampshire, K. A., Richmond, B., Thistlethwaite, G., & Willis, D. R. (2024). *Air pollutant inventories for England, Scotland, Wales and Northern Ireland: 2005–2022*. Retrieved from https://naei.energysecurity.gov.uk/reports/air-pollutant-inventories-england-scotland-wales-and-northern-ireland-2005-2022

Morgan, R. (2012). Environmental impact assessment: the state of the art. Impact Assessment and Project Appraisal, 30, 14 - 5. https://doi.org/10.1080/14615517.2012.661557.

Nassar, N., Wilburn, D., & Goonan, T. (2016). Byproduct metal requirements for U.S. wind and solar photovoltaic electricity generation up to the year 2040 under various Clean Power Plan scenarios. *Applied Energy, 183*, 1209–1226. https://doi.org/10.1016/j.apenergy.2016.08.062

NatureScot. (2024a). *Upland and moorland: Meeting the management needs of the varied habitats, species and land uses that Scotland's uplands and moorlands support is challenging*. Retrieved from https://www.nature.scot/professional-advice/land-and-sea-management/managing-land/upland-and-moorland

NatureScot. (2024b). *Managing nature for carbon capture*. Retrieved from https://www.nature.scot/professional-advice/land-and-sea-management/carbon-management/managing-nature-carbon-capture

NatureScot (n.d.). *Restoring Scotland's Peatlands.* NatureScot. https://www.nature.scot/professional-advice/land-and-sea-management/carbon-management/restoring-scotlands-peatlands

NESO. (2022). *ESO publishes Pathway to 2030—Major step to deliver 50GW of offshore wind by 2030*. Retrieved from https://www.neso.energy/news/eso-publishes-pathway-2030-major-step-deliver-50gw-offshore-wind-2030

NTNU Open. (2023). *Electromagnetic fields from subsea cables and their effects on marine organisms*. Retrieved from https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/3158616

Offshore Energy. (2024). *SSEN Transmission renews partnership with BAM and Siemens Energy*. Retrieved from https://www.offshore-energy.biz/ssen-transmission-renews-partnership-with-bam-and-siemens-energy

Pavel, C., Lacal-Arántegui, R., Marmier, A., Schüler, D., Tzimas, E., Buchert, M., Jenseit, W., & Blagoeva, D. (2017). Substitution strategies for reducing the use of rare earths in wind turbines. *Resources Policy, 52*, 349–357. https://doi.org/10.1016/j.resourpol.2017.04.010

Powe, N., & Willis, K. (2004). Mortality and morbidity benefits of air pollution (SO2 and PM10) absorption attributable to woodland in Britain. *Journal of Environmental Management, 70*(2), 119–128. https://doi.org/10.1016/j.jenvman.2003.11.003

Prosper Scotland. (2024). *SSEN Transmission secures awards for sustainable projects.* Retrieved from https://prosper.scot/awards24blog-ssen-t/

Rodrick, V. (2024, May 12). A million vehicles face city ban but data says air is OK. *The Times*. Retrieved from https://www.thetimes.com/uk/scotland/article/one-million-vehicles-banned-from-cities-as-low-emission-zones-enforced-pk97szz7s

Rural 21. (2020). Disturbed ecosystems recover, but not completely. *Rural 21 – The International Journal for Rural Development*. Retrieved from https://www.rural21.com/english/scientific-world/detail/article/disturbed-ecosystems-recover-but-not-completely.html

Sandanayake, M., Zhang, G., & Setunge, S. (2016). Environmental emissions at foundation construction stage of buildings—Two case studies. *Building and Environment, 95*, 189–198. https://doi.org/10.1016/j.buildenv.2015.09.002

Scottish Air Quality. (2024, November 28). *Homepage*. Retrieved from: https://www.scottishairquality.scot

Scottish Wildlife Trust. (n.d.). *Peatlands and soils*. Retrieved from https://scottishwildlifetrust.org.uk/our-work/our-advocacy/naturebasedsolutions/peatlands-soils

Siemens Energy. (n.d.). *Siemens Energy: Transforming energy*. Retrieved from https://www.siemens-energy.com/sa/en/home.html

Soini, K., Pouta, E., Salmiovirta, M., & Kivinen, T. (2011). Local residents' perceptions of energy landscapes: The case of transmission lines. *Land Use Policy, 28*(2), 294–305. https://doi.org/10.1016/j.landusepol.2010.06.008

SSEN. (2022). *Load growth in North of Scotland: Early analysis report.*Retrieved from https://www.ssen.co.uk/globalassets/about-us/dso/smart-and-local-benefits/2209-load-growth-in-north-of-scotland---early-analysis-report.pdf

SSEN. (2023). *SSEN Transmission's £10bn networks investment to support over 20,000 jobs throughout UK*. Retrieved from https://www.ssen-transmission.co.uk/news/news--views/2023/6/ssen-transmissions-10bn-networks-investment-to-support-over-20000-jobs-throughout-uk/

SSEN. (2024). *SSEN becomes the first utility to back projects for nature*. Retrieved from https://www.ssen.co.uk/news-views/2024/SSEN-becomes-first-utility-to-back-projects-for-nature

SSEN Transmission. (n.d.a.). *2030 FAQs: SSEN Transmission projects*. Retrieved from https://www.ssen-transmission.co.uk/projects/2030-projects/2030-faqs

SSEN Transmission. (n.d.b.). *Pathway to 2030 and our next Business Plan.* Retrieved from https://www.ssen-transmission.co.uk/information-centre/delivering-net-zero--Pathway-to-2030-and-our-next-Business-Plan/

SSEN Transmission. (n.d.c.). *Why are the Pathway to 2030 projects needed?* Retrieved from https://www.ssen-transmission.co.uk/projects/2030-projects/2030-need

Tobiasson, W., Beestermöller, C., & Jamasb, T. (2016). Public engagement in electricity network development: The case of the Beauly–Denny project in Scotland. *Economics and Policy of Energy and the Environment, 43*(1), 105–126. https://doi.org/10.1007/s40812-016-0030-0

UK Health Security Agency. (2022). *Chemical Hazards and Poisons Report*. Retrieved from https://www.scottishairquality.scot/air-quality

REGlobal. (2022). *Holistic network design: A key step towards achieving 50 GW offshore wind in the UK by 2030*. Retrieved from https://reglobal.org/holistic-network-design-a-key-step-towards-achieving-50-gw-offshore-wind-in-the-uk-by-2030/

Union of Concerned Scientists. (2019). CO_2 and ocean acidification. Retrieved from https://www.ucsusa.org/resources/co2-and-ocean-acidification

UNDP. (2024). What is climate change mitigation and why is it urgent? Retrieved from https://climatepromise.undp.org/news-and-stories/what-climate-change-mitigation-and-why-it-urgent

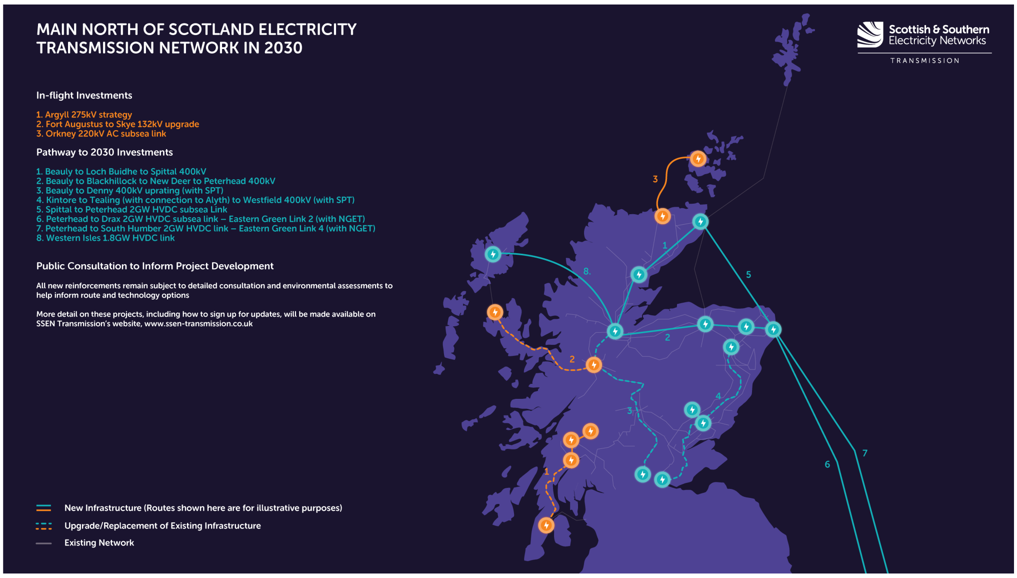
Vanwoensel, T., Creten, R., & Vandaele, N. (2001). Managing the environmental externalities of traffic logistics: The issue of emissions. *Production and Operations Management, 10*(3), 207–223. https://doi.org/10.1111/j.1937-5956.2001.tb00079.x

World Steel Association. (2024, May 27). *World steel in figures 2024*. Retrieved from https://worldsteel.org/data/world-steel-in-figures-2024

WWF. (2024). *Biodiversity and infrastructure: Investing – How infrastructure investors are factoring biodiversity impacts into decision-making*. Retrieved from https://www.worldwildlife.org/publications/biodiversity-and-infrastructure-investing-how-infrastructure-investors-are-factoring-biodiversity-impacts-into-decision-making

Appendix

Image 1



Retrieved from: https://www.ssen-transmission.co.uk/projects/2030-projects/

Table 1

Ecosystem	Function	Location
Peatlands	Carbon sink	Highlands | Flow Country
Moorlands	Carbon sink and natural flood defenses	Across Scotland | Northern England
Woodlands	Carbon sink and pollutant absorption	Norther England (Yorkshire, Northumberland) | Across Scotland
Coastal salt marshes	Carbon sink and natural buffer against storm surges	Eastern coast of Scotland | Northern England
Seagrass meadows	Carbon sink	Coastlines of the North Sea | West coast of Scotland
Marine sediments	Carbon sink	North Sea

Table 2

Project nubers relate to Image 1

Ecosystem	Projects Potentially Causing Harm
Peatlands	Subprojects 1, 2, 5: Northern Scotland (around Spittal, Flow Country)
Coastal Salt Marshes and Wetlands	Subprojects 6, 7: Eastern and Northeastern Scotland (near Peterhead)
Seagrass Meadows	Subprojects 6, 7, 8: North Sea coastal waters (HVDC subsea links to South Humber and Drax)
North Sea Seabed	Subprojects 5, 6, 7: Kelp forests, shellfish beds, and sediment carbon storage
Forests and Moorlands	Subprojects 2, 4: Central Scotland (transmission lines from Kintore to Tealing and Westfield)