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A Gravity Model Specification for Irish Green Energy Goods and Services

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A Gravity Model Specification for Irish Green Energy Goods and Services



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RESEARCH PAPER

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Table of Contents

Abstract	2
Chapter 1 : Introduction	3
1.1	Ireland’s Renewable Energy Policy Context.....	3
Chapter 2 : Literature Review	.....	5
2.1	What is the Gravity Model?	5
2.2	Why use the Gravity Model?.....	6
2.3	Intuitive Form of the Gravity Model	6
2.4	Limitations and Criticisms of the Gravity Model.....	8
2.5	Examples of Applications of the Gravity Model.....	9
Chapter 3 : Proposal for Gravity Model Specification	.....	13
3.1	Approach	13
3.2	Gravity Model Specification	13
3.3	Independent Variables	14
3.4	Criteria for Selecting Variables.....	15
3.5	Amenable to Policy Action	15
3.6	Less or Not Amenable to Policy Action	17
3.7	Dependent Variables – Potential Candidates for Inclusion in an Irish Gravity Model.....	18
3.7.1	Current Opportunities.....	18
3.7.2	Future Opportunities.....	20
3.8	Expected Results	20
3.9	Data Sources.....	21
Chapter 4 : Policy Recommendations and Risks	.....	23
4.1	Policy Recommendations	23
4.2	Risks.....	23
Chapter 5 : Conclusion	.....	25
Bibliography	.....	27

Abstract

As Ireland moves away from fossil fuels and toward more renewable energy sources, there is an opportunity to maximise the economic benefits arising from this transition, including job creation, and exporting goods and services as well as renewable electricity. The purpose of this paper is to explore whether and how a gravity model might help Ireland to seize green export opportunities. Gravity modelling has been used extensively in international trade literature to analyse and estimate the expected level of trade between countries. The Irish government has a stated ambition to create employment by exporting goods and services linked to the renewable energy sector, and even by exporting renewable electricity itself. By exceeding domestic demand, the opportunity to export excess energy goods, services, and renewable electricity grows. Applications of the model have been limited in an Irish context and have not been applied to green goods and services, or to renewable electricity. This paper aims to fill a gap in the research, by proposing a gravity model specification to explore the potential export opportunities arising from the energy transition in Ireland. Specifically, the proposed model specification suggests a number of factors that can explain Irish two-way trade in renewable energy goods and services, and renewable electricity. These factors include GDP, distance between countries, the level of regulation, and tariff and non-tariff barriers. The paper frames this in the context of Ireland's renewable energy potential with an extensive literature review, a sample of data sources, and a discussion of policy recommendations and risks. Themes include the evolution of the model, a detailed examination of dependent and independent variables, and expected results of the gravity model specification proposed. The paper concludes that a gravity model can indeed help Ireland to seize green export opportunities.

Chapter 1: Introduction

1.1 Ireland's Renewable Energy Policy Context

Ireland has ambitious policies and targets to reduce its greenhouse gas emissions as part of a global effort to address global warming and climate change (UN environment programme) and avoid the worst impacts of global temperature rises above pre-industrial levels of approximately 1 degree Celsius (Allen *et al.*, 2018).

Ireland's Energy Industries sector had a 14.3% share of Greenhouse Gas (GHG) emissions in 2023 (EPA, 2024). Along with Government policies aiming to reduce these emissions, there are also commercial opportunities stemming from the energy transition. These goals are highlighted in the Climate Action Plan (Government of Ireland, 2024).

Climate action can lead to market opportunities that enable sustainable economic growth and green job creation ... Ireland is well positioned to seize new high-growth green export ... opportunities.

An important part of the energy transition is interconnection. This is particularly important in Ireland, as to allow for exports, there needs to be infrastructure in place to export renewable energy in the form of electricity or hydrogen. Ireland currently has some existing interconnection in place, and there are targets to increase interconnection to the rest of Europe.

The Celtic Interconnector is a planned infrastructure project of common interest, connecting Ireland and France (EirGrid, 2024). After the completion of the interconnector, electricity can be traded between the two countries. The project was awarded over €500m from the European Commission's Connecting Europe Facility and is co-funded by EirGrid and Réseau de Transport d'Electricité. This will be the first interconnector to connect Ireland to mainland Europe. The Celtic Interconnector will give Ireland increased security of supply of electricity and create additional export opportunities for Ireland. The project will help the energy transition, as well as bringing sustainable and affordable energy to consumers.

Ireland has a range of policies in place to enable the energy transition. The 2024 Climate Action Plan refers to the possible economic benefits arising from climate action. The plan also states the opportunity Ireland has regarding green export opportunities. These

policies should be influenced by an understanding of factors influencing expected levels of trade.

Gravity modelling has been used extensively in international trade literature to analyse and estimate the expected level of trade between countries. The gravity model may help by estimating levels of trade, as well as showing which variables and factors have the most effect on trade, which may influence policy. The research question that this paper will aim to answer is, can a gravity model help Ireland to seize green export opportunities? In the past, the gravity model has been used to analyse overall trade between countries, and more recently, trade in renewable energy goods and services. By applying the gravity model, analysis has been conducted to show determinants of trade, as well as showing by how much individual variables affect trade. Examples of past topics for analysis and dependent variables include electricity, renewable energy goods, effectiveness of policies on trade and deviations from expected trade (Bejerano *et al.*, 2019; Kuik *et al.*, 2018; Morgenroth, 2009).

Chapter 2: Literature Review

2.1 What is the Gravity Model?

The gravity model in international trade is used to analyse and estimate trade flows, i.e. imports and exports between countries. As noted by Capoani (2023), much of the relevant literature attributes the proposal and introduction of the model (in an international trade context) to Tinbergen (1962). The model was, in fact, first introduced in that context by Isard (1954). Tinbergen then expanded upon the model, introducing the standard gravity equation. Head and Mayer (2014) detail the evolution of gravity equations, as well as discussions of various estimators proposed for use in the gravity equations.

The model has since become a fundamental model within the international trade sphere, being widely used to analyse and estimate trade between countries generally, as well as for green goods and services, and renewable electricity (Lawless, 2009; Lundmark *et al.*, 2017). The model shows that trade flows can, to an extent, be explained by the size of the origin and destination countries, usually expressed as GDP, as well as the distance between them. The fundamental gravity model, as utilised by Kuik *et al.* (2018: 474), is shown in Equation 1, where:

the trade flow T from country o (origin) to country d (destination) is positively linked to the economic sizes of the two countries (usually expressed in Gross Domestic Product (GDP)), M_o and M_d and negatively linked to the distance between them D_{od} (which refers to geographical distance but also other trade barriers). G is a constant measured by the inverse of the value of world production.

Equation 1

$$T_{o,d} = G \times \frac{M_o^{\beta_1} M_d^{\beta_2}}{D_{od}^{\beta_3}}$$

Although this is the modern form of the model, the gravity model was used much earlier, in relation to the social sciences (see Capoani, 2023 for a summary of the history of the gravity model). Use of the model in relation to migration can be found as far back as the mid-1800s. Since then, there has been a large expansion in the literature, particularly in the last thirty years.

2.2 Why use the Gravity Model?

The gravity model can be used to both analyse and estimate trade flows between countries. It can show the potential enterprise opportunities for future exports, as well as analysing the effects of various factors and how they affect trade. This analysis can help to advise policy decisions. For example, if it was found that higher levels of Research and Development (R&D) lead to higher exports, a policy decision could be made to further invest in R&D.

Referring to the research question, whether a gravity model help can Ireland to seize its green export opportunities, the Climate Action Plan (Government of Ireland, 2024) states that Ireland has an ambition to become a net exporter of green energy. As well as this, current renewable energy policies, such as the 37GW target for offshore wind by 2050, further show this ambition. It is estimated that 11 – 15GW of offshore wind will be required to achieve domestic net zero by 2050 (MaREI, 2023). With current targets, there would be a significant excess of energy that could be exported.

2.3 Intuitive Form of the Gravity Model

Since its origin, many researchers have chosen to use the gravity model in its fundamental form (Equation 1). However, the model has evolved, and it is now popular among researchers to log-linearise the model. This has allowed the model to be run as a linear regression, as well as enabling the estimated coefficients to be read as elasticities (a measure of sensitivity). This is useful, as results can be analysed in percentage terms, making them clear, intuitive, and understandable. An example of this will be shown in an applied section.

When the gravity model was first proposed, the two main explanatory variables were the economic size of countries, as well as the distance between them. In the years since, many new variables have been added to the model, and thus it has expanded and become more sophisticated. This has also led to the evolution of the gravity model equation. As well as this, estimation errors were discovered, and solutions were provided for these.

The modern gravity equation is in a log-linear format. An example can be seen below in equation 2 (Forfás, 2008: 103).

Equation 2

$$\ln x_{xm} = c_{xm} + \beta_1 (\ln GDP_x + \ln GDP_m) + \beta_2 \ln dist_{xm} + \beta_3 lang_{xm} + \beta_4 bord_{xm} + \varepsilon_{xm}$$

Note: the notation in this paper equates the subscript x to the country of origin and subscript m to the destination country. In this equation, the dependent variable x is exports, and c is a constant and ε an error term.

In this example, as well as the standard independent variables of GDP and distance, additional explanatory variables are considered. These are common language, and common border. These are both dummy variables, having a value of 0 or 1.

By transforming the equation to the log-linear format, the results can then be interpreted as elasticities. This allows for an intuitive measure, whereby the results will show what percentage change there will be in trade after a one percent increase in the independent variable. A result from the Forfás (2008) model estimated β_2 to be -0.869. For every one percent increase in distance, trade decreased by 0.869%.

Although the benefits of structuring the model in this way are clear, there were problems associated with this Ordinary Least Squares (OLS) method. Heteroscedasticity was found to be present in OLS estimations, leading to biased results. Santos and Tenreyo (2006) discuss this estimation bias and provide a solution. They propose a PPML (Poisson Pseudo Maximum Likelihood) estimator to be applied to the gravity model OLS regression. This estimator (whose performance was tested using Monte Carlo simulations) is applied to the regression and avoids measurement errors resulting from heteroscedasticity. As well as this, the PPML estimator also accounts for zero-trade flows, which can also lead to inaccurate estimations.

Krisztin and Fischer (2015: 451-470) discuss the advantages of the use of the PPML estimator in gravity model applications, but also note a disadvantage. It is found that when using the PPML estimator, biases may occur if the trade flows are not independent (which is generally not true). To account for this estimation bias, the authors propose 'eigenvector spatial filtering variants of the Poisson gravity model ... along with pseudo ML estimation'.

Ciuriak and Kinjo (2006: 189-197) discuss the lack of consideration for comparative advantage in past gravity model applications. They propose a trade specialisation variable,

designed to capture comparative advantage. The variable is defined by the Trade Specialisation Index, measured as 'net exports in a given sector divided by total two-way trade in that sector. The range of this variable is from 1 if a country only exports in a given sector to -1 if it only imports in that sector.' This additional variable was found to improve the goodness of fit and aided the explanatory powers of the model.

2.4 Limitations and Criticisms of the Gravity Model

The gravity model and the gravity equation face some limitations, as well as criticisms. Crymble (2019) discusses the issues that arise when using the gravity model in a migration context. This is due to the difference in nature between human behaviour and physics. As opposed to the laws of physics, humans with free will make unpredictable decisions.

The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) (2015) also outlines several weaknesses of the gravity model. One weakness discussed is that the gravity model cannot account for how trade flows in country pairs are affected by the trade costs of the third party. As well as this, another weakness of the model is that when estimating trade flows, the absolute trade costs do not matter, but relative trade costs do. A consequence of the two weaknesses detailed above is that the estimations for the OLS standard gravity equation experience omitted variable bias.

Kabir *et al.* (2017: 60-71) also discuss various limitations and criticisms of the gravity model. One criticism detailed is in the application of the model. Methodological issues were noted in numerous examples, such as a gravity model application which did not include panel data characteristics. Also discussed are limitations that arise due to the nature of the data. Gravity models examine data that is cross sectional spread out over a period. This can lead to 'heteroscedasticity, autocorrelation, and heterogeneity. These problems also occur because trade flows between relatively small countries tend to vary less than those between relatively large countries.' The authors summarise other econometric issues, along with solutions, including 'endogeneity; trade or no trade dichotomy and stationary or non-stationary for positive trade flows', and 'multicollinearity and identification problems'.

Chen *et al.* (2022: 271-309) test two Computable General Equilibrium (CGE) models of world trade. The two models tested are a 'classical' model and 'gravity' model. The classical model is the 'Hecksher-Ohlin-Samuelson model of goods and factor markets under perfect competition'. The gravity model 'adopts the same general market structure but imposes gravity assumptions on it, including typically imperfect competition, limited

substitutability across country-source of products, and a link from trade intensity to productivity'. From their analysis, they conclude that the classical model estimated trade levels closer to true values than the gravity model, and they recommend the classical model's use for policy analysis.

2.5 Examples of Applications of the Gravity Model

This section of the paper will discuss previous examples of gravity model applications. Some applications are for general exports, and some are specifically applied to the energy sector.

The *Energy Market Integration and Electricity Trade* paper (Bejerano *et al.*, 2019) is an international example of a gravity model application. The gravity model is used to analyse electricity trade flows, to analyse the effects of Energy Market Integration (EMI) in Europe. At the time of writing, the authors believed this to be the first application of the gravity model to a multi-country analysis of trade in electricity.

The methodology of the empirical analysis applied a gravity model to understand how electricity trade is affected by EMI. A log linearised gravity model equation is proposed. The authors state the estimation error of heteroscedasticity and propose the use of the PPML estimator to account for this. The independent variables chosen in this case include,

- GDP;
- yearly average electricity price;
- dummy variable for whether the countries have an energy integration agreement; and
- distance (controlled for within a set of fixed effects).

Results of the model find that trade significantly increased because of EMI agreements between countries. Although, trade diversion was also observed, with countries involved in EMI agreements trading less with countries without agreements, even if they had the same economic characteristics. By using the gravity model, the authors were able to estimate the effects of the EMI agreements on electricity trade and found that trade increased, a positive effect of the agreements. This result could be used to influence policy actions, showing the usefulness of the gravity model.

Another paper applying the gravity model is *Competitive advantage in the renewable energy industry: evidence from a gravity model* (Kuik *et al.*, 2018: 472-481). This paper

implements the gravity model to analyse the impact of renewable energy support policies on wind and solar PV exports in Europe. The aim of the paper is to ‘empirically estimate the effect of renewable energy support policies on the competitive advantage of domestic manufacturing firms that produce renewable energy technologies.’ The model specification is log-linearised, and once again, the PPML estimator is used to account for heteroscedasticity and zero-trade flows.

Independent variables include:

- GDP;
- a geography variable including distance;
- dummy variables for;
 - common language,
 - past colonial relationship,
 - regional trade agreements, and
 - common borders.
- demand in the destination country; and
- a proxy of the effectiveness of renewable energy policies in the origin country.

Results of the model show that exports of renewable energy components benefit positively from environmental regulation. The estimates also showed that policies promoting renewable energy improved competitive advantage of components in the renewable energy manufacturing industry. Also, it was observed that development of renewable technologies was significantly spurred by demand-pull tariffs, such as feed-in-tariffs.

The two papers mentioned previously focused on electricity and green energy goods as the dependent variable. The following paper *The Gravity Equation in International Trade in Services* (Kimura and Lee, 2006: 92-121) seeks to compare factors affecting both goods and services trade. Again, the paper applies a gravity model to explore these effects.

The specification in this case is also log-linearised. Independent variables include:

- GDP;
- distance;
- remoteness (based on relative distance);
- common border;
- regional trade agreement;
- Economic Freedom of the World (EFW); and
- common language.

The dependent variable included trade flows in both goods and services. Results showed that the gravity model demonstrated more explanatory power (denoted by a higher R^2 value) for services than goods. The model also showed that the distance between countries had more importance for services, rather than goods trade (it is acknowledged that this may be biased due to the services chosen for analysis). In terms of economic freedom, it was found that, 'as countries move toward economic liberalization, services trade will grow faster than goods trade, and hence ... will play an even more important role in the global economy.'

An example of a gravity model applied in an Irish context is *A gravity model approach to estimating the expected volume of north/ south trade* (Morgenroth, 2009). The report, commissioned by InterTrade Ireland, uses a gravity model to analyse the deviation from the expected level of trade for exports between Northern Ireland (NI) and Ireland. The specification was, once again, log linearised. However, as opposed to the PPML estimator, the Hausmann-Taylor estimator was used.

Results of the model show that trade is indeed below expected levels, and that the deviation is growing. It was observed that several of the variables lead to increased levels of trade between NI and Ireland. These include:

- GDP;
- population;
- common border;
- common language; and
- trade agreement.

Longer distances, on the other hand, lead to lower levels of trade. In terms of policy implications, the results stress the importance of removing trade barriers, and promoting trade and business relationships between NI and Ireland.

Explaining Bilateral Trade Flows in Ireland Using a Gravity Model: Empirical Evidence from 2001 – 2011 (Lang, 2014) applies the gravity model in an Irish context, where Ireland is the only origin country, and there are N number of destination countries. The aim of the paper is to examine whether a gravity model can explain bilateral trade flows between Ireland and other countries. Examples of data sources for Ireland are given, many of which are listed in this paper. Independent variables analysed include:

- GDP;
- population;
- distance;
- common official language; and
- colony.

The results show that the gravity model can indeed explain Irish bilateral trade flows. It is noted by the author that the model specification was a basic form of the gravity model, and that future work could include additional variables.

Chapter 3: Proposal for Gravity Model Specification

This section introduces a proposed gravity model specification for the Irish renewable energy sector. This paper does not apply the model, instead, showing what a gravity model used in an Irish context relating to green energy could include. This specification includes a list of independent variables, as well as examples of possible dependent variables. The rationale for the chosen variables will be discussed in detail.

3.1 Approach

There were several steps required to create a gravity model specification for green energy exports in an Irish context. Firstly, extensive research was carried out on past model applications, to both understand the evolution of the model, as well as to compile a list of variables used. As well as this, different estimation techniques were noted. Variables were selected from the larger compilation to be included in the specification. Over 40 variables were compiled, and selection criteria included statistical significance and relevance to the Irish context. Attention was also paid to possible interactions between independent variables for example, regulation and non-tariff barriers.

3.2 Gravity Model Specification

The gravity model specification presented in this paper represents a base model for Irish two-way trade in renewable energy goods and services. The specification places focus on Ireland as the main origin country, with no limit to possible destination countries. Although other countries may be included as origin countries, the specification and independent variables have been collated for an Irish renewable energy context. The independent variables proposed are deemed to be essential for any gravity model used in this context.

The model, as has been done extensively in previous literature, will be log linearised. To account for zero trade flows and heteroscedasticity, the PPML estimator would be applied. The results would be read as elasticities, allowing for an intuitive reading. As well as this, eigenvector spatial filtering would also be applied, as proposed by Krisztin and Fischer (2015).

An additional variable would be added to account for comparative advantage. This variable is the trade specialisation index, proposed by Ciuriak and Kinjo (2006) as discussed previously.

3.3 Independent Variables

This paper proposes 12 independent variables that are essential for a gravity model of green energy in an Irish context. The variables can be seen in Table 1, grouped into two categories.

Table 1: Independent (Explanatory) Variables

Amenable to Policy Action	Less or Not Amenable to Policy Action
Trade Agreements	GNI* of exporting country
Tariff and non-tariff barriers	GDP of importing country
Regulation (environmental strictness)	Distance
Demand in destination country	Population
Research and development (R&D)	Common Language
	Common Currency
	Landlocked or an island

The results of the model will show by how much each variable affects trade in renewable energy goods and services. This information could be used to inform policy. Variables that are amenable to policy action are more easily changed than those less or not amenable to policy action. For example, policymakers can readily change tariffs. However, it is not possible to change population size or language in order to realise trade policy aims.

3.4 Criteria for Selecting Variables

A list was compiled of the variables used in many gravity model applications (including Forfás, 2008; Kuick *et al.*, 2018; Morgenroth, 2009). Part of the criteria for the selection of the independent variables for this gravity model specification included frequency. Most of the variables were seen in more than one application. Statistical significance was also a factor in the selection. Most of the variables were found to be statistically significant for explaining the dependent variable (usually trade flows). Some independent variables added to this specification had been found to not be statistically significant in some literature. However, they are included as they may be relevant and significant in an Irish context. In some cases, such as R&D, previous theories and arguments were analysed and were also considered in the selection process. This is not intended to be an exhaustive list of all potential explanatory variables.

The reason behind the choice for each variable will now be discussed.

3.5 Amenable to Policy Action

The estimation results from a gravity model can inform policy action to help support economic activity and the related benefits. Policy action in response to the results can be less challenging in relation to some factors than others. This section outlines some of the factors that are more amenable to policy action.

Trade Agreements

This variable is a dummy variable (has a value of 0 or 1), for whether a trade agreement is present between country pairs or not. For example, the variable may take a value of one if the destination country is a member of the EU or has another form of trade agreement with Ireland (as Ireland is a member of the EU). The variable may also take a value of 1 if the EU has a trade agreement with another country or bloc.

Trade agreements between other countries and blocs (excluding Ireland) may also have an impact on Irish trade. For instance, countries within other trading blocs (such as the Association of Southeast Asian Nations (ASEAN)) are more likely to trade with each other than with countries outside of the bloc. As well as this, more trade is expected between Ireland and countries that have preferential trade agreements with the EU, and less trade is expected between Ireland and countries without preferential trade agreements.

Morgenroth (2009) finds in his model estimation that trade largely increased in the presence of a trade agreement (except for the fuel sector). The World Bank Group (2018) also state that trade agreements can increase international trade. The model may

estimate the extent to which this membership and other agreements affect Irish green energy exports.

Tariff and non-tariff barriers

Tariff and non-tariff barriers have been included to encompass both goods and services. If there are tariffs present in the destination country, exports to that country will decrease, due to higher import costs, and a loss of competitiveness (International Trade Council, 2022). Tariffs may also affect services trade if a good and service are complementary, and a tariff is placed on the good. Non-tariff barriers can affect levels of exports for both goods and services. If non-tariff barriers are present in the destination country, exports to that country will be lower.

Regulation (environmental strictness)

The Porter hypothesis theorises that higher levels of environmental regulation lead to a higher competitive advantage by 'stimulating and upgrading domestic demand' (Porter, 1990). Higher regulation encourages innovation, as well as requiring firms to adhere to strict standards for safety, environmental impact and product quality. Groba (2017) finds strong evidence for the Porter hypothesis in relation to solar energy technology components.

Demand in destination country

If the demand in the destination country falls, exports will decrease. This variable is important to include to increase the explanatory power of the model.

Research and Development

Grossman and Helpman (1994) show that research and development (R&D) subsidies increase levels of innovation when the market equilibrium leads to slow technological growth. Groba (2017) discusses how exports may be directly affected by R&D budgets.

3.6 Less or Not Amenable to Policy Action

The estimations from these variables can also inform policy but may be less or not amenable to action as those described in the section above.

GNI of exporting country*

This variable is included as one of the fundamental gravity model equation variables, although it has been altered. As Ireland is the main origin country proposed for this specification, GNI* star has been used instead of GDP (which is the widely used measure in gravity model literature), because Irish GDP overstates the size of the domestic economy. 'Modified GNI (GNI*) is an indicator that was recommended by the Economic Statistics Review Group and is designed to exclude globalisation effects that are disproportionately impacting the measurement of the size of the Irish economy (CSO, 2022).'

GDP of importing country

This variable is included as one of the fundamental gravity model equation variables.

Distance

This variable is included as one of the fundamental gravity model equation variables.

Population

This variable has been included as another measure of mass.

Common language

A dummy variable with a value of 0 or 1 to include the presence (or lack of) a common language. Results from a meta-analysis conducted by Egger and Lassmann (2011) found that there was a 44% increase in trade because of the existence of a common language.

Common currency

A dummy variable with a value of 0 or 1 to include the presence (or lack of) a common currency. Vicquéry (2021) shows a large positive impact of a common currency on trade.

Landlocked or located on an island

'Landlocked countries tend to trade less while islands tend to trade more (Morgenroth, 2009: 12).'

 This variable is relevant to Ireland, as an island. This variable would be interesting to estimate, particularly for services, where there may be a different result, due to digitalisation.

3.7 Dependent Variables – Potential Candidates for Inclusion in an Irish Gravity Model

This section discusses examples of dependent variables in the application of this gravity model specification. Some variables include goods and services that Ireland is currently exporting, and where there may be a competitive advantage. Also mentioned are goods that may have an advantage and export opportunity in the future. The rationale for the inclusion of the examples will be discussed.

Before presenting examples of current and future opportunities, some previous dependent variables applied in gravity model literature are listed (Groba, 2017; Bejerano *et al.*, 2019; Kuik *et al.* 2018):

- Bilateral export flows in solar energy technologies.
- Energy flow between origin and destination country in year t .
- Bilateral export flows for wind goods from origin to destination country at time t .
- Bilateral export flows for solar PV goods from origin to destination country at time t .

3.7.1 Current Opportunities

The level of data needed to carry out a gravity model application varies depending on the context, and dependent variable to be estimated. Context includes the proposed research question, the goal of the research being undertaken, and the sector(s) being examined. Data is also more readily available for some variables as opposed to others. Data availability also varies between countries. For several of the independent variables that are dummy variables, only basic data is needed. For other variables, the data required may be more complex. Thus, the availability of data influences which goods and services, as well as renewable electricity can be estimated currently, using this gravity model specification. For some goods or services there may be no data available. There are also several export opportunities highlighted by the Government of Ireland that are not, or only partially, developed.

While it may be difficult to predict future enterprise opportunities, it is likely that there are specific goods and services with greater export potential as part of Ireland's energy transition, which may be pointed to now to help inform policy. Some examples are presented below, but it is noted that this is not intended to be an exhaustive list of sectors with potential. These are in addition to the export of electricity itself (something which can be considered neither a good nor a service – see Polanyi, 1944; Christophers,

2024). Although green energy goods and renewable electricity may be theoretically distinct, this is often not the case for the data. The CSO presents data for electric current exports under goods (SITC code 35 – Revision 4) (CSO, 2024).

In terms of green goods, there are several opportunities that may exist currently, making them also good potential candidates for dependent variables in any gravity model (see Forfás, 2009; SEAI, 2014 for more detail):

- The technology (hardware and software) associated with renewable energy systems (solar, CHP, wind, heat pumps, etc.) given the strong ICT capabilities of Ireland. Examples of HS codes for these goods were compiled by Kuik *et al.* (2018).
- wind energy infrastructure components/ engineering (e.g. foundations, gearboxes, etc.);
- electricity transmission grid infrastructure components/ engineering; and
- LiDAR Buoy

The floating LiDAR buoy measures and collects various types of data offshore (Green Rebel, 2024) including:

- wind speed;
- wave height and direction; and
- climate.

The data collected can be used in the development of offshore wind farms.

Although the data for trade in green energy services may not be readily available, or available at all, some examples are listed below of other potential candidates for dependent variables in any gravity model (see Forfás, 2009; SEAI, 2014 for more detail):

- eco-construction;
- energy management/ efficiency services, energy management consultancy;
- anaerobic digestion;
- design, build, and install of combined heat and power systems;
- waste-to-energy services; and
- environmental consultancy (e.g. carbon offsetting, energy audits, environmental impact assessments, integrated pollution prevention and control (IPPC) licensing, and energy retrofitting services etc.). The CPC, Version 1.0 code for this service is 83131 (United Nations, 2002).

3.7.2 Future Opportunities

Electricity

As mentioned previously, there has been an emphasis on the goal of electricity exportation in renewable energy policies in Ireland. This can be seen in the significant 37GW target for offshore wind, as well as the development of the Celtic Interconnector. The National Policy Statement on Electricity Interconnection (Government of Ireland, 2023a: 2) states that one of the ‘primary drivers of Ireland’s interconnectivity needs are ... creating the necessary export opportunities to match the State’s growing renewable energy generation capacity’. This statement shows the intention of the Irish Government to use the excess energy capacity generated, once domestic net zero is achieved, as an export opportunity. The Policy Statement also considers other possible future interconnections to Europe. This includes interconnection to Spain, Belgium and the Netherlands, as well as further interconnection to Great Britain. Interconnection is necessary for both green electricity and hydrogen.

Green Hydrogen

Green hydrogen export opportunities are directly linked with the deployment of offshore renewable energy. The National Hydrogen Strategy (Government of Ireland, 2023b) discusses the Irish Government’s vision for green hydrogen’s use in hard to decarbonise sectors. There is also a potential for Ireland to export green electricity resulting from our potential capacity. The excess hydrogen could be exported, and as discussed in the strategy, this could have many benefits for domestic hydrogen development. Economies of scale would allow for reduced production costs, which would allow the hydrogen to be more competitive. As well as this, there may also be an increase in high skilled jobs and economic growth because of domestic hydrogen development. A gravity model could be used to explain the possible opportunities of hydrogen exports.

3.8 Expected Results

From previous gravity model research, as well as general economic theory, this section will detail what the expected results in the model would look like. General expected results for each of the independent variables are provided. Results may be similar for different dependent variables, although depending on the type of export (good, service, electricity) estimations may be more variable. For example, distance may have less of an effect on trade in energy management consultancy, (for example, if the service is provided digitally) than for electricity, which relies on interconnection.

- Regional trade agreements are expected to bring increased levels of trade.
- Tariffs are expected to decrease trade from Ireland, with non-tariff barriers also expected to decrease trade. This is due to increased costs and a resulting loss of competitiveness, thus less demand in importing countries.
- Higher levels of regulation (more environmental strictness) as theorised by the Porter hypothesis, are expected to lead to more competitive advantage, and better trade performance.
- If demand in the destination country is low, trade will worsen. On the other hand, if demand in the importing country is high, there will be higher levels of trade.
- Higher levels of R&D subsidies are expected to improve competitiveness and increase trade levels.
- Higher GNI* in Ireland is expected to lead to higher trade, as in the standard gravity model equation. Higher GDP is expected to lead to higher levels of trade, with GNI* used for Ireland and GDP used for destination countries.
- Longer distances are expected to lead to lower levels of trade, as in the standard gravity model equation.
- Trade is expected to increase to countries where populations are larger. As discussed by Morgenroth (2009: 12), 'countries with larger GDP have more goods to trade and greater demand for goods to import'.
- Common language is expected to increase levels of trade.
- Common currency is expected to increase levels of trade.
- As an island, Ireland is expected to trade more. Other island countries are also expected to trade more, while landlocked countries are expected to trade less.

3.9 Data Sources

Table 2 includes a list of data sources that may be used to gather data for carrying out the gravity model specification. The list is not exhaustive, and data may not always be readily available for Ireland. The table is a simplified version of a table in '*An Advanced Guide to Trade Policy Analysis*' (Yotov *et al.* 2016). The data sources have been grouped, as in the book.

Table 2: List of Data Sources

Data	Database	Link
Country- specific data	IFS	http://www.rug.nl/research/ggdc/data/pwt
	PWT	Groningen Growth and Development Centre | University of Groningen (rug.nl)
Disaggregated merchandise trade	Comtrade	UN Comtrade
	BACI	CEPII - Gravity
	Trade Map	Trade Map - Trade statistics for international business development
Service Trade Flows	OECDs Trade in Services	OECD Data Explorer - Archive • EBOPS 2002 - Trade in services by partner country
	Francois and Pindyuk's Trade in Service	Consolidated Data on International Trade in Services (repec.org)
Tariff Data	IDB/ CTS	Welcome to TAO - Tariff Analysis Online facility provided by WTO
	TRAINS	UNCTAD - Trade Analysis Information System (TRAINS) | DataBank (worldbank.org)
	I-TIP	WTO | Integrated Trade Intelligence Portal (I-TIP)
Technical barriers to trade (TBT)	TBT-IMS	http://tbtime.wto.org/
Service trade restrictiveness index (STRI)	World Bank's STRI	http://i-tip.wto.org/services/default.aspx
Preferential and regional trade agreements	RTA-IS	WTO | Regional trade agreements
	Larch's RTA	RTA-Data (uni-bayreuth.de)

Chapter 4: Policy Recommendations and Risks

4.1 Policy Recommendations

A significant benefit of the gravity model is its ability to show which variables affect trade flows, and the magnitude of the impact. If a model is carried out based on the specification suggested in this paper, evidence-based policy recommendations may then be made. By applying the model specification, export opportunities may be highlighted as well as analysed and estimated. This in turn would inform policy, enabling Ireland to seize green export opportunities.

Within gravity model literature, there are several results that have been commonly found. Policy action may take place before achieving actual results, where literature shows strong evidence of results. Individual firms may also act based on previous results.

For example, it is expected that increased renewable energy exports arise from countries with higher levels of environmental regulation. Policymakers may increase regulation to not only achieve renewable energy targets, but also to increase competitiveness and stoke innovation in firms. This could lead to Irish green energy firms having competitive advantage, and thus increasing their export opportunities.

The gravity model may be used for a wide range of goods and services, as well as for electricity. This specification has included twelve independent variables to try to explain as much of the dependent variable as possible. Results will vary with different dependent variables.

4.2 Risks

There are several risks associated with the future opportunities of green energy exports. These risks include:

- lack of demand in destination country;
- interconnection;
- lack of investment;
- skills gap; and
- Foreign Direct Investment (FDI) profit destination.

A lack of demand in destination countries may impact export opportunities. For example, although there is a target to export electricity produced from renewable sources, once the supply is created, there may not be sufficient demand for the electricity. This may be due to several reasons, such as a lack of competitiveness or a lack of consumer demand. For example, why would Spain import Irish electricity when it could import from a closer neighbour? This challenge highlights the need for competitive electricity exports. These factors are difficult to predict. In this case, predictions are more challenging as the supply goals are not set to be completed for over fifteen years. The same risk is present for other goods such as green hydrogen and sustainable aviation fuel.

Interconnection is another challenge that Ireland may face, especially as an island country. Although the Celtic Interconnector is under construction, Ireland still has very little interconnection for electricity exports. Although there is interconnection to the United Kingdom, wider interconnection to mainland Europe will likely not be available in the near-term.

A lack of investment in green energy products is also a major risk. For example, there is a medium risk (that would incur a medium level impact) that 'Ireland struggles to secure investment in floating wind construction ports as envisaged in deployment scenarios, holding back floating offshore wind deployment' (BVG Associates, 2024: 74).

A skills gap may also pose a risk to developments. For example, there may not be enough workers with the required skills for the construction of offshore wind farms. These workers may have to be imported from elsewhere.

The final risk that will be discussed relates to a lack of available financing. If offshore renewable energy development opportunities are commercially viable, then it is likely that foreign investors will fund such opportunities. However, additional financing is required for the development of the associated grid and port infrastructure, as well as the electrolysis facilities required for hydrogen production. Given the substantial level of financing required, it may be necessary to obtain financing from the EU or to collaborate with other countries that may also benefit from the development of the sectors (e.g. Projects of Common Interest).

Chapter 5: Conclusion

This paper has addressed the question of whether a gravity model can help Ireland to identify and seize green export opportunities. To answer this question, the paper presented a detailed literature review, which included an explanation of the gravity model, including its history, modern form, estimators, and criticisms of the model.

Current renewable energy policies in Ireland were also detailed. Several examples of applications of the gravity model were also examined.

A gravity model specification was then proposed. This specification is intended for use relating to green energy exports from Ireland. A detailed discussion of the variables used, as well as a sample of data sources were included. Several examples for possible dependent variables were given.

Following this, the next section discussed expected results for the model, detailing expectations for each independent variable. These expectations were estimated from general theories as well as the results from several gravity model applications. Several policy recommendations were given, and finally, the risks associated with current policies and goals were considered.

The proposed specification is intended for any gravity model analysis for green energy goods, services and renewable electricity exports in an Irish context. It is argued that each of the variables chosen are essential for any gravity model in this context. Independent variables selected for the specification include levels of regulation, demand in the destination country and the presence of a common language. The selection criteria for the variables were discussed, which included theoretical foundations, as well as statistically significant results from previous gravity model applications. Some variables were adjusted, due to the specification being designed for use in an Irish context. For example, it was found that for Ireland, GNI* is a better measure of economy size than GDP, a key variable in every gravity model.

From this exploratory analysis, a gravity model could indeed help Ireland to seize its green export opportunities. With its predictive and explanatory power, export opportunities can not only be predicted, but analysed. The model would show where there is the highest

opportunity, and the explanatory variables can be analysed individually, to see which variables affect the chosen dependent variable the most.

As well as analysing future exports, this gravity model specification has the potential to predict future imports to Ireland in key green technologies. Technologies may include wind turbines, electric vehicles and solar panels.

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