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Scaling up renewable energy storage with sodium ion batteries and green technology policy

Lavinia Heisenberg^a and Richhild Moessner^{a,b}

April 2025

Abstract

A key element in the transition to net zero carbon emissions is increasing the use of renewable energy, especially wind and solar energy, and scaling up energy storage sustainably to enable their greater use. This paper discusses the advantages and challenges of scaling up renewable energy storage with increased development and use of sodium ion batteries, and the role for green technology policy in addressing the externalities associated with these challenges. Sodium ion batteries can be built without the use of lithium and cobalt, in contrast to commonly used lithium ion batteries, thereby avoiding large environmental and social costs associated with mining of lithium and cobalt. There are externalities in building a recycling system for sodium ion batteries, since its components are not very valuable. Moreover, there are network externalities in building large-scale grid storage infrastructure, for which sodium ion batteries are suitable. Due to these externalities, there is a role for green technology support policies in helping to scale up renewable energy storage with sodium ion batteries.

JEL Classification: Q00; Q48; Q58; Q40; Q50; Q55

Key words: energy storage; renewable energy; batteries; energy grid infrastructure; externalities; green technology policies; sustainability; climate change.

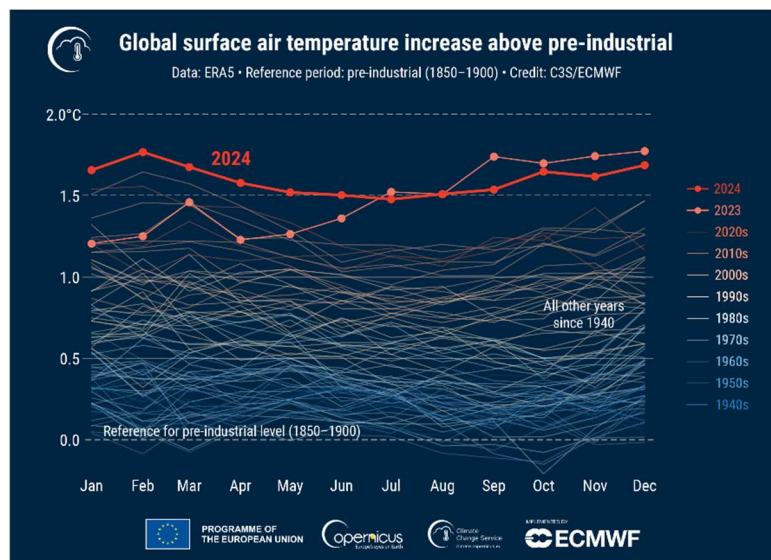
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1. Introduction

Global surface air temperatures have risen strongly further in 2023 and 2024 relative to the pre-industrial level, reaching unprecedented levels in 2024 (Figure 1) (Copernicus Climate Change Service (C3S), 2025). The year 2024 was globally the warmest year ever recorded, and it was the first calendar year during which the average global temperature exceeded 1.5°C above its pre-industrial level (C3S, 2025). In 2024 atmospheric greenhouse gases reached the highest annual levels ever recorded in the atmosphere (C3S, 2025). Standard climate change scenarios project an increase of around 3°C in global temperatures compared with pre-industrial levels over the course of the century if current climate policies are unchanged (United Nations Environment Programme, 2024). Climate policies therefore need to be expanded and made more stringent in order to reduce carbon dioxide emissions (IPCC, 2022). Such policies include carbon taxes and emissions trading systems (Stern, 2008; Metcalf and Stock, 2020; Kohlscheen et al., 2021), as well as other policies including green technology support policies (Aghion et al., 2022; Acemoglu et al., 2012; Coalition of Finance Ministers for Climate Action, 2023; Stern, 2008).

Figure 1: Daily global surface air temperature anomalies relative to pre-industrial level (1850–1900)



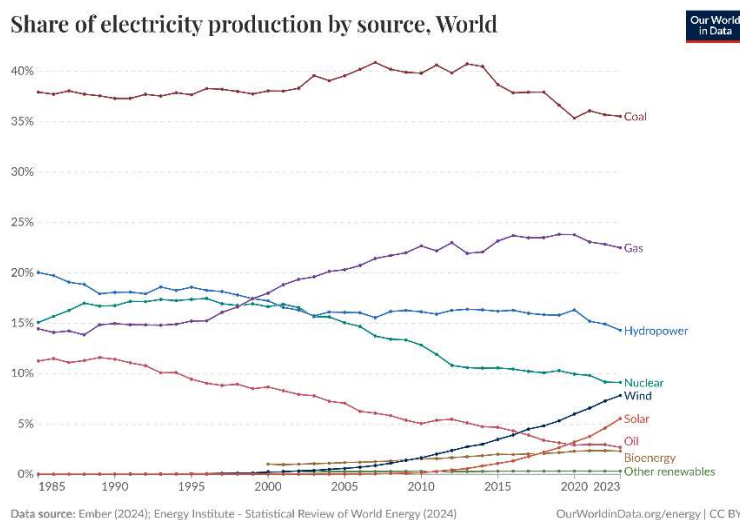
Source: Copernicus Climate Change Service (2025), fifth generation European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric reanalysis of global climate since January 1940 (ERA5), C3S/ECMWF.

A key element in the transition to net zero carbon emissions is increasing the use of renewable energies, especially wind and solar energy, and scaling up energy storage to enable their greater use. Energy storage is required due to the variability in the production of renewable energy, especially for wind and solar energy. The use of renewable energy for electricity production has increased (Figure 2), but it is being held back in part by a lack of sufficient energy storage capacity, and needs to be expanded more, and faster. Examples in 2024 include that wind energy produced in the North Sea off the coast of Germany could not be fully utilised, partly since it could not be stored in sufficient amounts. With sufficient grid-scale energy storage, the variability of wind and solar energy production could be smoothed out by storing surplus energy, and using this stored energy later when little is being produced. This would avoid using fossil fuels as backup to generate energy at times when little renewable energy is being produced, thereby avoiding carbon dioxide emissions from these fossil fuels.

Sodium-ion batteries (NIBs) are promising electrical power sources complementary to lithium-ion batteries (LIBs) and could be crucial in future electric vehicles and energy storage systems (Zhao et al., 2023). Sodium-ion batteries match LIBs in energy density, but are cheaper and can be used for large-scale grid energy storage (Hirsh et al., 2020). Sodium-ion batteries are attractive for energy storage on account of their elemental abundance and promising electrochemical performance (Hirsh et al., 2020).

Compared with lithium-ion batteries, sodium-ion batteries are more environmentally sustainable and cheaper (Ould et al., 2024b). New developments in sodium battery materials have made it possible to produce high-voltage and high-capacity cathodes which do not contain elements which are very problematic to obtain such as lithium, cobalt and nickel (Hirsh et al., 2020).

Figure 2: Share of global electricity production by energy source



Source: Ember (2024), Energy Institute (2024), Our World In Data (2025).

There has been recent cutting-edge research on developing sodium ion batteries (see eg Ould et al., 2024a). But given the huge potential of sodium ion batteries in scaling up energy storage and thereby enabling greater use of renewable energies, more research is needed. There is much potential in developing materials for sodium ion batteries. For example, Ould et al. (2024b) highlight that the electrolyte composition (both salt and solvent) of sodium-ion batteries remains underdeveloped.

2. Key advantages of scaling up the use of sodium ion batteries for energy storage

Scaling up sodium-ion batteries supports the renewable energy sector by addressing the pressing need for safe, cost-effective, and sustainable energy storage solutions. Their inherent advantages over lithium-ion batteries in terms of cost, sustainability, safety, and adaptability make them a promising choice for the future of renewable energy storage. Their scalability, lower environmental impact, and improved operational safety are especially valuable for grid-scale energy storage, making sodium-ion batteries an important technology for advancing global clean energy goals. Key advantages of scaling up the use of sodium ion batteries for energy storage are discussed below.

2.1 Cost-effectiveness

Abundant resources

Sodium is the sixth-most abundant element in the earth's crust (Kozłowski, 2020) and is widely available in salt form (sodium chloride). It is far more abundant than lithium, which reduces the cost pressure from raw materials (Zhao et al., 2017). This abundance is especially advantageous as demand for batteries grows rapidly and lithium prices continue to rise due to high demand for lithium-ion batteries in electric vehicles (EVs) and energy storage, especially large-scale grid energy storage (Ponnada et al., 2022).

Lower production costs

Sodium-ion batteries use materials that are cheaper than those in lithium-ion batteries. For instance, they can employ aluminum rather than copper for current collectors (Desai et al., 2022). Aluminum costs less than copper and is also lighter, which can reduce the overall weight of the battery. Additionally, the sodium-ion battery manufacturing process shares many similarities with lithium-ion battery production,¹ allowing manufacturers to transition without costly changes to their facilities. This cost advantage can also make energy storage more accessible to lower-income regions and accelerate the widespread deployment of renewable energy storage.

2.2 Improved sustainability

Environmental impact

The extraction and refinement of lithium, cobalt, and nickel used in lithium-ion batteries are associated with environmental problems, including water depletion, soil degradation, and ecological harm in mining areas. Sodium mining is far less environmentally damaging, and the waste generated in its refinement has a lower environmental impact. Sodium-ion batteries also avoid using cobalt, which is both environmentally problematic and associated with labor and ethical issues in supply chains. Consequently, sodium-ion batteries are more environmentally sustainable than lithium-ion batteries (Ould et al., 2024b).

Resource security

Lithium resources are heavily concentrated in a few countries, such as Bolivia, Chile, and Australia, making supply chains vulnerable to geopolitical tensions and supply shortages. In contrast, sodium resources are more evenly distributed globally, reducing dependency on specific regions. This widespread availability enhances energy security, making sodium-ion batteries a more resilient choice for large-scale energy projects that seek to avoid reliance on politically sensitive or volatile supply chains.

2.3 Safety and stability

Thermal stability

Sodium-ion batteries are inherently safer than lithium-ion batteries (Velumani and Bansal, 2022). Sodium-ion batteries may generally have higher thermal stability compared to lithium-ion batteries, implying operation at higher temperatures without the risk of overheating. This characteristic reduces the chances of thermal runaway, a condition where overheating triggers a self-sustaining chain reaction that can lead to fires or explosions. Higher thermal stability would make sodium-ion batteries more suitable for large-scale installations where safety is paramount,

¹ Private communication by Dame Clare Grey in a conversation after her presentation of a physics colloquium at University of Heidelberg on 2 February 2024.

as well as for installation in hotter climates. More research on the thermal properties of sodium-ion batteries would be useful (Sirengo et al., 2023; Yue et al., 2024).

Safer operation and transportation

Sodium-ion batteries may generally safely handle overcharging and short-circuiting better than lithium-ion counterparts. While lithium-ion batteries require complex battery management systems to ensure safe operation, sodium-ion batteries may function with simpler (and cheaper) monitoring systems. The increased operational safety of sodium-ion batteries would be particularly valuable in grid-scale storage where reliability and safety are crucial for avoiding operational interruptions and ensuring a stable energy supply. More research on the operational safety of sodium-ion batteries would be useful (Bhutia et al., 2024). Due to their use of an aluminum current collector which is strongly resistant against oxidation, sodium-ion batteries can have greater OV stability than lithium-ion batteries, making them safer during external short and/or over-discharge, and thereby safer for transportation (Desai et al., 2022).

2.4 Compatibility with existing infrastructure

Manufacturing process

One of the biggest hurdles for new battery technologies is the need for specialized manufacturing equipment. Fortunately, sodium-ion batteries can be produced using much of the same infrastructure as lithium-ion batteries, especially as they utilize similar materials, cathodes, and anodes in terms of design. This compatibility allows manufacturers to shift to sodium-ion technology without a large capital investment, which helps to scale up production quickly and meet growing demand.

Ease of adoption

Given the similar manufacturing process, companies and governments interested in promoting sodium-ion technology for energy storage would not need to invest heavily in building new facilities. Additionally, existing lithium-ion battery factories can quickly switch to sodium-ion battery production, which can reduce the cost of entry for new players in the market and further increase competition and innovation.

Use of existing infrastructure

Some of the infrastructure of decommissioned coal power plants can be used as large sodium-ion battery sites. This importantly includes using existing connections to the grid of the former coal power plants for feeding electricity from sodium-ion batteries into the grid (Marshall, 2024). This also includes using existing concrete foundations and repurposing existing concrete for housing batteries, which is particularly advantageous for sodium-ion batteries on account of their larger size than lithium-ion batteries; in the United Kingdom decommissioned coal power plants are already being turned into large battery energy storage sites (Marshall, 2024).

2.5 Efficiency for grid storage

Long cycle life

Grid-scale storage systems need batteries with a long cycle life to be economically viable. Sodium-ion batteries are likely well-suited for such applications because they may last longer than lithium-ion batteries when used in low-energy-density, stationary applications (Patel, 2023). This advantage means sodium-ion batteries could be more cost-effective over their lifetime, as they would require fewer replacements in large-scale renewable energy storage solutions. More

research on extending the cycle life of sodium-ion batteries for large-scale energy storage systems would be useful (Zhang et al., 2023).

Low-temperature performance

Unlike lithium-ion batteries, which can experience significant performance drops in cold weather, sodium-ion batteries may operate more effectively in low-temperature environments (Zhao et al., 2024). This low-temperature performance would make sodium-ion batteries ideal for use in colder regions without requiring additional energy for battery heating systems. In turn, this would reduce the overall operational costs of large-scale storage systems and make them adaptable across diverse climates. More research on the low-temperature performance of sodium-ion batteries would be useful (Zhao et al., 2024).

2.6 Support for renewable energy integration

Grid-level applications

Renewable energy sources such as wind and solar are inherently variable and require stable storage solutions to smooth out supply fluctuations. Sodium-ion batteries provide an affordable and scalable storage option that supports continuous integration of renewable energy into the grid. Their capacity for grid-level applications helps address the intermittency problem of renewables by storing excess energy generated during peak production periods and releasing it during low generation periods, ensuring a steady power supply. Sodium ion batteries can serve the needs for large-scale grid energy storage better than lithium ion batteries (Hirsh et al., 2020).

Modularity for scalability

Sodium-ion battery systems are modular and scalable, meaning they can be customized to suit both small and large renewable projects (Fraunhofer Institute for Solar Energy Systems, 2025). This modularity is essential in enabling flexible and adaptive storage solutions that can meet varying demands, from small community solar installations to large utility-scale wind farms. This flexibility is critical as the energy sector moves toward decentralized energy grids with a mix of small, medium, and large renewable installations.

3. Key challenges in scaling up energy storage with sodium ion batteries

Key challenges in scaling up energy storage with sodium ion batteries are the following.

Sodium ion batteries are larger than lithium cobalt batteries. But the larger size is not so relevant for some stationary applications. And even for the use in moving vehicles, they have already been employed as car batteries in vehicle prototypes by some Chinese car manufacturers (Schirber, 2024).

There has been relatively little development and production of sodium ion batteries, especially in Germany, where companies often focus on supplying lithium batteries for car manufacturers, which have been lagging behind by international comparison in adopting environmentally friendly cars, including electric vehicles. Policymakers need to consider how the research and development of sodium ion batteries, as well as their production, can be increased and speeded up.

Increasing the production of sodium ion batteries is held back if lithium prices fall temporarily, for example because of reduced demand on account of production problems with electric vehicles

using lithium batteries. Given that lithium mining involves large environmental and social costs, which are not accounted for in lithium prices, policymakers should consider how to prevent lower lithium prices from holding back the production of sodium ion batteries.

Sodium ion battery components are not very valuable, so that there is little incentive to recycle sodium ion batteries, in contrast to lithium cobalt batteries, whose components are more valuable. Sodium ion batteries should be recycled to protect the environment (Zhao et al., 2023). Therefore a recycling system needs to be designed. Zhao et al. (2023) suggest that ways to facilitate recycling spent sodium ion batteries should be put in place during the early commercialisation stage in order to ensure that they are designed for ease of recycling, which would help in creating a circular economy for the sodium ion battery industry. Since sodium ion batteries are still in the early stages of development, there is still an opportunity of creating such a circular economy in their production.

It is not clear how grid energy storage will be paid for. Given the network externalities in building large-scale grid storage infrastructure, this needs to be specified, coordinated and regulated by policymakers. Examples of existing models to pay for grid energy storage in the United States include renewable energy and storage power purchase agreements, and tolling and capacity contracts (Thomson et al., 2023). Examples of regulation include that in the United States the Federal Energy Regulatory Commission issued orders (No. 841 and No. 2222) relevant for grid energy storage in 2018 and 2020 (Thomson et al., 2023). The US Inflation Reduction Act of 2022 extended investment tax credits to qualifying energy storage technology property (Thomson et al., 2023).

4. Role for green technology policy

Given the externality that lithium and cobalt mining involves large environmental and social costs, which are not accounted for in the prices of lithium cobalt batteries, there is a role for green technology policy in speeding up and increasing the development and production of sodium ion batteries.

There are also externalities in building a recycling system for environmentally harmful sodium ion batteries, whose components are not very valuable, which provide a case for policy to regulate such a recycling system, at a time when the technology is still under development, so that it is in place in time for their wider use.

Moreover, since sodium ion batteries can be a means for large-scale grid energy storage, there is a role for green technology policy in designing the grid infrastructure, which is subject to network externalities, including deciding how grid storage is paid for and how it is regulated.

Such green technology policy to support the development and production of sodium ion batteries, and design the associated large-scale grid energy storage infrastructure, would help to increase the use of renewable energy sources, especially of wind and solar energy. This would enable a quicker transition to net zero carbon emissions. Such a quicker transition to net zero is needed to reduce the detrimental effects of global warming.

5. Conclusions

A key element in the transition to net zero carbon emissions is increasing the use of renewable energies, especially wind and solar energy, and scaling up energy storage in an environmentally

sustainable way to enable their greater use. This paper discussed the advantages and challenges of scaling up renewable energy storage with increased use of sodium ion batteries, and the role for green technology policy in addressing the externalities associated with these challenges.

Given the clear advantages in avoiding large environmental and social costs associated with the mining of lithium and cobalt for lithium cobalt batteries, the development, production and use of sodium ion batteries should be increased and speeded up. Given the externality that lithium and cobalt mining involves large environmental and social costs, which are not included in the prices of lithium cobalt batteries, there is a role for green technology policy in speeding up and increasing the development and production of sodium ion batteries in order to scale up renewable energy storage.

There are also externalities in building a recycling system for environmentally harmful sodium ion batteries, whose components are not very valuable, which provide a case for policy to regulate such a recycling system, at a time when the technology is still under development.

Since sodium ion batteries can be a means for large-scale grid energy storage, there is a role for green technology policy in designing the grid infrastructure, since it involves network externalities, including deciding how grid storage is paid for. This would allow to speed up the transition to net zero carbon emissions, which is required to limit global warming, by facilitating an increased use of renewable energies.

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