



Sustainable Energy Authority of Ireland

National Energy Research, Development &  
Demonstration Funding Programme

## FINAL REPORT TEMPLATE

### SECTION 1: PROJECT DETAILS – FOR PUBLICATION

<b>Project Title</b>	Low-Cost Sustainable Battery Systems for Enhanced Grid Penetration of Intermittent Renewable Energy
<b>Lead Grantee (Organisation)</b>	University of Limerick
<b>Lead Grantee (Name)</b>	Dr Tadhg Kennedy
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<b>Report Submission Date</b>	

	<b>Name</b>	<b>Organisation</b>
<b>Project Partner(s)</b>	N/A	
<b>Collaborators</b>	N/A	

#### Project Summary (max 500 words)

As part of the National Development Plan, the Irish Government has targeted that 55% of the energy required for electricity generation in Ireland by 2030 comes from renewable sources. To increase the penetration of renewable energy, one of the key challenges that needs to be addressed is the intermittent nature of wind and solar power which can lead to curtailment in times of peak generation. To overcome this, an integrated electricity system is needed that uses storage to provide more flexibility to the grid. There is a growing realisation that electrochemical systems such as rechargeable batteries can provide a number of high-value opportunities. The mobility and flexibility in performance means that batteries have the potential to be implemented at all levels of the grid, performing a number of different functions such as curtailment reduction at generation level to peak shaving at customer level. Lithium-ion is the current dominant rechargeable battery technology, however its widespread implementation at grid-level is unsustainable due to the limited global reserves of lithium and cobalt, both essential elements in the battery. As such, there is a pressing requirement to move beyond lithium-ion to a more sustainable chemistry. The goal of this project is to develop a low-cost sodium-ion battery consisting of abundant, non-toxic, sustainable electrode materials such as sodium, iron, sulphur and tin. The aim is to produce a sustainable battery chemistry for grid-scale applications with an energy density comparable to the standard lithium-ion technology on the market today, but at a fraction of the cost.

<b>Keywords (min 3 and max 10)</b>	Renewable Energy, Energy Storage, Low-Cost Battery, Sodium-ion battery, Alloying Anodes
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## Glossary

LIBs – Lithium-ion Batteries	WEM – With existing measures
SIBs – Sodium-ion Batteries	WAM – With additional measures
BESS – Battery energy storage systems	NW – Nanowire
SnSb – Tin-antimony	SCE – Standard concentration electrolyte
CZTS – Copper zinc tin sulphide	HCE – High concentration electrolyte
REC – Renewable energy capacities	

## SECTION 2: FINAL TECHNICAL REPORT – FOR PUBLICATION

(max 10 pages)

### 2.1 Executive Summary

The dominance of lithium-ion batteries (LIBs) in the rechargeable battery market is increasingly unsustainable due to the rising demand for lithium driven by the electric vehicle boom. As lithium reserves are geographically concentrated and limited, their supply risk will escalate, making grid-scale energy storage based on LIBs economically unviable. Sodium-ion batteries (SIBs) offer a promising alternative, utilizing abundant, low-cost, and non-toxic materials. This project aimed to address technical challenges associated with SIBs, develop sustainable electrode materials, and provide policy recommendations for large-scale integration of Battery Energy Storage Systems (BESS) in Ireland's grid. The following is a summary of the key project objectives:

1. Economic and Environmental Impact Assessment: Evaluate the benefits and impacts of integrating Na-ion battery systems for grid-scale energy storage in Ireland.
2. Policy Guidance: Analyze global regulations and policies to inform Irish policymakers on enhancing renewable energy penetration using BESS.
3. SIB Anode Development: Produce a high-capacity tin-based nanowire anode and a copper zinc tin sulfide nanorod electrode for Na-ion batteries.
4. SIB Cathode Development: Develop a sustainable polyanion-based cathode material.
5. Sustainable Na-ion Battery Prototype: Demonstrate a low-cost, sustainable sodium-ion battery with an energy density of 200 Wh/kg.

Key findings and outcomes from the policy study underscores the critical role of government intervention in the successful integration of BESS into renewable energy systems. By examining policies from twelve leading markets, several key recommendations emerged. The importance of early and ambitious policy formulation was identified as early adopters of BESS policies in the 2010s now lead the market, emphasizing the importance of early action. Findings from the study also show the importance of establishing clear legislative and regulatory frameworks for energy storage and implementing diverse financial supports to increase uptake, including system services, capacity markets, and direct financial supports. Planning processes need to be streamlined to ensure timely grid connections to support infrastructure development. In terms of public engagement, it will be important to enhance public understanding and acceptance of energy infrastructure to facilitate deployment at grid scale.

An economic and environmental impact assessment of grid integration of large-scale BESS was performed using EnergyPLAN and BatPac software. The results indicated that expanding BESS capacity will significantly increase renewable energy shares in Ireland, with diminishing returns beyond 5 GW due to grid limitations. Once the technology has matured, installing Na-ion batteries for grid applications can offer over 20% cost savings compared to LIBs due to the lower material costs afforded. SIBs also have a substantially lower environmental impact, with a 50% reduction in global warming potential and a 28% reduction in fossil depletion potential compared to LIBs.

A number of technological advances were made over the course of the project. The development of a tin-antimony (SnSb) alloy anode, which maintains a capacity of 350 mAh/g for over 1600 cycles,

represents a significant breakthrough. This anode's durability and stability make it suitable for various applications, including grid storage and electric vehicles, providing a viable alternative to LIBs. The project also produced high-performing copper zinc tin sulphide (CZTS) nanorod anodes and polyanion-type cathodes, further enhancing the feasibility of SIBs.

In conclusion, this project demonstrates the potential of SIBs as a sustainable and economically viable solution for grid-scale energy storage, while offering strategic policy insights to support their integration into renewable energy systems.

## 2.2 Introduction to Project

LIBs have dominated the rechargeable battery market to date, however their continued success at the current growth rate is unsustainable for several reasons. With the advent of electric vehicles, the demand for lithium is expected to soar in the next 20 years. As the world's lithium reserves are limited, it is predicted that the supply risk in the short term will be due to a narrow geographical reserve concentration. This means that widespread grid-scale energy storage based on this chemistry will not be economically viable in the future as the demand for lithium and other critical raw materials required for LIB manufacturing (e.g. Ni, Mn, Co) increases further. As such, there is a pressing requirement to move beyond LIBs to a more sustainable chemistry based on low-cost, abundant elements such as sodium.

SIBs in contrast to LIBs contain materials that are abundant, cheap, less toxic and globally available. For example, on the anode side,  $\text{Na}_2\text{CO}_3$  and  $\text{NaCl}$ , both common precursors to SIB anode materials, are low cost, non-toxic and highly abundant salts contained in minerals and brine. The much lower cost of sodium sulphate precursor (about ~ €100 per ton), compared to lithium carbonate (about ~ €20,000 per ton) is an illustrative example of the savings that can be made on materials costs by switching to SIB from LIB technology. A further advantage of SIBs is that cobalt is not required in the cathode, further reducing the cost of materials and toxicity of the battery significantly. These factors indicate that if some technical challenges can be overcome regarding the energy density and charge rate capability, SIBs are the perfect candidate for grid-scale storage of renewable energy due to the inexpensive, abundant and non-toxic materials employed compared to LIBs.

The realisation of grid-scale BESS requires not only technological advances, but also implementation of strong governance policies to support it. To provide guidance to policy makers in this regard, a study was performed carrying out a thorough examination of existing governance policies and regulations around the world that have been implemented to facilitate this type of large-scale integration. A detailed economic, technical and environmental impact assessment was also performed on the large-scale integration of low-cost battery energy storage as an ancillary service to Ireland's grid infrastructure. A further primary aim of this project was to develop a low-cost, long cycle-life, fast charging sodium-ion battery using sustainable electrode materials and to demonstrate that BESS's such as these can effectively be integrated as an ancillary service to Ireland's grid. This was achieved using an innovative battery architecture consisting of a high capacity nanostructured Sn composite anodes with the ability to accommodate volume expansion without pulverisation, high-voltage doped polyanion cathodes based on sodium, iron, oxygen and sulphur in conductive carbon matrices with increased ambient stability and electronic conductivity and bespoke high concentration electrolytes using carbonate-based polymer forming additives for electrode surface passivation.

## 2.3 Project Objectives

Due to their diverse applications at all levels of the grid, BESS systems are a promising technology to enhance grid penetration of renewable sources and to reduce curtailment. However, for batteries to become the dominant storage technology at grid-level will require a reduction in the cost. This project aimed to overcome this through development of a low-cost sodium-ion battery from abundant and sustainable materials such as Na, Fe, S and Sn. Realisation of BESS at grid-scale requires a synergy between technological developments and governance policies that support their integration. Another main objective was to analyse existing regulations/policies around the world designed to improve penetration of renewable energy using BESS systems at all levels of the electrical grid. The intention is to inform policy makers in the future as Ireland moves toward a predominantly renewable electricity supply.

### *Summary of Project Objectives*

1. Perform economic and environmental impact assessment of Na-ion battery system for grid-scale energy storage
2. Inform policy makers on existing regulations/policies around the world designed to improve penetration of renewable energy using BESS at all levels of the electrical grid
3. Produce a tin-based nanowire anode and a copper zinc tin sulphide nanorod electrode suitable for use in a Na-ion battery
4. Fabrication of a fast-charging polyanion-based cathode material using sustainable and abundant elements
5. Demonstration of a novel low-cost sustainable sodium-ion battery prototype exhibiting an energy density of 200 Wh/kg

## 2.4 Summary of Key Findings/Outcomes

### ***Innovation 1: Informing policy makers on existing regulations/policies around the world***

A key research question in work package 1 of the project was how the outputs and outcomes of public policies have influenced the deployment of grid-scale batteries (Figure 1). Our comparative analysis of Ireland with twelve leading and promising international markets for storage finds great diversity in BESS policy mixes. While government intervention seems universally necessary in order to facilitate the development of storage and BESS, there is no single successful policy formula. The development of BESS is highly dynamic, and in many cases the full effects of current policy developments have yet to play out, so that the promising markets of the early 2020s may become leaders by the end of the decade. We have identified several common markers of policy leadership:

- Today's leaders on BESS were *early starters* in the early 2010s. This underlines the medium- and long-term effects of storage policies;
- Many leaders and promising markets have included a *definition of storage* in legislation and have recognised storage in other regulatory frameworks;
- They have established and regulated markets, including for system services, capacity, and arbitrage; leaders have also started to define a role in these markets for Long Duration Energy Storage (LDES);
- There is a wide variety of financial supports available across the twelve countries studied;
- While the study does not provide a comprehensive overview of *R&D policies*, it is evident from individual cases like the UK and South Korea that some leaders on BESS have also been leaders on R&D on storage/BESS.

These markers of leadership resonate with lessons drawn from our case study of Ireland, including interviews with stakeholders during 2022, which emphasise past successes, but also present opportunities and perceived shortcomings in Ireland's policy mix. The case study identifies as key areas for policy development:

- the publication of an overarching storage policy (in development at time of writing);

- the definition/recognition of storage in legislation and regulations;
- the detailed identification of storage needs, targets and scenarios;
- clarification of remuneration prospects (in DS3, capacity markets including LDES, and spot markets);
- ensuring the planning system can process applications related to vital energy infrastructure in a timely manner;
- taking measures to improve public understanding of that infrastructure;
- speeding up grid connections.

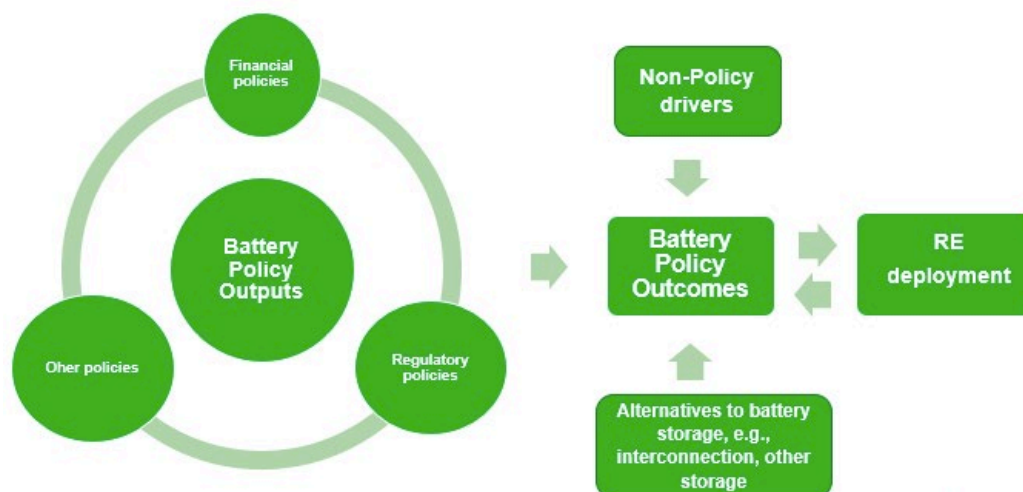


Figure 1. Drivers of battery policy outcomes and the deployment of renewable energy

The imperative to facilitate and support the deployment of BESS in the short term is very strong, in the context of high-level targets for 2030 and 2050, and in view of the relatively long delivery timelines for alternative sources of flexibilities. At the same time, there is a time lag between formulating and adopting policies, implementing them, and seeing outcomes (e.g., installed capacity) from those policies. Just as leaders on storage/BESS now tend to have been early starters, storage policies adopted today can be anticipated to have effects well into the 2030s.

### ***Innovation 2: Perform economic and environmental impact assessment of Na-ion battery system for grid-scale energy storage***

An assessment on the benefits and environmental impact of installing BESS systems in Ireland was carried out. EnergyPLAN software used to examine the potential impacts of grid-scale battery installations on Ireland's energy future. The model was designed to analyse the impact of battery storage on the Ireland's energy system with the demands and renewable energy capacities (REC) that are anticipated for 2040. Two baseline summaries were developed defined as REC-1 and REC-2 in the NECP.

- REC-1 (with existing measures - WEM) - Policies and measures in place by the end of December 2018 are modelled in this scenario.
- REC-2 (with additional measures – WAM)

Models were created for each scenario, representing incremental 0.5GW increases in battery capacity, from 0GW to a maximum of 10GW. The expansion of battery storage from 0 GW to 5 GW in the REC-2 scenario results in a 2.1% increase in renewable shares, compared to 1.1% for the REC-1 scenario. Beyond 5 GW, the increase is negligible in renewable shares. It is likely that this plateau marks a limitation to storage characterised by the structural constraints of the national energy system. The potential impact of electricity storage is generally limited to some degree by the grid-stabilisation requirements and the interconnective capacity of a nation's energy system. In the Irish context, the energy system still relies on conventional power plants to maintain a stable grid, while also having a

relatively low interconnection capacity. The extent to which stores of excess electricity can be utilised is thereby limited. This is in agreement with similar studies in other countries.

To assess the cost benefits of installing sodium-ion batteries compared to LIBs for a moderately sized wind farm (>80 MW), BatPac software was used to identify the battery costs for each chemistry. Considering 4 hours of equivalent storage to be economically optimal based on the literature, a 100 MWh battery was considered in costing. The results show that the complete cost of installing a 100 MWh Na-ion battery for grid applications will be €32 M, >20% less than for a Li-ion battery installation. The environmental impact of the battery was also assessed. The environmental parameters for each component was evaluated based on a comprehensive life cycle inventory published by Peters et al. The analysis shows that switching a BESS from an LIB to the SIB chemistry cuts the global warming potential of the battery in half (210 vs. 107 kg CO<sub>2</sub>.Eq per kWh of storage capacity) and reduces the FDP by 28% (43 vs. 31 kg oil.Eq per kWh of storage capacity).

### ***Innovation 3: Development of Alloying Anode Materials and Polyanionic Cathodes for Sodium-ion Batteries***

Sn was originally selected as the alloying anode material in this project as it boasts a high theoretical capacity of 847 mAh g<sup>-1</sup> and is relatively low cost. However, it experiences a large volume change of 520% during (de)sodiation, which leads to cracking, pulverisation, and ultimately results in a rapid capacity fade of the anode.(1) As such, nano-structuring of the Sn was investigated to help reduce pulverisation. Various approaches were investigated including the development of CZTS nanorod anodes, Sn coated Cu<sub>15</sub>Si<sub>4</sub> nanowire (NW) arrays and SnSb coated current collectors.

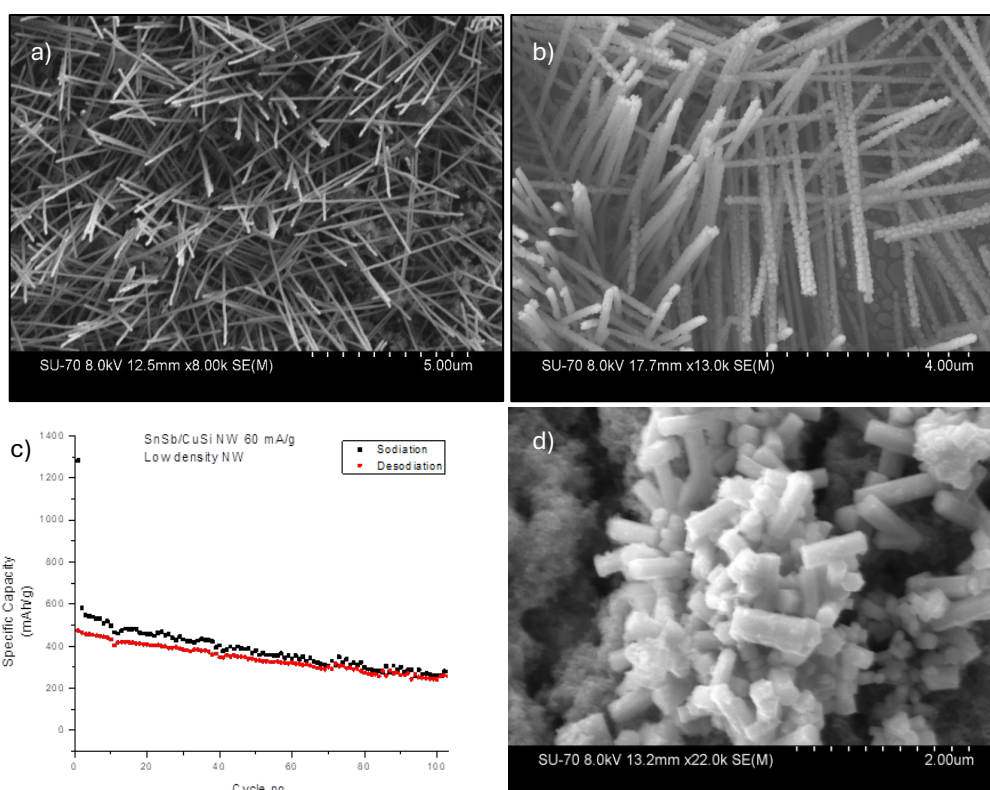


Figure 2. SEM images of a) Cu<sub>15</sub>Si<sub>4</sub> NWs, b) Cu<sub>15</sub>Si<sub>4</sub> NWs coated with Sn in a core shell structure, c) galvanostatic charge/discharge cycling data of SnSb/CuSi NW over 100 cycles at a current density of 60 mA/g and d) CZTS nanorods.

In the NW approach, Cu<sub>15</sub>Si<sub>4</sub> NW arrays were synthesised on a copper substrate via a solvent-vapor growth technique. Phenylsilane was used as the silicon precursor and was injected into the reaction vessel at high temperatures to produce the Cu<sub>15</sub>Si<sub>4</sub> NW arrays (Figure 2a). This NW array was coated with Sn in a core shell structure via physical vapour deposition (Figure 2b). This coating was varied

from 20 to 100 nm. The Sn coated  $\text{Cu}_{15}\text{Si}_4$  NW arrays were tested using galvanostatic charge/discharge cycling in a half-cell configuration versus sodium metal, however the performance was poor with negligible capacity exhibited after 100 cycles. SEM analysis of post-mortem electrodes showed signs of Sn agglomeration occurring during cycling. This results in the active material losing contact with the NW host, resulting in a poor capacity retention. As such, SnSb alloys were investigated instead of elemental Sn. SnSb is another promising alloying anode material for SIBs. Similar to Sn, it boasts a high theoretical capacity of  $751 \text{ mAh g}^{-1}$ . Unlike Sn, SnSb has an inherent buffering effect during (de)sodiation to mitigate pulverisation. This is due to the fact that Sn and Sb (de)sodiate at different potentials. While Sb is alloying with Na to form  $\text{Na}_3\text{Sb}$ , Sn acts as a buffer and conversely,  $\text{Na}_3\text{Sb}$  acts as a buffer during alloying of Sn with Na at lower potentials. When SnSb was coated onto the  $\text{Cu}_{15}\text{Si}_4$  NW array, a noticeable improvement in the capacity retention was observed, with the SnSb/ $\text{Cu}_{15}\text{Si}_4$  NW anodes exhibiting a capacity retention of  $>200 \text{ mAh/g}$  after 100 cycles (Figure 2c). Given this improvement in performance, other SnSb anode architectures were developed by evaporation of Sn and Sb layers on various current collectors including stainless steel and dendritic copper to see if the performance can be improved further on more commercially relevant current collectors. SnSb on stainless steel showed a very impressive capacity retention, maintaining a capacity of  $350 \text{ mAh g}^{-1}$  for over 1600 cycles. SnSb on dendritic Cu also showed impressive capacity retention for 150 cycles, while also allowing for the mass loading to be increased to  $0.4 \text{ mg cm}^{-2}$  from  $0.05 \text{ mg cm}^{-2}$ . The excellent performance of the anode material was facilitated by the high concentration electrolyte formulation developed within the project, namely 4 M  $\text{NaClO}_4$  in Dimethoxyethane with 3%(w/w) FEC additive. To our knowledge this is the first time that has been used in SIBs, with conventional 1M or standard concentration electrolytes (SCE) providing limited performance with the SnSb alloying anode.

In the nanorod approach, CZTS nanorods were produced via colloidal synthesis. By adjusting the precursor concentrations and the reaction parameters, the dimensions (length and diameter) and composition (Sn poor / Sn rich) could be varied. The nanorods (Figure 2d) were processed into anodes for SIBs using slurry processing. A slurry composition of CZTS:C45:CMC (65:20:15) was used. The electrodes exhibited a reasonably high initial capacity in excess of  $300 \text{ mAh/g}$ , retaining  $\sim 100 \text{ mAh/g}$  after 200 cycles.

At the cathode, polyanion-type cathodes were developed due to the sustainability of the chemistry. A synthetic method based on co-precipitation was developed wherein iron and sodium sulphate precursors were dissolved in hydroquinone and an intermediate was precipitated in glycerol and isopropanol, prior to synthesis of the final sodium iron sulphate product in a tube furnace. X-ray diffraction confirmed the synthesis of the alluaudite phase. When galvanostatically charged and discharged vs. a Na metal counter electrode, the material exhibited a capacity of  $<50 \text{ mAh/g}$ , below the targeted performance of  $>100 \text{ mAh/g}$  (Figure 2c). This was due to the inherent poor electronic conductivity of the material. To overcome this, the material was synthesized via a solid-state reaction with the inclusion of a conductive carbon additive. This enhanced to the performance considerably, with the material exhibiting a specific capacity in excess of  $100 \text{ mAh/g}$ .

## 2.5 Project Impact

The policy study emphasizes the pivotal role of government in the successful integration of battery storage technologies into renewable energy systems. By highlighting the centrality of public policy, it underscores that government actions are indispensable for fostering BESS markets, suggesting that policymakers need to be proactive and strategic. The context-specific nature of BESS deployment elucidated in the study indicates that policymakers must tailor strategies to their unique national circumstances. This includes understanding their energy generation mix, technological development, and socio-economic factors. For Ireland, this means recognizing its specific energy needs and leveraging both local insights and international best practices. The time lag in realizing policy outcomes stresses the importance of long-term planning and commitment. Policymakers are urged to make informed decisions today to secure future benefits, contributing to the broader goal of decarbonization.

This foresight is crucial as early policy decisions shape the energy landscape well into the future. Dynamic outcome leadership revealed by the study suggests that countries should continuously innovate and adapt their policies to maintain leadership in BESS deployment. For Ireland, this involves staying abreast of global advancements and remaining flexible in policy formulation. The diversity of successful policy mixes demonstrates that there is no universal solution. Instead, Ireland can draw from a range of international experiences, adapting and combining elements that fit its unique context. This pragmatic approach allows for more tailored and potentially more effective policy solutions. Finally, Ireland's opportunity to learn from both its own history and international cases highlights the value of adaptive learning in policy-making. By analyzing what has worked and what hasn't, Ireland can avoid past mistakes and capitalize on successful strategies from other nations, accelerating its progress toward an 80% renewable energy target.

The development of a novel anode and cathode chemistry for Na-ion batteries, particularly the SnSb alloy anode, represents a significant advancement in energy storage technology. The SnSb alloy anode's impressive performance, maintaining a high capacity over 1600 cycles, has several impactful implications. The material's ability to retain high capacity over a prolonged cycle life indicates excellent durability and stability. This is crucial for practical applications where long battery life and consistent performance are required. Furthermore, the robust performance of the SnSb alloy anode expands the potential applications of Na-ion batteries. They could be used in various sectors, including grid storage, electric vehicles, and portable electronics, offering an alternative to lithium-ion batteries. The development of a robust Na-ion battery chemistry within the project can have wide-reaching implications for the energy sector. By providing a viable alternative to lithium-ion batteries, this technology can diversify the energy storage market, reducing dependency on a single type of battery chemistry. This diversification can enhance energy security and promote the adoption of renewable energy technologies, contributing to global efforts to mitigate climate change. The shift to Na-ion batteries can have other substantial environmental benefits also. The extraction and processing of lithium pose significant environmental challenges, including water usage and habitat disruption. Sodium, being more abundant and easier to extract, presents a more sustainable option. Additionally, the long cycle life of SIBs means fewer batteries would need to be produced and disposed of over time, reducing the environmental impact associated with battery manufacturing and waste.

## 2.6 Recommendations

A number of recommendations arise from the policy component on this research project related to successes and gaps in battery energy storage systems deployment. Ireland's experience with policies facilitating the early deployment of Battery Energy Storage Systems offers valuable insights. These insights can guide future policy directions to enhance BESS deployment and achieve renewable energy targets. Here are key recommendations based on Ireland's policy journey:

### ***Policy Recommendations for Success***

1. ***Establish an Ambitious Broader Policy Context:*** Set high, ambitious targets for emissions reduction and renewable energy sources. Develop policies that explicitly recognize and integrate the role of storage within broader climate and energy goals.
2. ***Create Robust Remuneration Streams:*** Implement programs like DS3 to provide primary remuneration sources for BESS owners. Include storage in capacity markets to incentivize investment in BESS.
3. ***Design Long-lasting Policies:*** Formulate policies with a long-term perspective, recognizing that early decisions will shape medium-term deployment and impact RE and climate targets for the 2030s.
4. ***Leverage Flexibility in Isolated Grids:*** Utilize BESS to provide essential flexibilities for isolated grids, where alternatives like interconnections have high startup costs and long lead times.

### **Addressing Policy Gaps**

1. *Clearly Define and Recognize Storage:* Establish legislative and regulatory frameworks that recognize storage as a distinct entity within the energy system.
2. *Analyze Future Targets and Scenarios:* Conduct a shared analysis of future storage scenarios, including the scale and types of storage needed for Ireland's renewable energy development.
3. *Clarify and Diversify Remuneration Opportunities:* Expand and clarify revenue streams from system services, capacity markets (including long-duration energy storage), spot markets, and potential direct financial supports. Ensure these diverse remuneration opportunities are central to further BESS development.
4. *Enhance Planning and Grid Connection Processes:* Improve the capacity of key organizations to process applications efficiently. Streamline the planning system to facilitate timely infrastructure and grid connection developments.
5. *Improve Public Acceptance:* Increase efforts to enhance public understanding and acceptance of vital energy infrastructure, including BESS. Address public concerns regarding lifecycle impacts and safety issues related to batteries.

### **Cross-cutting Recommendation:**

*Ensure Investor Certainty:* Provide clarity and certainty about the future operational roles, income-generating potential, and climate contributions of energy storage. Establishing this certainty is essential for advancing Ireland's storage policy and supporting renewable energy goals for 2030 and beyond.

By following these recommendations, Ireland can create a supportive policy environment, establish diverse remuneration opportunities, and implement long-term planning for successful BESS deployment. Addressing current gaps, particularly in policy clarity and public acceptance, will be crucial to advancing Ireland's energy storage capabilities and achieving its renewable energy targets. These recommendations, derived from Ireland's experience, can also guide other countries in effectively integrating BESS into their renewable energy strategies, fostering a more sustainable and resilient energy future.

## **2.7 Conclusions and Next Steps**

The project successfully demonstrated the potential of SIBs as a sustainable and cost-effective alternative to LIBs for grid-scale energy storage. The key findings highlight several important conclusions. SIBs offer significant cost savings, with a complete installation cost over 20% less than LIBs. The environmental impact of SIBs can be considerably lower, cutting the global warming potential and reducing fossil depletion considerably compared with LIBs. The development of the SnSb alloy anode represents a major breakthrough, maintaining a high capacity over extended cycling periods, indicating excellent durability and stability. In terms of policy recommendations, the study underscores the critical role of government policies in fostering BESS market development. Countries that have adopted early and ambitious policies now lead in BESS deployment. A comprehensive policy framework tailored to Ireland's unique context is essential for successful integration and increased penetration of renewable energy. To build on the successes of this project, several next steps are recommended to further advance the development and integration of SIBs and support Ireland's transition to a predominantly renewable energy supply. These include continuing R&D efforts to further improve the performance and cost-effectiveness of the SIB chemistry, focusing on advanced materials and novel battery architectures. In terms of policy, Ireland needs to develop and adopt a detailed policy framework that includes clear definitions, regulatory recognition, and financial incentives for BESS. By pursuing this, Ireland can harness the full potential of sustainable BESSs, enhancing its energy security, reducing environmental impact, and achieving ambitious renewable energy targets.