Jump-Starting Global Grid Decarbonization: US-Dutch Partnerships Energize Utility-Scale Battery Deployment

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https://doi.org/10.38126/JSPG240116
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Keywords: renewables; energy storage; power grid; decarbonization; science diplomacy

Executive Summary: The United States and the Netherlands heavily invest in renewable energy as part of their individual commitments to net zero emissions by 2050. Weather-dependent fluctuations in wind and solar power, along with limitations in legacy infrastructure and systems, restrict the on-demand use of these renewables and pose substantial bottlenecks to the energy transition. Integration of dynamic energy storage technologies into modernized electrical systems will provide crucial solutions to overcome these challenges. Herein, we profile stakeholder perspectives on the energy transition and present our recommendations for US-Dutch collaboration on utility-scale electrochemical battery solutions to update power grids with robust, accessible, and sustainable carbon-free flexible energy capacity.

I. The intermittency challenge of renewable energy

Worsening climate change demands rapid and robust deployment of clean energy technology to reduce carbon emissions and transition from fossil fuels to sustainable and equitable energy systems. This energy transition strategy, called "grid decarbonization," along with the electrification of transportation, industrial, and residential operations represents the primary strategy to keep temperatures from rising above the 2 °C warming threshold (IPCC, 2022). Despite advancements in technology to harness wind and solar energy, the weather-dependent intermittency of these renewable energy generators demands that their development, manufacture, and integration to the grid be supported by Battery Energy Storage Systems (BESS). However, the 4-8 hour duration time of current BESS technology severely restricts storage capacity during *"dunkelflaute*," a German term describing periods during which significant energy cannot be generated from wind or solar power. These extended "dark, windless" periods highlight the need to extend BESS duration to 8–12 hours—or even to a day or longer. The advancement of utility-scale battery technology thus plays a critical role in accelerating the energy transition (IEA, 2021). Modernizing the grid with energy storage technology will support the integration of renewable energy by allowing "on-demand" use of natural intermittent resources.

The United States and the Netherlands share the need to upgrade aging electrical grids to meet the increasing demand for electrification which threatens to outpace the integration of renewable energy to the grid. Years-long wait lists for grid expansion constrain the deployment of rapid technological developments in clean energy generation and storage. Inconsistent energy demand in the US and the Netherlands require both countries to rely primarily on fossil fuels and nuclear fission for rapidly dispatchable energy generation to meet current needs and to smooth congestion. Both countries share the goal to reduce greenhouse gas emissions to zero by 2050. Towards this aim, we partnered with the Consulate General of the Netherlands in San Francisco to provide recommendations for brokering US-Dutch stakeholder partnerships in grid decarbonization and energy storage solutions. We interviewed fifteen energy storage and energy transition experts from various stakeholder groups, including energy departments at the national and state levels, energy affairs specialists, critical minerals and energy government research institutes, international energy business association and coalitions, grid owners and operators, energy generation organizations, energy solution start-ups, and energy technology incubators and accelerators.

II. Landscape of energy storage solutions

Developments in battery and energy storage are rapidly advancing as a result of industry demand and R&D investments. Pumped storage hydropower has significant storage duration and scale which has enabled long-term electricity storage capacity in some regions of the US However, the climate dependence of the technology renders it vulnerable to leakages, evaporation, and drought, while its topographical requirements, e.g., hills and mountains, restrict access to remote grid sites and application to geographically flat regions such as the Netherlands (Blakers et al. 2021). Alternative methods such as thermal energy storage are limited by high cost, large footprints, and low efficiency. Thus, electrochemical storage, namely utility-scale lithium-ion (Li-ion) batteries, leads the BESS market due to their storage lifetime, efficiency, and convenience of direct, on-site storage. The high energy density of Li-ion batteries suits their application to BESS, with some cost and safety concerns due to poor capacity retention and degradation over time.

Scarcity of the minerals such as lithium and cobalt required for battery manufacture means that the extraction and processing of these critical minerals is the most crucial step of the battery supply chain (Manthiram 2020). Critical mineral deposits are not evenly distributed throughout the world; although the US contains some lithium deposits, the expense and pollution from past mining operations have fueled public skepticism of new projects (Semuels and Cough 2023). Both the US and the Netherlands primarily rely on foreign imports for the crude materials required for grid-scale battery storage (National Renewable Energy Laboratory 2021). Moreover, the majority of critical mineral processing and refining occurs in China, which can leverage competition for these exports in geopolitical disputes (Wilson Center 2022). In some cases, significant environmental, social, and governance (ESG) issues arise, such as in the Democratic Republic of Congo, where cobalt mining has been used to fund armed groups (Zounmenou et al. 2019). To integrate grid-scale energy storage into an updated energy grid, the US and the Netherlands must address ESG concerns when acquiring a steady supply of critical minerals and consider investment in more circular manufacturing processes.

Increasing geopolitical competition over scarce critical minerals can generate supply chain bottlenecks, providing the incentive to diversify BESS technologies. Vanadium redox flow batteries (VRFB) have emerged as potential competitors due to their higher capacities, recyclability, and rechargeability compared to Li-ion batteries (Scott 2023). Their improved affordability and safety profiles further aid projections that VRFB deployment in the US could reach gigawatt-hour scale within a decade from the time of this writing (Rodby et al. 2023); however, their low energy density and temperature requirements prevent VRFB from outpacing the more compact and dynamic Li-ion technology in BESS applications (Ren et al. 2023).

III. Infrastructure and market challenges to battery deployment

Both the US and the Netherlands must balance increasingly strict ESG standards with the convenience of the status-quo energy infrastructure in meeting their climate mitigation goals. US and Dutch interviewees agreed that grid decarbonization will require complex, large-scale solutions, but they offered divergent perspectives on relevant legacy infrastructure, policy bottlenecks, and market challenges. US interviewees noted that misinformation and ideological divisiveness, exacerbated by entrenched interests in the fossil fuel industry, render investment funding highly volatile. Further, the entrenched utility business model relies on energy-buying contracts to incentivize implementation of new technologies since there is no well-established market for these functions as a standalone (Bowen, Chernyakhovskiy, and Denholm 2019). Dutch interviewees mentioned long connection queues due to congestion and high voltage loads within interconnected European energy grids. One interviewee highlighted the additional challenge in integrating customer-generated electricity from solar panel home installations into a grid system originally designed for centralized one-way-flow, likening system upgrades to "changing the tire on your bike while riding it."

The novelty of BESS presents further timeline challenges with manufacture and waste streams; for example, the critical mineral recycling market is underdeveloped compared to the extraction and processing markets. Interviewees juxtaposed accessible sources of government and private funding for BESS pilot projects with a well-documented lack of funding sources needed to bring new technologies to market and implement new recycling systems. An interviewee from a US battery recycling startup posited that funding scarcity likely stems from a lack of investor confidence in technologies not yet supported by a historic record in profitability, as well as in the difficulty in forecasting energy consumption vs. generation/load expectation. The Dutch government aims to mitigate similar challenges by achieving a fully circular economy by 2050 through a transition program focusing on Li-ion battery recycling, sustainable procurement of Information and Communications Technology (ICT), and energy neutrality in construction (Government of the Netherlands). However, investments in recycling and renewable energy take effect slowly; reduction and reuse of primary material resources in the Netherlands have barely increased from 2014 to 2020 (CBS NL 2023), and the aim to halve raw materials consumption by 2030 will require a drastic cuts to fossil fuels and primary metal materials, 100% of which will be imported by the end of 2023 (Olabi 2019, van Oorschot et al. 2022). US and Dutch interviewees generally agreed on BESS-related priorities including longer storage BESS, diversified energy solutions, and developing a more resilient supply chain for critical minerals.

IV. Policy recommendations

Arguably, the central challenge to the energy transition lies in divestment from the cost-effectiveness and convenience of fossil fuels and their established infrastructure. This ambitious undertaking of grid decarbonization will require bold investments and a diversity of progressive socio-technical solutions rather than one centralized technology or optimization strategy. Interviewees noted, "we can only trust [optimized technology] to work well because it has been allowed to fail in the past;" and a Dutch interviewee expressed "we have to rethink the concepts of reliability … and let go of the idea that energy can be supplied any time we want." Societal attitudes about the energy grid likely need to change as utilities embrace energy production methods that pollute less but provide less on-demand power. This is especially true in the Netherlands where power outages are virtually unheard of. Addressing societal changes in attitudes is outside the scope of our policy recommendations, instead we focus on diplomatic opportunities. We present the following recommendations to promote US-NL grid modernization partnerships.

i. Investment in research collaboration

Research partnerships present attractive opportunities for collaboration on innovative international projects like heterogeneous battery deployment in China (Peng et al. 2023). Dutch stakeholders noted some difficulty in forming industry partnerships with American companies, citing competitive industry environments that impede the sharing of novel results and technologies. Although the application-centered industry approach more directly facilitates creation of new products, redirecting investment towards academic collaboration through lead agency agreements would motivate information exchange toward common goals. Academic research models lessen the chances of redundant investments due to a greater culture of open science and more focus on basic science than industry research models could lead to higher potential rewards. International academic projects can be tailored to more directly contribute to product development through existing mechanisms for research partnerships like the Net Zero World Initiative. Joining this initiative would allow the Netherlands to access US-led programs that support peer-to-peer learning and and capture joint engagement in R&D, supply chain modeling, and industry support previewed in the DOE's Strategy to Support Domestic Critical Mineral and Material Supply Chains (2021-2031).

ii. Participation in international partnerships
Collaboration between governments will be crucial for the global transition from dependence on fossil fuels to a practical application of renewable energy. Joining US-partnered international coalitions will provide the Netherlands with more opportunities to participate in the global energy transition. Announced in 2022, the Minerals Security Partnership (MSP) is an international effort between 14 countries, including the US, to ensure that the critical mineral supply chain promotes transparency, accountability, and raw material traceability for ethical social, labor, and environmental practices around the world. This includes ESG risk management associated with the impacts of critical mineral and clean energy technology supply chains such as geopolitical tensions, armed conflicts, human rights violations, bribery and corruption, emissions, water stress, and loss of biodiversity (EIA 2022, US Department of State 2023; Patrahau et al. 2023). The Sustainable Critical Material Alliance (SCMA), announced at COP15, supports the international dialogue on sustainability expectations of critical minerals supply chain with the policy goal to halt and reverse biodiversity loss by 2030. The Energy-Resource Governance Initiative (ERGI) developed a toolkit to "share and reinforce best practices" for policy stakeholders across the international mining sector. International initiatives through these coalitions will need to traverse bold cultural and political shifts to meet environmental justice goals and divest from outdated models of geological power and "mineral estate" that have historically fueled geopolitical conflict, systemic racism, and inequalities (Walker & Johnson, 2023; Hine & Mayes, 2023; Donaghy et al.,2023). Such international partnerships will require actionable knowledge and participatory action research to legitimize decision-making power of historically disenfranchised and disadvantaged communities (Mach, et al., 2020; Jordan, 2018).

iii. Promote government financing and policy incentives
The hesitancy of the private sector to finance risky investments will require government funding to scale new technologies into full-size projects with demonstrated profitability. Additionally, governments need to create specific monetary compensations for the types of grid services that batteries provide so that energy generators have an economic reason to invest in energy storage. Several Dutch interviewees mentioned interest in US policies like the Inflation Reduction Act that incentivize 70-80% reduction of emissions goals by 2030 (NASEM, 2023). The US $1.2 trillion infrastructure law contains significant investments in power grid updates, weatherization of energy infrastructure, transportation modernization, and electrification (The White House 2021). The $240 billion earmarked for environmental justice projects represents the largest investment in the country's history seeking a clean energy economy that is climate resilient while ensuring historically disadvantaged communities are reaping the benefits of these investments. Screening tools have been developed to identify the eligibility of projects for the infrastructure law and monitor associated environmental justice goals such as EJScreen, CEJST, EJI (Federal level), and CalEnviroScreen (California). The interviews and literature suggest that Dutch implementation of policies with similar environmental justice provisions to the US IRA might propel the national effort to reach net-zero emissions, alleviate grid congestion, and upgrade obsolete electrical infrastructure. IRA guidelines have been designed for this knowledge exchange and have been cited as a strong incentive to increase the competitiveness of advanced battery companies active in the Dutch and European Union markets (Patrahau et al., 2023).

V. Summary
Toward mutual advancement of BESS, we present the following recommendations to the Dutch Consulate in San Francisco to promote collaboration between the US and the Netherlands. First, we suggest furthering international academic partnership, perhaps through lead

agency agreements, to promote transparent science-diplomacy relations for clean energy storage R&D and deployment. To further critical mineral supply chain initiatives and address their geopolitical implications, we recommend consulate inquiry into joining international coalitions such as the MSP, the ERGI, and the SCMA to institutionalize ESG standards and support the challenging effort to secure a resilient, transparent, and more equitable global critical minerals supply chain. Finally, we propose optimizing the financial support systems in the technology sphere, such as R&D tax credits towards industry, venture capital funding towards innovation, and valuing stand-alone battery services specific to grid-decarbonization for more targeted market incentives. Among these, we prioritize recommendation ii: the burgeoning critical mineral industry is an important window of opportunity to critically rethink mining and energy infrastructure governance, thus innovation and collaboration policy solutions need to consider the challenges of energy storage beyond technology innovation to include sociocultural transitions, environmental justice advocacy, and investor activism. Participation in programs like the MSP will propel the Dutch effort to develop a circular economy (NCPE, 2023) and stimulate global objectives to "shift the burden of disposal or recycling from users or waste companies to the entities designing and manufacturing the products" (Cleri et al, 2023).

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Acknowledgements

The authors thank the National Science Policy Network along with the invaluable support of Patricia Gruver for coordinating this project through the Science Diplomacy Fellowship program. We are grateful for the Netherlands Innovation Network team's willingness to give the authors first hand experience in science diplomacy, especially Karin Louzada and Tyrone Pater for their kind mentorship and guidance in organizing interviews and compiling this study. Thank you to Emma McMullan for summarizing the clean energy funds made available in the Inflation Reduction Act (2022) and for her help collecting interview data. Finally, we thank all of the interviewees and webinar speakers who generously lent us their time and expertise which made this study possible.

Appendix. Interview Data and Methods

Semi-structured interviews were conducted between June and July 2023 to deeply discuss the challenges and opportunities of energy storage solutions for decarbonization and climate mitigation goals (Questions are described below.) Fifteen energy storage and energy transition organizations from the Netherlands (9) and the US (6) were interviewed. The interviewees provide a broad range of perspectives from different stakeholder types, including: energy departments at the national and state levels, energy affairs department, critical minerals and energy government research institutes, international energy business association and coalitions, grid owners and operators, energy generation organizations, energy solution start-ups, and energy technology incubators and accelerators.

i. Interview questions:

1. How would you describe your roles and experience in the field of clean energy/grid modernization/energy storage?
2. From your organization's perspective, what are the main challenges of utility-scale energy decarbonization/clean energy/wind and solar?
3. From your organization's perspective, what is the role of energy storage technology in energy decarbonization?
4. What energy storage technologies have you interfaced with? What are their main challenges (follow up: supply chain)?
5. How has your organization's work focus shifted in the past 5 years, and how do you see those trends continuing?
6. Are there any people/organizations/programs you recommend we research/contact?
7. What role does collaboration play in your organization's work (related to utility-scale batteries)? Can you give an example of a time your organization leveraged partnerships between different stakeholders/regions/countries to accomplish a goal?
8. How do you incorporate social equity/environmental justice into your approach to energy transition challenges?
9. What do other stakeholders/organizations get wrong about clean energy/BESS?
10. If your organization could enact any policy change (regardless of feasibility) to support energy transition/decarbonization, what would it be?

ii. Stakeholder interview data

Country	Affiliation	Number Interviewed
US	Energy Dpt., State government	2
US	Energy affairs, critical minerals, Federal Government	1
US	Energy solution start-up	1
US	Critical minerals research, Federal government	1
US	International affairs, Europe, Federal Government	1
NL	Energy Dpt., Federal Government	1
NL	Energy Business Association/Coalition	2
NL	Energy tech solutions incubators/accelerators	1
NL	Grid owners and operators	4
EU (GE, NL)	Energy generation company/department	1