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# ALL-ISLAND CO-ORDINATION OF ENERGY INFRASTRUCTURE AND RENEWABLE ENERGY SUPPORTS

CATHAL MENTON, GENARO LONGORIA, NIALL FARRELL AND MUIREANN LYNCH


ESRI ECONOMIC & SOCIAL RESEARCH INSTITUTE

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Cathal Menton

Genaro Longoria

Niall Farrell

Muireann Lynch

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## THE AUTHORS

Cathal Menton was a Research Intern with the ESRI at the time of this study. Genaro Longoria was a Postdoctoral Researcher with the ESRI at the time of this study. Niall Farrell is a Senior Research Officer at the Economic and Social Research Institute (ESRI) and an Adjunct Associate Professor at Trinity College Dublin (TCD). Muireann Lynch is a Senior Research Officer at the Economic and Social Research Institute (ESRI) and an Adjunct Associate Professor at Trinity College Dublin (TCD).

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# ABBREVIATIONS

| | |
|---|---|
| DSO | Distribution System Operator |
| ENGINE Model | Electricity Network and Generation INvEstment model |
| IC | North-South Interconnector |
| I-SEM | Integrated Single Electricity Market |
| NoIC | No North-South Interconnector |
| RES-E | Renewable energy share in electricity |
| SEM | Single Electricity Market |
| TSO | Transmission System Operator |

# EXECUTIVE SUMMARY

## INTRODUCTION

This research project quantifies the impact of renewable energy policy co-ordination in the Single Electricity Market of Ireland. Renewable energy targets are determined independently by both jurisdictions on the island. To date, renewable electricity targets have been similar in each jurisdiction. The primary contribution of this paper is to identify the impact of continued alignment, as compared to a counterfactual where the levels of renewable targets are unaligned. In doing so, the analysis considers whether unaligned policy targets could lead to sub-optimal infrastructure development on the island and calculates any resulting costs, should they exist. The project also considers the principle of 'effort sharing', as outlined in the Kyoto Protocol, by examining a scenario where there is a single target for the whole island of Ireland. A further contribution of this analysis is to consider the proposed North-South 400 kV Interconnection development. We consider the effect this installation may have on the power system, and how it will interact with various configurations of renewable energy policy targets.

## METHODS

The analysis in this paper adopts an *ex ante* methodology by simulating the net impact of renewable electricity generation under various future renewable targets, as well as the presence or absence of the proposed North-South Interconnector. In addition, it determines the sensitivity of these system and market impacts to policy alignment and all-island policy across both jurisdictions.

The methodology used for this study is the Electricity Network and Generation INvEstment (ENGINE) model. ENGINE was developed within the ESRI and is a least-cost planning model for the Irish generation and transmission system. ENGINE determines the lowest cost method of meeting electricity demand across the whole island of Ireland, at transmission node level, while respecting the technical limitations of the electricity network assets (transformers and lines) and generation assets (conventional power plants, renewable generation sources and electricity storage devices) on the system.

The ENGINE model is calibrated with data out to 2030 and the model considers the optimal investments required in both 2025 and 2030 as part of its results. The required inputs include the existing generation and transmission assets, the demand profiles at each node in the transmission network, the availability of wind and solar at each transmission node, the investment costs of new generation and the operational costs of new and existing generators. Taking these inputs, the model determines the required investment in new generation and transmission assets and the operation of new and existing assets. Other resulting variables include the locational marginal prices at each system node, the unserved demand at each node (if any) and the carbon emissions from the power system.

The demand at each transmission node is forecast out to 2030 using data from the Transmission System Operators (TSOs), EirGrid and SONI. The assumptions for the costs of each generation asset, along with fuel price projections, are based on estimates from the European Commission (European Commission, 2018).

To answer the questions that motivate this study, a number of scenarios are considered. Each scenario considers a different combination of renewable energy generation in Ireland and Northern Ireland and North-South Interconnector availability. In particular, we consider the scenario where Ireland has a higher renewable energy target than Northern Ireland (80 per cent and 70 per cent respectively), the scenario where they have the same target of 80 per cent, and a third scenario where there is a single island-wide target of 80 per cent, which we call effort sharing. We consider each of these three scenarios under a setting of no Interconnector (the current state of play) and an operating Interconnector (which is expected from 2025). This makes six scenarios in total.

## FINDINGS

This paper finds that added renewable energy capacity will result in a changing pattern of renewable energy absorption on the island. Without the North-South Interconnector, an aligned target reduces the storage requirement in Northern Ireland and an increase in storage in Ireland.

The introduction of the North-South interconnector facilitates more efficient transmission of electricity on the island. Without alignment, the storage requirement is reduced. Aligned policy targets requires additional storage, along the lines of what was necessary prior to the introduction of the Interconnector. This suggests that increased storage in Ireland is a robust policy option, particularly at high levels of RES-E, and facilitates the alignment of RES-E targets and policies.

Additional renewables lower wholesale electricity prices through a mechanism known as the merit order effect. Should market prices fall through merit order effects, this may increase the subsidy requirement. However, this is predicated on wholesale prices being less than the subsidy price. In 2022, wholesale prices were high and exceeded the subsidy price in Ireland, leading to negative policy costs (i.e. a rebate for consumers). Should high energy prices persist, the impact that merit order effects have on policy cost will be of lesser concern. Indeed, should renewable energy be supported by Renewable Energy Support Scheme (RESS)-style policies, then additional renewables will provide a strong hedge against rising prices.

Finally, this paper has explored the potential efficiency benefits that may be achieved through effort sharing of policy targets on the island of Ireland. We have found that such impacts are relatively modest, changing total costs by less than 1 per cent. Of particular interest in this context, however, is the role of the

North-South Interconnector. Establishment of the North-South Interconnector brings the deployment trajectory for assets on the island closest to the theoretical optimal. Indeed, establishment of the North-South Interconnector has a proportionally greater impact than effort sharing.

# CHAPTER 1

## Introduction

This research project quantifies the impact of renewable energy policy co-ordination on the island of Ireland. Renewable energy targets are determined independently by both jurisdictions on the island. To date, renewable electricity targets have been similar in each jurisdiction. This paper determines the benefits (and drawbacks) of continued alignment, as compared to a counterfactual where the levels of renewable targets are unaligned. The analysis considers whether unaligned policy targets could lead to sub-optimal infrastructure development on the island and calculates any resulting costs, should they exist. The project also considers the principle of 'effort sharing', as outlined in the Kyoto Protocol, by examining a scenario where there is a single target for the whole island of Ireland.

A further contribution of this analysis is to consider the proposed North-South 400 kV Interconnector, and the effect it will have on the electricity system on the Irish electricity market under various configurations of renewable energy policy targets. We therefore consider three sources of policy alignment: (i) alignment of the renewable energy share in electricity (RES-E) policy targets, (ii) infrastructure, via the North-South Interconnector, and (iii) effort sharing. As (i) and (iii) are mutually exclusive, this leads to a total of six scenarios that are compared.

The electricity system on the island of Ireland consists of two interconnected power systems, one north and one south, with a single electricity market setting one market price across the island. This Single Electricity Market (SEM) was launched in 2007 and an updated market structure was introduced in 2018 (known as I-SEM). Designed to accommodate the geographically isolated nature of the island, the single market reduces the costs of electricity generation and drives efficiencies across both jurisdictions (di Cosmo and Lynch, 2016; EirGrid plc and SONI Ltd, 2021).

While the single market has brought about regulatory and market alignment, renewable generation policy is set separately in each jurisdiction. In Ireland, up to 80 per cent of electricity must come from renewables by 2030, according to current targets (DECC, 2021; Government of Ireland, 2021). In Northern Ireland, the target for 2030 has recently been increased from 70 per cent to 80 per cent (Northern Ireland Assembly, 2022). To meet these targets, renewable electricity is supported through subsidy schemes. Subsidy payments are made to renewable generators when wholesale market prices are sufficiently low. The costs of these subsidies in Ireland have historically been recovered from electricity users via a Public Service Obligation (PSO) levy, which is currently added to electricity bills. In Northern Ireland, renewable energy subsidy costs have been recovered via similar levies on the electricity consumers, such as the Northern Ireland Renewable Obligation

(NIRO) scheme. This scheme closed for new applicants in 2017, the cost of which was socialised across all electricity consumers in the UK. The precise structure of the replacement scheme has yet to be decided.

In this research, we assess the impact that changing renewable electricity targets may have on electricity investment and market outcomes. We focus on system requirements under the condition that targets will be met. There is the possibility that either or both jurisdictions will fail to meet their renewable energy targets; however, 2020 renewable electricity generation in both Ireland and Northern Ireland exceeded their respective 40 per cent targets (EirGrid plc and SONI Ltd, 2021).

Variables of interest include (1) the investment in generation, storage and transmission assets, (2) the viability gap (i.e. the gap between costs and revenues) for renewable generators, which determines the level of subsidisation required, and (3) the portfolio of generation required to support the renewable targets, e.g. the storage investment required. These outcomes are compared under various renewable energy target scenarios. Regarding market outcomes to date, previous research that performed an ex post evaluation of prices in the SEM has found that increased renewable generation reduced electricity prices on the island of Ireland (di Cosmo and Malaguzzi Valeri, 2018). In addition, it was found that this reduction in electricity bills more than offsets the cost of subsidisation to renewable generators on the island. The analysis in this paper adopts an ex ante methodology by simulating the net impact of renewable electricity generation under various future renewable targets, as well as the presence or absence of the proposed North-South Interconnector. In addition, it determines the sensitivity of these system and market impacts to policy alignment and all-island policy across both jurisdictions.

Regarding network investment, previous research has found that increased levels of renewable generation require increased transmission and/or storage investment, with storage and transmission often acting as substitutes (Fitiwi, Lynch and Bertsch, 2020b and 2020c). This research determines whether and to what extent this result varies when different renewable targets are in place in both jurisdictions and when the proposed North-South Interconnector is operational. The increased network investment requirements as a result of continued alignment of renewable energy targets are quantified.

Renewable energy policy supports in Ireland and Northern Ireland have tended to move in tandem. Prior to October 2021, Ireland had a 70 per cent renewable energy target for 2030, which was increased to 80 per cent in 2021 (Department of Public Expenditure and Reform, 2021). A similar trajectory was observed in Northern Ireland. In December 2021, the Department for the Economy's energy strategy entitled 'The Path to Net Zero Energy' was launched, which put in place a 70 per cent renewable energy target for 2030 (Department for the Economy, 2021). This was revised in June 2022, with the publication of the Northern Ireland Climate Change Act (Northern Ireland Assembly, 2022). Under this Act, Northern

Ireland has an 80 per cent renewable energy target for 2030, which therefore sees continued alignment of policy targets in both Ireland and Northern Ireland. This continued alignment will avoid any potential inefficiencies that may have arisen through 'unalignment', and forms the motivation for this study.

When analysing the impact of moving from a 70 per cent target to an 80 per cent target, it is reasonable to expect that an increase in system costs will result, as additional renewable energy capacity will require investment. Complementary investment in the transmission and/or storage assets may also be required. Network investment effects take the following form. Conditional on a given renewable energy target, a certain degree of network upgrade may be required. The extent of any likely upgrade is predicated on the expected system development trajectory. Alignment of policies may guide a different pattern of infrastructure investment between now and 2030. Indeed, there may be implications for achieving further decarbonisation targets post-2030.

The recent alignment of policies across the island may have implications for the cost of electricity. Additional renewable capacity on the system allows increased generation from renewable sources to replace fossil fuel-based generation. There is a positive cost associated with producing each additional unit of fossil fuel generation, while the cost of producing an additional unit of electricity from renewable sources is zero for technologies such as wind and solar (whose costs are all fixed). This substitution of renewable for non-renewable generation dampens the electricity price, via a process known as the merit order effect (Sensfuß, Ragwitz and Genoese, 2008; di Cosmo and Malaguzzi Valeri, 2018). This can lower prices across the island, irrespective of where the new renewable capacity is located. In addition, renewable energy often receives a price support. The cost of these price supports is jurisdiction-specific: Northern Irish-located generation is supported by levies on the electricity consumed by Northern Irish consumers and similarly, Irish-located generation is supported by Irish consumers through levies on electricity bills. However, if wholesale electricity prices are high (e.g. the high prices experienced in 2022), then the price supports may result in a negative policy cost and a net benefit to consumers.

In addition to these effects, two further sources of policy alignment between Ireland and Northern Ireland are explored. The first is to consider the installation of the North-South Interconnector. This piece of infrastructure has been subject to several delays and is currently expected to be delivered by 2025. The successful delivery of this project will require close collaboration between regulators and landowners both north and south. This research therefore explores the economic impacts arising from timely delivery of this piece of infrastructure.

We also wish to consider the potential benefits of deepening the alignment of climate targets through effort sharing. The principle of 'effort sharing' has featured in many international climate change agreements, beginning with the Kyoto Protocol, continued presently as part of the EU's Effort Sharing Regulation. Effort sharing provides options to achieve jurisdictional compliance with climate targets in a flexible, cost-effective way; a jurisdiction may borrow or transfer their binding commitment to another jurisdiction to allocate mitigation effort in the most efficient way (Peeters and Athanasiadou, 2020). The island of Ireland, with a shared electricity system, provides an obvious application of this concept. We test this hypothesis in Section 4. We compare the cost of achieving separate 80 per cent IE and 80 per cent NI renewable energy targets with an all-island 80 per cent target, facilitated through effort sharing. In doing so, we can identify how close the current policy structure is to the theoretical optimum and whether further co-operation could unlock additional efficiencies.

# CHAPTER 2

## Literature, Policy, Institutional Background

This research considers multiple aspects of the electricity sector on the island of Ireland. The electricity market on the island of Ireland determines costs, revenues and investments by generation companies, in Ireland and Northern Ireland alike, and determines one set of market prices that holds across both jurisdictions. The market is overseen by electricity regulatory bodies, the Commission for the Regulation of Utilities (CRU) in Ireland and the Northern Ireland Authority for Utility Regulation (NIAUR) in Northern Ireland. These bodies co-operate on the regulation of the all-island market via the Single Electricity Market (SEM) Committee. Finally, policy decisions, including decisions regarding renewable energy (RES-E) targets are determined separately for each jurisdiction.

This determination of market, regulatory and policy decisions across and between jurisdictions mirrors practices in other European countries, where markets are cleared and often regulated jointly or in co-operation, while RES-E targets are set at national level. In this section, we outline the roles and responsibilities of the various bodies and actors and explain the decisions that are made within each jurisdiction.

### THE ALL-ISLAND ELECTRICITY GRID

Electricity in Ireland is generated as one synchronous island system. This means that electricity flows via a meshed alternating current (AC) network over the whole island, with supply and demand balanced in real time for the whole island. The island is interconnected via two direct current (DC) interconnectors to Great Britain. The Moyle Interconnector has a capacity of 450MW and runs from Northern Ireland to Scotland, while the East-West Interconnector has a capacity of 500MW and runs from Ireland to Wales. Two further interconnectors are planned, Greenlink, a 504MW interconnector to Great Britain, due to be present from 2024, and the Celtic Interconnector, a 700MW interconnector to France, due to be present from 2027.

The single synchronous system is subdivided into two separately operated power systems, one in Ireland and the other in Northern Ireland. The System Operator for Northern Ireland (SONI) operates the electricity system in Northern Ireland, while EirGrid operates the electricity system in Ireland. The system operators manage the demand-supply balance on each system in real time, taking account of power flows from one system to the other. Thus, the system operators manage the power generation on each system and send instructions on whether to generate to the various generators.

The two systems are 'weakly' interconnected: transmission lines exist but the flow of electricity between systems is constrained. Interconnection is due to be strengthened via the construction of a new 400kV overhead power line connecting the two systems, called the North-South Interconnector. At present, the Interconnector has received planning permission in Ireland but is subject to a judicial review in Northern Ireland. The Interconnector is therefore currently expected to be available to transport electricity between Ireland and Northern Ireland by 2025.

## THE ALL-ISLAND SINGLE ELECTRICITY MARKET

While the all-island grid is made up of two separate systems with separate system operators, all electricity on the island is traded through one all-island market, known as the Single Electricity Market (SEM). The SEM was launched in 2007 and was relaunched under a new design in 2018. Generators in both jurisdictions submit bids to sell energy into one market, and energy consumers in both jurisdictions buy energy from one market. Interconnectors can also buy and sell energy from the market to trade in Great Britain (and, in the future, France).

Under the current design of the electricity market, all electricity bought or sold in the SEM must be done via the central market dispatch. This means in practice that bilateral trades for physical flows of energy between suppliers and generators are not permitted, although financial trades may be made between generators and suppliers which allows energy companies to hedge the risks they face by signing forward contracts with a counterparty. In practice, forward markets in the SEM are not liquid, and generators and suppliers often hedge their position via the gas market (di Cosmo and Lynch, 2016).

Large energy consumers in both jurisdictions may source their electricity directly from the wholesale market, while smaller consumers, whether domestic or commercial, typically source their electricity from electricity supply companies. Some of these companies have both generation and retail arms, while others provide a retail service only. In Ireland, the legacy monopolist ESB operates in the generation market as ESB PowerGen, while the supply arm of ESB Group is Electric Ireland. ESB PowerGen and Electric Ireland are the largest players in the generation and supply sides of the Irish market, respectively. In Northern Ireland, the legacy monopolist is Power NI, which has the greatest share of electricity consumers in Northern Ireland, but has very few generation interests in Northern Ireland following the sale of their generation assets. Power NI is part of Energia Group and operates exclusively in Northern Ireland, while Energia is also part of Energia Group and operates in Ireland. Electric Ireland operates in Northern Ireland as Electric Ireland NI. Other generation and supply companies, such as SSE, have presences in both jurisdictions, while still others operate in one jurisdiction only.

## REGULATION OF THE ELECTRICITY SECTOR

The market is operated by the Single Electricity Market Operator (SEMO). SEMO is a contractual joint venture between two system operators, SONI and EirGrid plc.

The decision-making authority for SEMO is the SEM Committee (SEM-C), which is made up of representatives of the Commission for the Regulation of Utilities (CRU), the Northern Ireland Authority for Utility Regulation (NIAUR) and two independent members. The SEM-C is underpinned by legislation in Ireland and the UK.

The design and re-design of the SEM was overseen by the SEM-C. The SEM-C is also responsible for continuous monitoring of the market to ensure the market is competitive and is providing value for consumers. The Market Monitoring Unit (MMU) of the SEM-C produces regular reports that analyse market outcomes, such as prices and quantities, as well as the behaviour of market participants.

## ENERGY POLICY FORMATION IN IRELAND AND NORTHERN IRELAND

Energy policy is determined separately in each jurisdiction. In Ireland, the relevant department is the Department of Environment, Climate and Communications, while in Northern Ireland the relevant department is the Department of Enterprise, Trade and Investment. Amongst other considerations, both departments are responsible for setting targets related to renewable energy in each jurisdiction.

In Ireland, there is a target that up to 80 per cent of electricity be from renewable sources by 2030 (Government of Ireland, 2021). In addition, the recently-agreed sectoral ceilings under Ireland's Climate Action Plan indicate that carbon budget-consistent power sector emissions in 2030 should be 3Mt of $CO_2$ equivalent (Government of Ireland, 2022). Renewable electricity accounted for 42 per cent of all generation in Ireland in 2020. This aligned with the policy target set for the sector; however, SEAI (2021) notes that the final official share corresponds to 39.1 per cent due to statistical adjustments. These account for annual variations in weather on wind and hydro energy production (Sustainable Energy Authority of Ireland, 2021).

In Northern Ireland, the Climate Change Act (Northern Ireland) 2022 set a target of at least 80 per cent of electricity generation to come from renewable electricity (Northern Ireland Assembly, 2022). This realigns RES-E targets in Ireland and Northern Ireland, with the caveat that the target in Ireland is for 'up to 80 per cent' of electricity to be generated by RES-E, while the new target for Northern Ireland is for 'at least 80 per cent' of consumption to be from RES-E. For the purposes of this paper, we will compare unaligned targets of 70 per cent/80 per cent RES-E with aligned targets of 80 per cent in both jurisdictions.

Table 1 summarises the various market, policy and regulatory bodies under various categories.

**Table 1: Summary of regulatory, policy and market bodies in Ireland and Northern Ireland**

| Body | Jurisdiction | Description | Notes |
|---|---|---|---|
| EirGrid | IE | Transmission system operator | Responsible for electricity generation scheduling<br>Balances demand and supply in real time |
| SONI | NI | Transmission system operator | Responsible for electricity generation scheduling<br>Balances demand and supply in real time |
| SEM | All-island | Market regulator | Regulates and oversees the all-island electricity market |
| NIAUR | NI | Utility regulator (incl. energy sector) | Regulates the utilities sector in Northern Ireland<br>Responsible for remunerating RES-E generators in NI via subsidy payments (if any) |
| CRU | IE | Utility regulator (incl. energy sector) | Regulates the utilities sector in Ireland<br>Responsible for remunerating RES-E generators in IE via subsidy payments (if any) |
| DECC | IE | Relevant department | Responsible for setting energy policy in IE<br>Sets RES-E targets in IE and designs the subsidy schemes |
| DETI | NI | Relevant department | Responsible for setting energy policy in NI<br>Sets RES-E targets in NI |

## LITERATURE REVIEW

The literature review summarised here has two strands: the impacts of RES-E on electricity generation and the impact of differentiated RES-E targets. In both strands, we consider ex ante and ex post research.

The impact of RES-E on electricity investment and prices has been studied in several contexts in the literature. Amongst the ex post literature, di Cosmo and Malaguzzi Valeri (2018) and O'Mahoney and Denny (2013) calculate the impacts of wind generation in Ireland and find that it has put downward pressure on wholesale electricity prices, resulting in a net saving to consumers when subsidy costs are accounted for. These findings align with the international experience: Swinand and Godel (2012) in the case of Great Britain, de Lagarde and Lantz (2018) in the case of Germany, Nieuwenhout and Brand (2011) in the Netherlands, and Figueiredo and da Silva Pereira (2017) in the case of the Iberian market all find evidence of the suppression of electricity prices by renewable generation. Twomey and Neuhoff (2010) provides a theoretical explanation of the dynamics of this effect, while Ben-Moshe and Rubin (2015) provides a review of the empirical evidence of this phenomenon.

In terms of the ex ante literature, several market studies have been performed in Ireland examining the potential for RES-E generation to reduce electricity prices. Applications in Ireland include Tuohy et al. (2009), which used the WILMAR modelling tool, Clancy et al. (2015), which uses the PLEXOS modelling tool, and Lynch and Curtis (2016), which uses the FAST modelling tool. These studies find that wind generation decreases costs and emissions for the Irish power system under various assumptions around the future electricity system.

The contribution of this paper builds on this strand of the literature in two main ways. First, instead of examining the impacts of increased RES-E on the operational cost savings of the electricity system, this paper performs a long-run investment and planning model that incorporates RES-E targets. This sets it apart from the ex ante research cited above, which examined operational issues only. Second, this research considers the impacts of jurisdiction-specific RES-E targets. This brings us to the second strand of the literature.

Electricity markets often span jurisdictional borders, while RES-E targets often tend to be jurisdiction-specific. Thus the interaction between market regulations and policy targets can have an impact on final market outcomes and so has been explored in the literature. Jacobsen et al. (2014) reviews potential co-operation mechanisms to achieve EU renewable targets and finds that future RES targets are creating uncertainty for the future value of RES credits, which in turn reduces co-operation between jurisdictions. Lynch, Tol and O'Malley (2012) examines the interaction of RES-E targets in north-west Europe, under differentiated jurisdictional RES-E targets and a global RES-E target. They find that the optimal interconnection between jurisdictions depends heavily on the design of the policy targets. Newbery et al. (2018) considers the optimal market design for EU power markets in the presence of high RES-E integration, and finds that optimal trade and interconnection between the various jurisdictions is an important enabler of efficient market operation. On the island of Ireland, the impact of jurisdictional energy policy has been explored by Curtis, di Cosmo and Deane (2014). Using an electricity dispatch model, they found that unilateral climate policy at the UK government level, if extended to Northern Ireland, would have affected consumer welfare across the island of Ireland, with the magnitude and direction of the welfare effects in each jurisdiction varying based on whether the carbon price floor was also adopted in Ireland. Finally, Fitiwi, Lynch and Bertsch (2020b) finds that the presence of the North-South Interconnector on the island of Ireland will change the costs and benefits of RES-E integration policies.

This article contributes to the literature by covering many of the themes discussed in the research above, but with new methodologies and applications. In particular, this research explicitly considers the interaction between aligned RES-E targets in a single synchronous power system which is cleared under one electricity market. The costs and benefits of RES-E policies, both within and across jurisdictions, are examined with respect to the presence of the North-South Interconnector. Several papers have also considered the impact of renewable energy policy costs on consumer levies and surcharges (Farrell and Lyons, 2015; Grösche and Schröder, 2014). This paper links this strand of the research with cross-jurisdictional policy alignment.

The final contribution comes from the methodological focus of this paper. Where Curtis, di Cosmo and Deane (2014) used a market dispatch model, this study utilises the ESRI's generation and transmission expansion planning model, the Electricity Network and Generation INvEstment (ENGINE) model (Fitiwi, Lynch and Bertsch, 2020a; Fitiwi, Lynch and Bertsch, 2020b). The ENGINE model determines the least-cost deployment of electricity generation and transmission assets across the entire electricity system of the island of Ireland. Furthermore, the ENGINE model is a least-cost expansion planning model and determines the optimal investment of such assets for the electricity system as a whole. The optimal investment can be determined under various renewable generation investment scenarios, and the total network capacity investment required under each scenario can be quantified and costed. In this way, we can quantify the total cost impact for island-wide electricity generation and transmission arising from a harmonised renewable capacity expansion.

# CHAPTER 3

# Methodology

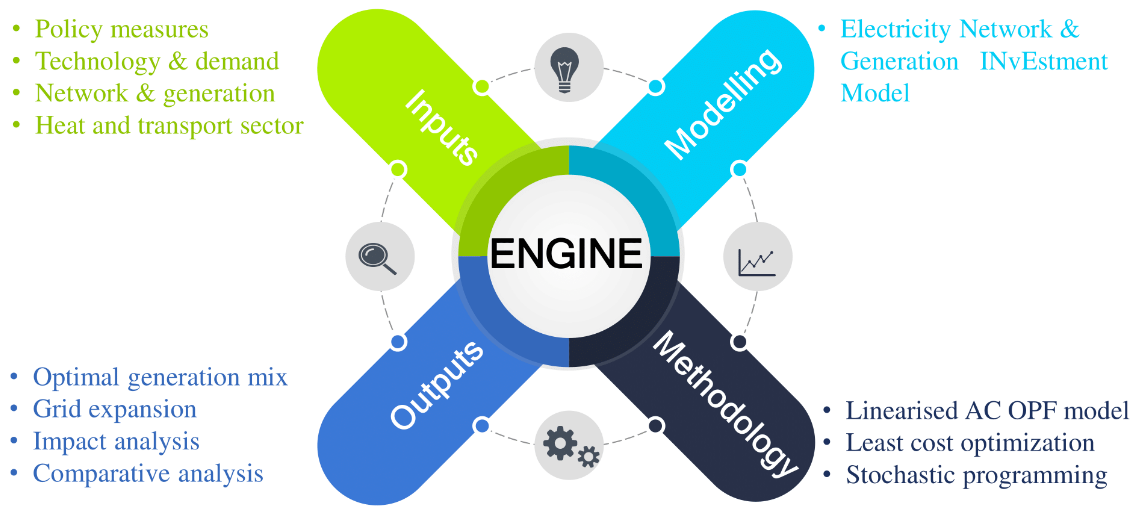
The methodology used for this study is the Electricity Network and Generation INvEstment (ENGINE) model. ENGINE was developed within the ESRI and is a least-cost planning model for the Irish generation and transmission system. In particular, ENGINE determines the lowest cost method of meeting electricity demand across the whole island of Ireland, at transmission node level, while respecting the technical limitations of the electricity network assets (transformers and lines) and generation assets (conventional power plants, renewable generation sources and electricity storage devices) on the system. The ENGINE model takes the form of a linearised Alternating Current Optimal Power Flow (ACOPF) model. Optimal power flow models determine the optimal flow of electric power between all nodes in the power system. Alternating current models take into account the physical constraints on the power flow, represented by Kirchhoff's Laws. A full AC model includes non-linear functions, which are computationally challenging to solve, and so the ENGINE model linearises these functions by making certain reasonable assumptions regarding the voltage angle. As such, the ENGINE model determines the flow of electricity between all points of the transmission network, taking voltage as well as electrical current into account.

The ENGINE model is calibrated with data out to 2030, and the ENGINE model considers the optimal investments required in both 2025 and 2030 as part of its results. In determining the optimal investment in, and operation of, each generation technology, the model also determines the locational marginal price (LMP) at each transmission node in the network. These LMPs can be aggregated to give an estimate of the system-wide marginal price, which is a proxy for wholesale electricity prices in the SEM.

The inputs considered by the ENGINE model therefore include the existing generation and transmission assets, the demand profiles at each node in the transmission network, the availability of wind and solar at each transmission node, the investment costs of new generation and the operational costs of new and existing generators. The variables determined directly by the model are the investment in new generation and transmission assets and the operation of new and existing assets. Other resulting variables include the LMPs at each node, the unserved demand at each node (if any) and the carbon emissions from the power system.

A graphical representation of the ENGINE model is shown in Figure 1. A full description of the ENGINE model is available in Fitiwi, Lynch and Bertsch (2020a) and Fitiwi, Lynch and Bertsch (2020b).

**Figure 1: The ENGINE model**




In this study, the ENGINE model is used to determine the least-cost investment in, and operation of, transmission and generation assets for the whole of the island. The demand at each transmission node is forecast out to 2030 using data from the TSOs, EirGrid and SONI. The assumptions for the costs of each generation asset, along with fuel price projections, are based on estimates from the European Commission (European Commission, 2018).

This analysis considers the following set of scenarios. The first scenario considered is where Ireland has a higher RES-E target than NI (80 per cent vs. 70 per cent). The second scenario considers the situation where Ireland and Northern Ireland have the same target of 80 per cent. A third scenario considers a single island-wide target of 80 per cent, which we call effort sharing. We consider each of these three scenarios under a setting of no interconnector (the current state of play) and an operating interconnector (which is expected from 2025). This makes six scenarios in total. Table 2 shows the scenarios considered.

**Table 2: List of scenarios considered**

| Case | IE RES-E | NI RES-E | All island RES-E | Interconnector |
|---|---|---|---|---|
| Unaligned, IC | 80% | 70% | n/a | Yes |
| Aligned, IC | 80% | 80% | n/a | Yes |
| Effort sharing, IC | n/a | n/a | 80% | Yes |
| Unaligned, NoIC | 80% | 70% | n/a | No |
| Aligned, NoIC | 80% | 80% | n/a | No |
| Effort sharing, NoIC | n/a | n/a | 80% | No |

Note: 'IC' refers to the scenario where the North-South Interconnector is operational. 'NoIC' refers to the scenario where the North-South Interconnector is not operational.

# CHAPTER 4

# Results

To easily compare results across scenarios, we report findings as a percentage change against a baseline. This minimises sensitivity to many underlying assumptions; while absolute cost values may change, the relative difference should remain consistent, as the only difference between scenarios stems from RES-E integration and the presence of the North-South Interconnector.

We first examine changes in generation and transmission investment decisions brought about by alignment of RES-E targets without the North-South Interconnector (i.e. comparing Unaligned, NoIC to Aligned, NoIC). We then examine the impacts of the interconnector first without alignment (comparing Unaligned, NoIC to Unaligned, IC) and then with alignment (comparing Unaligned, IC to Aligned, IC). Next, we consider the impact of effort sharing on the variables of interest, by comparing Aligned, NoIC to Effort Sharing, NoIC and comparing Aligned, IC to Effort Sharing, IC. Finally, we consider the impacts of alignment on electricity prices and RES-E policy costs.

## GENERATION AND TRANSMISSION INVESTMENT UNDER ALIGNED POLICY TARGETS

### Investment without the North-South Interconnector

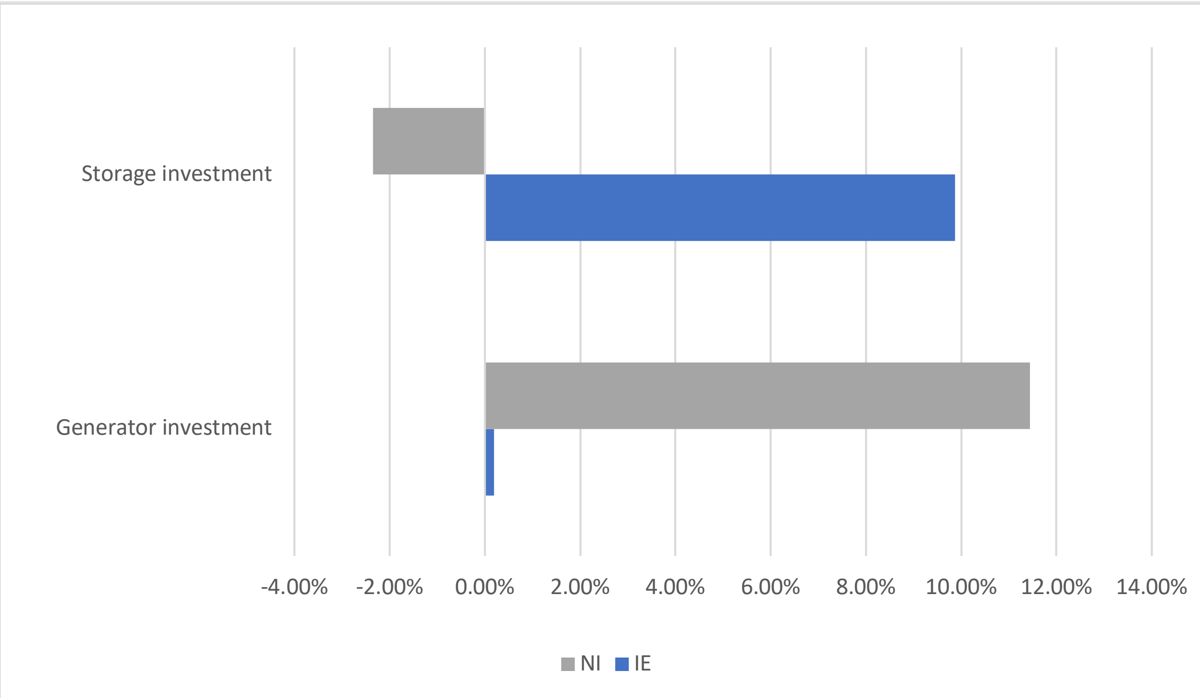
We first examine the impacts of aligned RES-E targets with no investment in the North-South Interconnector. Moving from Unaligned, NoIC to Aligned, NoIC has a noticeable impact on renewable energy installations, as well as the installation of energy storage technologies. Under Aligned, NoIC, renewable generation capacity increases by 11.44 per cent in Northern Ireland, relative to Unaligned, NoIC. This additional capacity is expected, given the higher RES-E target in Northern Ireland, and changes the pattern of renewable energy absorption across the electricity market.

There are no additional network upgrades required. This is unexpected; additional renewable energy capacity places a greater burden on the system, often in remote locations that would otherwise have had relatively low transmission capacity requirements. This often requires upgrade. However, there are notable changes in the siting of electricity storage on the island. Renewable energy is variable and so must be either used at the point of generation; transmitted to other locations for immediate usage; stored; or go unused. The results from ENGINE show that it is optimal for surplus RES-E generation in Northern Ireland to be used in Ireland for storage. This impact is likely determined by the relative population sizes, and thus the relative electricity demand, in the two jurisdictions; a greater population in

Ireland presents a greater opportunity for variable renewables to be absorbed. This results in additional storage capacity required in Ireland (an additional 9.86 per cent) and a lesser requirement for storage locally in Northern Ireland (a reduction of 2.34 per cent). The reduction in storage capacity in Northern Ireland is likely due to the increased local generation reducing the requirement for local storage. These developments are shown in Figure 2.

These results confirm previous results from the literature that find that transmission and storage are substitutive, particularly at high levels of RES-E (Fitiwi, Lynch and Bertsch, 2020b and 2020c). However, these results suggest that the benefits of alignment of policies can exploit this substitutive effect in new ways. In particular, increased RES-E generation in one jurisdiction can be complemented by increased storage in another jurisdiction, particularly when interconnection is limited.

**Figure 2: Relative change in renewable energy and storage investment under aligned RES-E targets (interconnector not operational)**

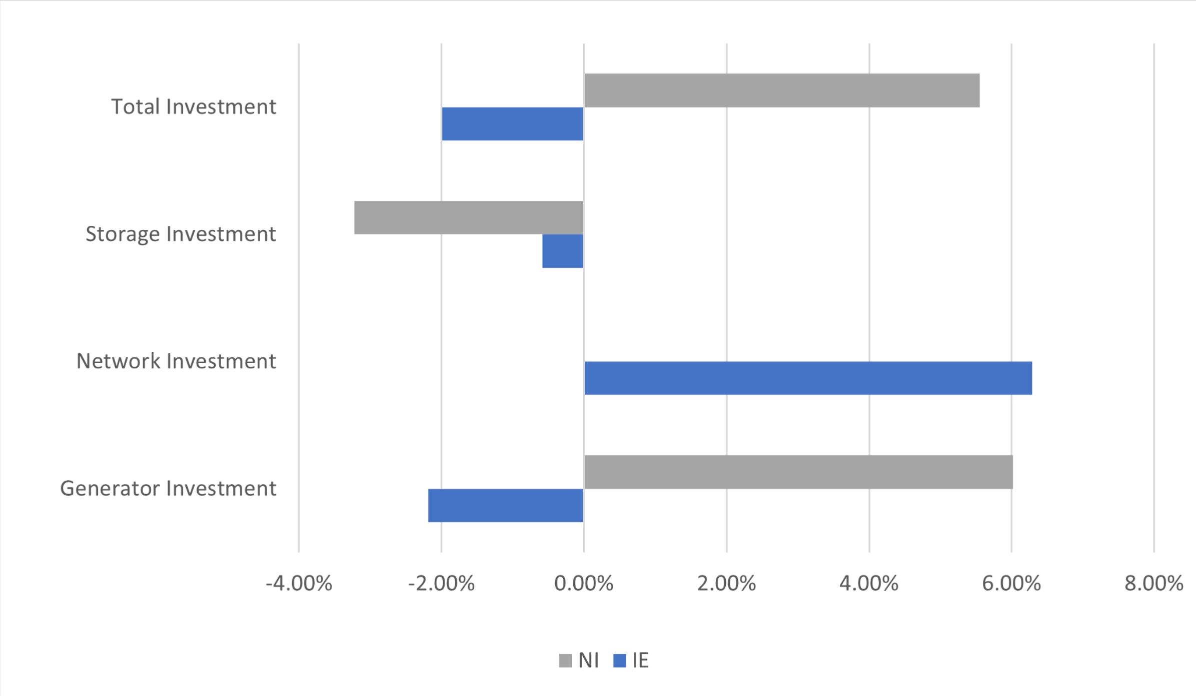



Note: Figure shows change in the cost of optimal renewable energy and storage capacity installations between 2020–2030 on foot of changing from Unaligned, NoIC to Aligned, NoIC. The 80 per cent target in Ireland does not change. Source: Authors' calculations using ENGINE model.

## The impact of the North-South Interconnector without policy alignment

The North-South Interconnector has positive system benefits even before the recently announced alignment of renewable energy targets (Curtis, di Cosmo and Deane, 2014). Figure 3 shows the changes in optimal infrastructure investment under this scenario.

**Figure 3: Change in investment due to installation of the North-South Interconnector with unaligned RES-E policies**




Note: Figure shows change in the cost of optimal renewable energy and storage capacity installations between 2020–2030 on foot of moving from Unaligned, NoIC to Unaligned, IC. Source: Authors' calculations using ENGINE model.

The North-South Interconnector increases the opportunities for the transmission of electricity between jurisdictions, leading to a more efficient spatial allocation of generation assets on the island. Prior to the introduction of the North-South Interconnector, a greater proportion of generation assets are located in Ireland, driven by its higher demand. When the North-South transmission infrastructure is in place, this enables greater investment in generation capacity in Northern Ireland, improving security in that jurisdiction, as surplus electricity can be exported to Ireland. The increased generation capacity is therefore economically justified by the interconnector. This gives rise to a net increase in generation in Northern Ireland (+6%) and a net reduction in Ireland (-2.2%).

A greater share of generation activity in Northern Ireland has implications for the electricity system but it may also have industrial policy and regional development implications. While any potential change in investment activity is relatively small, it is likely to have a proportionally greater effect on the Northern Irish economy than the economy in Ireland.

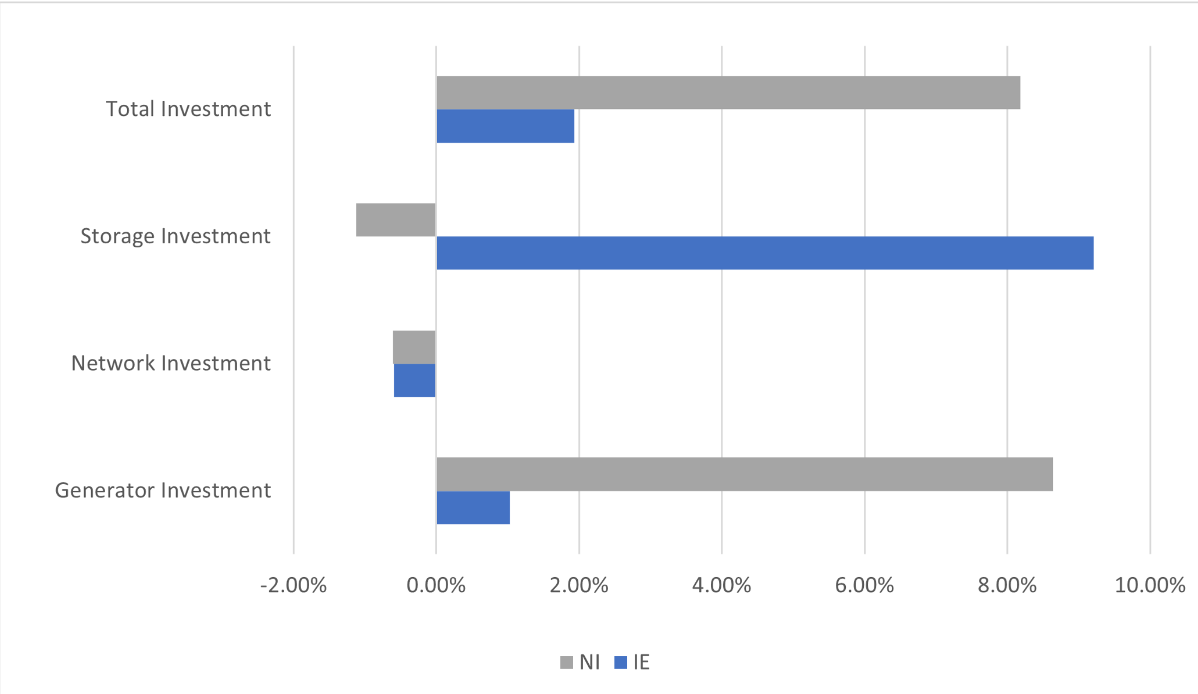
A greater ability to transmit electricity between Ireland and Northern Ireland through transmission lines reduces the need for electricity storage in both jurisdictions prior to alignment. Figure 3 shows that the storage requirement falls in Northern Ireland particularly (by 3.22%), with storage in Ireland staying relatively constant (a fall of <1%). Figure 3 also shows that investment in the North-South Interconnector prompts further network infrastructure investment in Ireland, with ENGINE finding an increase of 6.29% to facilitate optimal system operation. No increased network investment is observed in Northern Ireland.

### The impact of the North-South Interconnector with policy alignment

We now consider the changes from moving from Unaligned, IC to Aligned, IC, shown in Figure 4. Two insights emerge. First of all, the higher RES-E target in Northern Ireland again gives rise to an increased requirement for storage in Ireland, even in the presence of the North-South Interconnector. Aligned policy targets, and the resulting higher investment in RES-E increases the need for storage in Ireland. This result holds whether or not the North-South Interconnector is present. This suggests that increased storage in Ireland is a robust policy option, particularly at high levels of RES-E, and facilitates the alignment of RES-E targets and policies.

The second piece of insight relates to network infrastructure. Figure 4 shows that, once the interconnector is operational, the aligned policy targets give rise to less network investment than the pre-alignment scenario. This is perhaps related to the additional storage that comes with the aligned policy targets. With additional renewables comes a greater requirement for storage. This storage is likely to act as a substitute for much of the transmission investment that would otherwise take place under an unaligned policy scenario.

**Figure 4: Infrastructural change under aligned RES-E targets (North-South Interconnector operational)**




Note: Figure shows change in the cost of infrastructural investments between 2020–2030 on foot of changing from Unaligned, IC to Aligned, IC. Source: Authors' calculations using ENGINE model.

## THE BENEFITS OF EFFORT SHARING

The principle of 'effort sharing' has featured in many international climate change agreements (Peeters and Athanasiadou, 2020). The rationale for such a facility is built on the premise that it does not matter where the avoidance of carbon emissions takes place for the purposes of mitigating the effects of climate change, and it may be more efficient to re-allocate effort between jurisdictions. We test whether this is the case for the island of Ireland. We compare the cost of achieving separate 80 per cent IE and 80 per cent NI targets with an all-island 80 per cent target, facilitated through effort sharing. This effort-sharing regime is close to the theoretical optimal as we allocate effort based on economic considerations alone, and so provides a useful benchmark against which to compare the aligned and unaligned policy targets. Through this benchmark, we identify how close the current policy structure is to the theoretical optimal and whether further co-operation through effort sharing could unlock additional efficiency.

We find that the introduction of an all-island effort-sharing mechanism would not lead to considerable cost reductions. However, the establishment of the North-South Interconnector is an important determinant of this finding. Table 3 shows the difference in total system costs between effort sharing scenarios, relative to a baseline of Unaligned, NoIC. Differences in cost are small, with an operational North-South Interconnector minimising total system costs. Interestingly, it can be seen from Table 3 that the North-South Interconnector leads to greater efficiencies across the island than effort sharing.

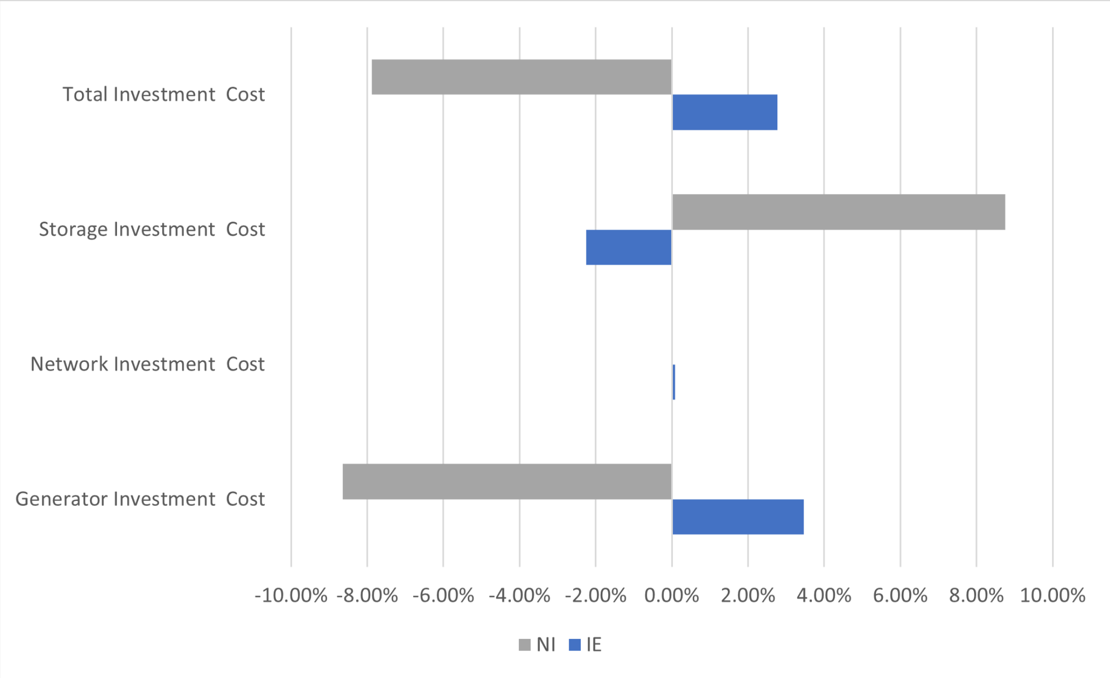
**Table 3: Impacts of effort sharing and the North-South Interconnector relative to a baseline of aligned policy targets with no interconnector**

| | North-South Interconnector | |
|---|---|---|
| **Targets** | **Not Operational** | **Operational** |
| **Individual** | 0.234% | 0.195% |
| **Effort sharing** | 0.217% | 0.185% |

Note: Table shows proportional change in total cost relative to baseline of total costs under Unaligned, NoIC.

The difference in infrastructural investment when moving from Aligned, NoIC to Effort Sharing, NoIC is shown in Figure 5. This figure shows that while the change in total costs associated with effort sharing are negligible (Table 3), there are significant changes with respect to the components of total cost, specifically the location of generation and storage investment. Without the interconnector, effort sharing shifts generation investment from Northern Ireland to Ireland, and shifts storage investment from Ireland to Northern Ireland. In particular, the optimal renewable generator investment increases by 3.46 per cent in IE and decreases by 8.65 per cent in NI, compared with regional targets of 80 RES-E in both IE and NI.

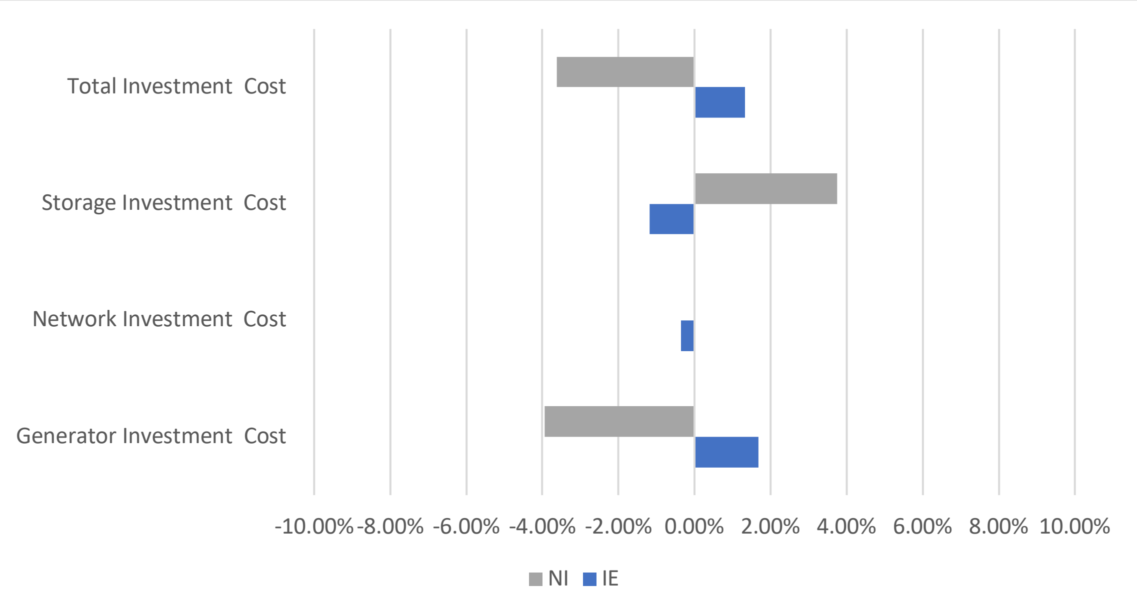
**Figure 5: Cost components under effort sharing compared to aligned targets with no interconnector**




Note: Figure shows change in the cost of infrastructural investments between 2020–2030 on foot of changing from Aligned, NoIC to Effort Sharing, NoIC. Source: Authors' calculations using ENGINE model.

Figure 6 shows, however, that these changes in optimal infrastructure are approximately halved should the North-South Interconnector be operational. Without the interconnector, optimal storage investment reduces by 2.24 per cent in IE and increases by 8.75 per cent in NI (Figure 5), with the change falling by approximately half in both jurisdictions once the interconnector is in place (Figure 6). This reflects the greater proportion of total generation investment in Ireland. The variability of renewable generation means that supply may exceed demand if weather conditions allow, with the interconnector allowing this surplus supply to be absorbed in Northern Ireland. The requirement for additional storage is therefore reduced.

Figure 6: Cost components under effort sharing compared to aligned targets with the North-South Interconnector




Note: Figure shows change in the cost of infrastructural investments between 2020–2030 on foot of changing from separate 80 per cent renewable energy targets in Ireland and Northern Ireland to an all-island 80 per cent target facilitated by effort sharing. The North-South Interconnector is operational. Source: Authors' calculations using ENGINE model.

In summary, the introduction of effort sharing seems to prompt a shift in the location of generation and storage investment, but with no significant reduction in total costs. The presence of the North-South Interconnector reduces the changes in location as a result of effort sharing. In either case, the total investment costs are not significantly reduced by effort sharing.

## PRICES AND POLICY COSTS

The final focus of this report is to assess the impact that policy alignment may have on energy prices and renewable energy policy costs in Ireland and Northern Ireland. We first consider the impacts that the recent alignment may have on electricity prices, followed by a discussion of the impacts on investment profitability and therefore on renewable support costs.

### Impact of policy alignment on electricity prices

It is well documented that additional renewable energy generation tends to depress wholesale electricity prices, as zero marginal cost generation replaces generation with a positive marginal cost. This is known as the 'merit order effect' with research quantifying the extent to which this has occurred both internationally and in an Irish context (Sensfuß, Ragwitz and Genoese, 2008; di Cosmo and Malaguzzi Valeri, 2018). We find evidence that the recent alignment of Northern Irish renewable energy targets may lead to a further reduction in electricity prices across the island.

The SEM clears with a single system-wide price, while ENGINE identifies 'nodal prices', or the marginal cost incurred in delivering electricity at each given location on the system. While spatial heterogeneity of prices is not captured in the SEM, including this level of detail in the ENGINE model allows for the spatial distribution of system costs to be identified, while the system-wide marginal price can be estimated by calculating the weighted average of the Locational Marginal Prices (LMPs) across the system.

We find that aligning renewable targets decreases average nodal prices in NI and IE by a similar amount (i.e. the average marginal cost of delivery at either jurisdiction) relative to the unaligned case; average marginal prices in IE and NI decrease by 4.2 per cent and 4.5 per cent respectively. Therefore, the system benefit of increasing the renewable energy target in Northern Ireland is distributed evenly across NI and IE. This converts to a system-wide reduction in prices of just over 4 per cent. The impact that the interconnector has on electricity prices is relatively small. These results are summarised in Table 4.

**Table 4: Proportional change in locational marginal prices due to alignment and/or interconnector**

| Scenario | IE | NI |
|---|---|---|
| UnAligned, NoIC to Aligned, NoIC | -4.21% | -4.47% |
| UnAligned, IC to Aligned, IC | -4.34% | -4.54% |
| UnAligned, NoIC to UnAligned, IC | -0.08% | 0.10% |
| Aligned, NoIC to Aligned, IC | -0.21% | 0.03% |

### Impact of policy alignment on policy costs

Renewable technologies such as wind have historically been more expensive than fossil fuel-based alternatives, requiring public support for viable investment (Kalkuhl, Edenhofer and Lessmann, 2013; Farrell et al., 2017; AURES II, 2021; Matthäus, 2020; Artelys Optimisation Solutions, 2019; Nicolini and Tavoni, 2017; del Río, 2017; Steinhilber, 2016; del Río, 2016; Fitch-Roy and Woodman, 2016). The gap between market remuneration and the remuneration required for viable investment has closed in recent years due to falling investment costs (Way et al., 2019). Nevertheless, should a gap between market revenues and investor costs exist, policy supports will be required to bridge the shortfall. Renewable energy is supported by two schemes in Ireland: the Renewable Energy Feed-in Tariff (REFIT) and the Renewable Electricity Support Scheme (RESS). Both schemes operate by offering investors a minimum guaranteed price, with the shortfall between the market price and the guaranteed price comprising the subsidy. The more recent RESS scheme emulates a contract-for-difference; price supports are offered should market prices be less than the guaranteed minimum. However, firms must pay the difference should market prices exceed this minimum. This provides a hedge for consumers unavailable under the REFIT scheme, where firms retained any revenues in excess of the agreed minimum.

The costs of REFIT and RESS are levied on consumers by means of a flat-rate public service obligation levy. In Northern Ireland, renewable generation is supported as part of the UK-wide cost-recovery mechanism levied on consumers.

Alignment leads to a negligible change in renewable energy deployment in Ireland, and therefore a negligible change in any associated policy costs. The quantity of RES-E deployed remains constant, while the 4 per cent drop in electricity prices slightly increases the viability gap (gap between costs and revenues) for RES-E projects in Ireland, which puts upward pressure on policy costs. In Northern Ireland, the quantity of RES-E installed increases and the price received by generators (including RES-E) falls, leading to a greater viability gap for RES-E. This gap is primarily driven by the increased investment rather than the decreased prices, however.

Table 5 quantifies the impact of this drop in prices on the profitability of renewable energy during the 2020–2030 period. Alignment reduces the total profitability of renewable energy investment in Ireland by 11.6–12 per cent, due to merit order effects. Should investment costs be such that price supports are required, this may lead to a marginal change in the price support offered. In Northern Ireland, alignment leads to an increase in total RES-E generator profits in the order of 5 per cent, driven by the additional quantity of renewable energy deployed to meet the 80 per cent target. However, the profitability per MW of RES-E installed declines by 11.63 per cent, due to the merit order effect. These effects are relatively stable between interconnector/no interconnector scenarios.

**Table 5: Change in viability gap per MW installed for RES-E projects under aligned RES-E targets**

| Jurisdiction | No interconnector | Interconnector |
|---|---|---|
| **Ireland** | -12.25% | -12.55% |
| **Northern Ireland** | -11.63% | -11.87% |

Note: Table shows proportional change in renewable energy profitability per MW installed capacity relative to baseline of UnAligned, NoIC.

## Impact of high fossil fuel prices

The subsidy cost is driven by the difference between the guaranteed minimum ‘strike’ price and the market price of electricity. Higher electricity prices can therefore decrease subsidisation costs if supported by a RESS-style policy (discussed above). This is due to the nature of this policy design; when electricity prices exceed the guaranteed minimum, RES-E generators pay the difference between the wholesale and the guaranteed minimum ‘strike’ price back to consumers. Thus, while aligning renewable energy targets may reduce profitability at high fossil fuel prices, a subsidy cost will accrue to consumers only when the market price is less than the agreed ‘strike’ price.

As wholesale market prices exceeded the ‘strike’ price in 2022, RESS-supported renewable energy generation in Ireland returned revenues earned in excess of the agreed minimum. This may occur in the future, and consistently high wholesale prices increases the possibility of a rebate for consumers. Indeed, this aligns with previous literature, which suggests that renewable energy is particularly useful at times of very high fuel prices (Lynch and Curtis, 2016).

In this way, renewable energy supported by schemes like the RESS can provide a hedge against high fossil fuel prices. The magnitude of this hedge is determined by the quantity of renewables installed and the nature of the policy of support. Alignment will lead to a greater potential hedge for consumers in Northern Ireland, if this capacity is supported by a contracts-for-differences-style support mechanism similar to those in place in Ireland (under the RESS scheme) and Great Britain.

# CHAPTER 5

# Discussion and conclusion

## SUMMARY OF FINDINGS

Northern Ireland has recently announced a renewable energy target of 80 per cent by 2030, a target which has led to alignment between both Ireland and Northern Ireland. As both jurisdictions share a single electricity market, the implications that this alignment may have on the cost and operation of the system has been assessed in this paper. A number of findings have emerged.

First, it has been found that the added renewable energy capacity will result in a changing pattern of renewable energy absorption on the island. As renewable energy is variable, it must be either used instantaneously, transmitted for consumption elsewhere, stored, or discarded. A certain proportion of the additional renewable energy generation in Northern Ireland can be absorbed by local demand. Without the North-South Interconnector, an aligned target reduces the storage requirement in Northern Ireland. The reduction in storage capacity in Northern Ireland is likely due to the increased local generation reducing the requirement for local storage. In addition, this leads to an increase in storage in Ireland. As the added electricity generation must be used, much of this is used in Ireland due to the greater population and total demand. Without a North-South Interconnector, this is stored in Ireland next to the point of demand. This cross-border movement of electricity highlights the potential for alignment of policy targets to increase co-operation and security across the market.

The introduction of the North-South Interconnector facilitates more efficient transmission of electricity on the island. Without alignment, the optimal trajectory of investment on the island reduces the storage requirement. However, with the introduction of the aligned policy targets, it is immediately clear that additional storage will be required, along the lines of what was necessary prior to the introduction of the interconnector.

Additional renewables lower wholesale electricity prices through a mechanism known as the merit order effect. Increased renewable energy deployment leads to an increased merit order effect on the island, experienced in both Northern Ireland and Ireland. This reduces electricity prices across the island by around 4 per cent. A potential mitigating factor to this merit order effect is the impact it may potentially have on renewable energy price supports. These price supports are publicly funded (often through levies charged on electricity consumers) and comprise the difference between the market price and the agreed ‘strike price’. Should market prices fall through merit order effects, this may increase the gap between the market price and the strike price, increasing subsidies. However, this is predicated on wholesale prices being less than the strike price. In 2022, wholesale prices were high and exceeded the strike price in Ireland, leading to negative policy costs (i.e. a rebate for consumers). Should high energy prices persist, the impact that merit order effects have on policy cost will be of lesser concern.

Finally, this paper has explored the potential efficiency benefits that may be achieved through effort sharing of policy targets on the island of Ireland. We have found that such impacts are relatively modest, changing total costs by less than 1 per cent. Of particular interest in this context, however, is the role of the North-South Interconnector. Establishment of the North-South Interconnector brings the deployment trajectory for assets on the island closest to the theoretical optimal. Indeed, establishment of the North-South Interconnector has a proportionally greater impact than effort sharing.

## LIMITATIONS

There are several limitations of this study that should be considered when interpreting the results. First, the ENGINE model assumes a least-cost expansion of generation and transmission investment across the SEM. In practice, investment decisions in generation and storage assets are determined by market players based on commercial realities, while investment in transmission infrastructure is determined by the TSO's assessment of the system requirements, but is also subject to planning and regulatory restrictions. It is not feasible for ENGINE to take account of these constraints, and so the final investment under TSO and energy-market participant decisions may differ from the least-cost investments identified here. Nonetheless, the results provide a useful benchmark for the expansion and operation that would occur in a least-cost, or perfectly competitive, market.

Second, ENGINE is not a market model and so the locational marginal prices (LMPs) calculated in the model represent a proxy for electricity prices only. Furthermore, revenues from the capacity market and ancillary services market are not considered in this research. For this reason, we present results in terms of percentage changes, as while the absolute values of electricity prices arising from ENGINE may not reflect market prices, the trends and relative magnitudes should mirror those of the SEM.

Some of the results may prove sensitive to certain assumptions made on input parameters. In the context of increased fossil fuel prices, the total system costs estimated by this model may be lower than those that will actually unfold between now and 2030. In practice, this means that the reduction in costs as a result of increased wind generation, both in Ireland and in Northern Ireland, will be even greater than those estimated here.

Furthermore, the cost of storage may impact on the results. Previous research on the all-island power system using the ENGINE model (Fitiwi, Lynch and Bertsch, 2020c) found that lower storage costs, which in turn increased the optimal level of storage investment, decreased both investment in other technologies and also decreased the proportion of energy not served. In other words, storage increased the security of the system and decreased the probability of blackouts. It can be plausibly surmised that should storage prove more expensive than that modelled here, there would be a resulting increase in thermal generation and/or a decrease in reliable electricity supply. Unaligned targets that give rise to greater RES-E in one jurisdiction over another would see greater energy not served in the jurisdiction with a (relatively) higher RES-E target. It should be noted also that the costs of storage are not the only uncertain variable; the possibility of regulatory or planning delays may also impact on storage, as well as other energy infrastructure investments.

Finally, ENGINE is an investment model, with an emphasis on ensuring robust results relating to investment decisions. The specifics of generator operation may not be as reliable. For this reason, the results focused on installed quantities rather than the operation of the various units.

## DISCUSSION OF RESULTS AND FURTHER POTENTIAL POLICY IMPLICATIONS

There are a number of potential policy implications arising from this study. Firstly, we find that unlocking the most efficient pattern of infrastructural investment requires co-ordination of investment across both jurisdictions on the island. For instance, we show that increased renewable energy generation in Northern Ireland can be optimally absorbed by additional storage in Ireland. It is likely that effective market signals will guide such co-ordinated investment. However, investment is predicated on confidence that proposed action will be undertaken and may therefore be further strengthened through strong information transfer between jurisdictions and industry relating to progress in renewable energy deployment and future policy development. Furthermore, the existence of the SEM allows investment to occur in a common market and regulatory framework, which allows investment signals in Ireland to be influenced by investment decisions in Northern Ireland and vice versa.

Secondly, the alignment of policies between Ireland and Northern Ireland may guide us towards a more efficient long-term trajectory, post-2030. The preceding analysis has shown that policy alignment leads to a changed pattern of infrastructure investment, particularly in relation to storage deployment. Should the unaligned policy development have transpired, for instance, there would have been much less storage deployment on the island, particularly in Ireland. However, if one considers that the long-term trajectory post-2030 is that of net zero decarbonisation, an 80 per cent target in Northern Ireland would have to be achieved at some point. Assuming that Northern Ireland would eventually surpass the 70 per cent target and converge on 80+ per cent renewables in the electricity mix, greater storage investment would likely be required in the long run, and aligned policy targets allows this storage investment to take place in an optimal manner, avoiding the possibility of storage assets built in Northern Ireland being under-utilised or stranded. These results align with the literature on the importance of certainty with respect to policy targets, particularly in the long run.

A similar piece of insight is observed with respect to transmission investment. Under unalignment, additional transmission is required in Ireland to facilitate efficient operation of the system once the North-South Interconnector is operational. Upon alignment, this transmission investment would be less valuable. Should alignment take place at a later date, transmission assets that were justified and built under unaligned policies may be under-utilised or stranded. This suggests that the alignment of policy targets has positioned both transmission and storage development on the island closer to that which best facilitates longer-term decarbonisation.

Interestingly, we find that the North-South Interconnector has a modest impact on the storage requirement on the island (much less than the impact of renewable policy alignment); however, it is impactful on the optimal distribution of generation assets on the island. By opening up a greater transmission line between Ireland and Northern Ireland, there is greater scope for the siting of generation assets in Northern Ireland. While this has immediate energy policy implications and leads to a more efficient operation of the system, it may also have wider industrial policy implications.

The importance of the North-South Interconnector is made clear in the final piece of analysis contained within this paper. Theoretically, one would expect that introducing an 'effort sharing' regime across both jurisdictions would allow additional efficiencies with respect to renewables deployment. We find that while this is the case, the magnitude of the effect is negligible. Indeed, deployment of the North-South Interconnector has a proportionally greater impact on total system costs than effort sharing on the island.

Finally, we find that the recent announcement of policy alignment in Northern Ireland will lead to added 'merit order effects' across the island. This is welcome in the context of rising wholesale energy prices, whereby a greater merit order effect leads to a reduction in wholesale energy prices by 4 per cent across the island. In addition, there may be further benefits for consumers in Northern Ireland, should these renewable energy additions be supported by Contracts for Differences-style price supports in a manner similar to policies in place in Ireland and Great Britain. Under such contracts, generators return any market revenues in excess of an agreed strike price to the consumer. The policy support for these future renewable energy installations in Northern Ireland has yet to be finalised. If such policies are put in place in Northern Ireland, then this may put further downward pressure on electricity costs for Northern Irish consumers.

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Whitaker Square,
Sir John Rogerson's Quay,
Dublin 2
Telephone **+353 1 863 2000**
Email **admin@esri.ie**
Web **www.esri.ie**
Twitter **@ESRIDublin**

ECONOMIC & SOCIAL RESEARCH INSTITUTE