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Stakeholder outcomes in a wind turbine investment; is the Irish energy policy effective in reducing GHG emissions by promoting small-scale embedded turbines in SME’s?

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Abstract

As a member state of the European Union (EU), Ireland has adopted an energy policy which includes promoting wind powered electricity generators as an economically viable, GHG-reducing, alternative to environmentally damaging fossil-fuel driven electrical generators. This longitudinal, inductive in-depth study investigates the outcomes for the government and other stakeholders involved in a wind turbine project investment by a Small-to-Medium-Enterprise (SME) based in rural Ireland. A case study research methodology is used to acquire and analyse quantitative numerical data from multiple sources including electrical power and energy meters, historical electricity bills and company sustainability reports. The study found that the installation of this wind turbine did not contribute significantly to the EU-binding Green-House-Gas (GHG) national emissions targets. The research uncovered weaknesses in the sustainability reporting mechanism. The numbers of kWh energy units thought to have been produced by the wind turbine were overstated and this error went undetected by all of the stakeholders involved in this venture. This exploratory study will be of benefit to all stakeholders, including the national government who are promoting wind energy as a major player in the overall energy policy as they target a reduction of Green-House-Gas emissions.

1. Introduction

This research is conducted within the stakeholder theoretical framework. Stakeholder theory holds that business activity affects not only the people who have capital invested in the business and desire a profitable return on that investment, but its activities also has an effect on interested parties including its employees, customers, competitors, suppliers, government, and media. Stakeholder theory is an integral part of Corporate Social Responsibility (CSR) as claimed by Agudo-Valiente et al. [1]. Holme and Watts [2] define CSR as a continuing commitment by businesses to economic development while improving the quality of life of the workforce and their families as well as of the local community and society at large. Stakeholder theory is further developed for a long-term perspective in Sustainable Development [3]. Research by Hansen et al. [4] found that sustainability management and CSR have become closely integrated. Sustainability management in businesses must account for financial, human, and environmental issues. Elkington [5] identifies these discrete elements as the 3-P’s (Profit, People, and Planet). Kealy [6] claims that these discrete components are interconnected; if one element is weak then it brings down and impedes the overall development of the business. This research focuses on one specific aspect of CSR, namely the environment, and more concisely one aspect of the environment, namely climate change. It is alleged by many scientists that the climate is changing at a dangerous pace with, among other things, an increase in global temperatures that could have catastrophic effect on the peoples of the world in the not-too-distant future. It is claimed that the phenomenon of global warming is partly due to the emission of greenhouse gases into the atmosphere by the burning of fossil fuels (gas, oil, coal) to power electricity generators. It is therefore incumbent on society, with the help of governments, to develop alternative renewable sources of energy to reduce the dependence on fossil fuels. It is in this context that wind energy generators are promoted as having the potential to contribute positively to the seemingly unsustainable global energy situation. However, there is little empirical evidence that wind energy...
initiatives are having a profound effect on renewable energy targets. This research into a wind turbine installation by a Small-Medium-Enterprise (SME) as part of their CSR initiatives will help to assess the Irish government policy as they aim to reduce the legally binding EU emission targets, which may be very costly if these targets are not achieved.

2. Literature review

2.1. Stakeholder theoretical framework

Increasing awareness surrounding the social responsibility of businesses would appear in part to be driven by three factors, changed customer expectations, more regulation (EU and National) and stakeholder pressure [4]. The broad-ranging stakeholder theory appears to have replaced the narrow-focused classical shareholder theory. Stakeholder theory holds that the purpose of a business is to provide return of investment for shareholders and increase the wealth of investors who risk capital in the business. Milton Friedman [7] famously stated that the only social responsibility of business is to ‘use its resources and engage in activities designed to increase its profits as long as it stays within the rules of the game’. There have been other shareholder theory protagonists since then [8] who question the role of CSR in business activity, but the majority of businesses appear to have embraced the fact that measuring their success on a single bottom line of profit alone will not sustain the company into the future [9]. Stakeholder theory argues that businesses do not solely have to consider the interests of shareholders, but to also account for other parties having a ‘stake’ in the decision-making of the business [10]. Other parties in this context include employees, customers, competitors, investors, and suppliers (primary stakeholder) and governments, interest groups and media (secondary stakeholders). This importance of consideration of all stakeholders has in part been driven by social media and the internet age empowering consumers and the general public with our instant awareness of sloppy practices by corporations in (un)sustainable business activities. One such example is the Volkswagen (VW) scandal in 2015 whereby the large car manufacturer declared that it had understated the levels of carbon dioxide emissions in up to 800,000 cars sold in Europe [11]. The challenge for the company now is dealing with the backlash from the public as it tries to reclaim trust and renew its dented public relations (PR) image. Stakeholder theory is an integral part of CSR [1]. Stakeholder theory is then developed for a long-term perspective in Sustainable Development [3]. Indeed, Hansen et al. [4] found that sustainability management and CSR have become closely integrated. Indeed some would argue that stakeholder theory origins may be linked to the spiritual sphere and religion have distinctive and different approaches to understanding reality, it can be fruitful to both to enter into intense dialogue in the move towards an integral ecology and the full development of humanity [12, Ch 2, 62].

2.2. Corporate social responsibility (CSR)

There are many definitions of CSR [13] however the one used by Holme and Watts [2] is used in this research. They declare that ‘Corporate Social Responsibility is the continuing commitment by businesses to behave ethically and contribute to economic development while improving the quality of life of the workforce and their families as well as of the local community and society at large’. Bolis et al. [14] add to this declaration by suggesting that even though Sustainable Development and CSR are distinct segments, they are strongly related and can be used interchangeably.

2.3. Sustainable development

In the business community, it appears that the term ‘sustainable development’ is ‘nebulous and contested’ as stated by Sandelands and Hoffman [15] with a general acceptance that the more familiar Corporate Social Responsibility (CSR) term falls under the remit of sustainable development [6]. Sustainable development is defined by the Bruntland Commission in 1987 as ‘Development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (http://www.un.org). Research by Hansen et al. [4] found that sustainability management and CSR have become closely integrated. The authors claim that businesses have sensed the increased importance of environmental, social and ethical issues. Both the financial and non-financial segments of business management are shown in Fig. 1. Of the three discrete segments (the 3-P’s, People, Profit, Planet, Elkington [5]), financial reporting is the most established entity. The financial report gives periodic (quarterly, half-yearly or annually) details of the financial activities and position of a business. The other two non-financial (human and environment) reporting frameworks are less well established [16]. Kealy [6] found that all three elements in Fig. 1 are interconnected and a failing in any one of the circle elements affects the outcomes of the entire model. In the context of this piece of research, it means that an investment by a corporation in a wind turbine project must be sound financially, environmentally and beneficial for all the people involved in the investment. This research investigates the effectiveness of a wind turbine
investment in contributing in a positive manner to the Environment (green) part of their CSR activities depicted in Fig. 1. The wind turbine is expected to reduce GHG emissions by displacing electrical energy units normally supplied by fossil-fuel burning generators. It must be remembered however, that wind power output is variable and when business owners/investors are considering appropriate wind turbine size and technology, it is useful to have information regarding estimates of resulting wind turbine variability [17]. This research aims to inform interested parties in this regard.

2.4. The environment

There are a number of pressing environmental issues currently needing attention on a global scale, among which are resource depletion, climate change, environmental degradation, and pollution. The singular issue which though has grabbed most recent media and government attention appears to be climate change. However, despite the growing institutional, human, financial, and scientific resources made available nationally and globally in the fight against climate change, such as the €280,000 capital investment by the SME in this case study, GHG emission continues to rise at an unacceptable rate [18]. Androde and Puppim de Oliveira [19] suggest several factors that may explain the failure in the process of reducing emissions, one of which is the lack of implementation and effectiveness of the global climate and energy governance regimes. Governance of the climate change initiatives is generally of a non-regulatory manner and it is left up to each corporation (and each Nation) to report on a voluntary basis stating their non-financial aspects of its operations. Prado-Lorenzo and Garcia-Sanchez [20] suggest that as the triple-bottom-line (TPL) reporting framework of the three aspects (People, Profit, and Planet) has a voluntary nature, it could be targeted at other business objectives. The authors claim that, as the production of these TPL reports create significant costs, it may be logical to expect the companies to search for positive effects, other than just concealing their less appropriate practises in the field of sustainability. The effectiveness of such energy governance regimes in an Irish context are discussed in this study.

2.5. Climate change

The increase in the average temperature of the Earth’s climate system is termed global warming. The dominant neoclassical business growth model has put pressure on our vast but finite, natural resources. Traditionally, most of the electrical energy purchased by businesses was generated using fossil-fuel (oil, coal, or gas) driven generators but it is now widely accepted that the Greenhouse Gas (GHG) emissions, due to the burning of fossil fuels, contribute to the phenomenon of global warming. It is therefore incumbent on business, from a corporate citizenship point-of-view and a public relations (PR) point-of-view that corporations endeavour to be responsible global citizens by embracing technologies that will reduce their dependency on fossil-fuel technology [21]. The area of GHG emissions is a major political issue gaining attention on a global platform [22]. Boiral et al. [23] claim that social pressure to reduce GHG emissions are one of the main determinants or businesses commitment to climate change. Faced with increasing pressure from stakeholders, companies feel the need to disclose information on climate performance and GHG emissions in order to legitimise their industrial activities [24]. A common method of disclosing information on climate change is through sustainability reporting [25]. Sustainability reporting gives information on the non-financial aspects of the business operations, including the effect that their operations are having on the natural environment. It is anticipated that by seeking alternative, renewable, energy sources to generate electrical power required in the business and thereby displacing the amount of fossil-fuel driven CO₂ emissions, the effect will be to slow down the phenomenon of global warming.

2.6. Alternative energy systems

This research focuses on one specific aspect of CSR, namely the environment, and more concisely one aspect of the environment, namely climate change. It focuses on how alternative energy systems can help in the battle against climate change by reducing harmful GHG emissions. Alternative energy systems include Solar PV panels, Hydro-electric, Biomass, and Wind turbines. This case study focuses on a wind turbine installation. The wind turbine strategic investment by the participant SME is in response to Irelands’ initiative to comply with the EU Directive 2009/28/EC which mandates the levels of renewable energy use within each member state. The Directive sets a target for Ireland of a 16% share of energy from renewable sources in its gross final consumption of energy by 2020. Failure to reach this binding EU target may result in large fines being imposed on the Irish government. A breakdown of this EU overall target of 16% shows that 40% of electricity generation is due to come from renewable sources, this currently stands at 22.7% [26]. Irish government energy policy has prompted recent intense activity in wind turbine proposals and installations, in the hope that wind will be a large contributing factor in reaching that 40% target.

2.7. Wind energy

In recent years, many Small-to-Medium-Enterprises (SME) have installed on-site embedded/autoproducing wind turbines in response to government energy policy to encourage businesses to supply some or all, of their electrical energy requirements. These renewable energy initiatives appear to be environmentally-friendly alternatives to fossil-fuel burning electrical power turbines. The burning of fossil-fuel sources (coal, oil and gas) are generally considered to be contributing to the phenomenon of ‘global warming’ which can have catastrophic effects on the world’s population. However, there is little empirical evidence to suggest that wind turbines are having the desired effect on reducing GHG emissions by reducing fossil-fuel powered energy requirements in SME installations. A second major advantage of embracing indigenous renewable energy sources is to help in reducing the country’s dependence on imported fossil fuel. A November 2015 report ‘Energy in Ireland 1990–2014’ commissioned by the Sustainable Energy Authority of Ireland (SEAI) [26] claims that while there was a modest reduction in overall energy use by 0.5% in 2014, Ireland still had an import dependency of 85% in 2014, costing €5.7 billion. According to Eurostat, the European Union’s official statistics body, only Malta, Luxembourg, and Cyprus fared worse in terms of imported energy dependency in 2014. The UK had an imported energy dependency of 45.5%, below the European average of 53.4%. The final consumption of electricity in Ireland in 2014 was almost static on the previous year at 24.14 TWh’s with a 0.7% reduction in the fuel inputs. The final electricity consumption figures were sourced from data provided by the Commission for Energy Regulation (CER). As part of its role, the CER jointly regulates the all-Ireland
wholesale Single Electricity Market (SEM) with the utility regulator in Belfast. Their data is collected from the retail market reports published by the 7 current active suppliers in the electricity retail business and domestic markets. A 6-year summary of final electricity consumption was:

- 24.14 TWh (2014)
- 24.2 TWh (2013)
- 24.2 TWh (2012)
- 24.9 TWh (2011)
- 25.4 TWh (2010)
- 25.3 TWh (2009)

The share of electricity generated by wind in 2013 was 16.4%. This is calculated according to EU Directive 2009/28/EC and includes normalisation rules for wind. The EU Directive states that electricity form wind (and hydro) needs to be normalised to smooth out the effects of annual variations. Normalised generation is calculated using the weighted average load factor over the last five years for wind. In 2014 wind generation accounted for just 18.2% of electricity generated despite the increase in the number of wind turbine installations. The installed capacity of wind generation reached 2.211 GW by the end of 2014 and also there was 0.224 GW of wind generation installed in 2015 (approximately 2.4 GW of wind energy generation capacity at the end of 2015) and a further 1.027 GW contracted by the end of 2016. The overall share of fossil-fuels used in electricity generation was 80.8% in 2014, down modestly from 82.6% in 2013. The total power output of connected fossil-fuel driven generators is approximately 6.23 GW of electrical power [27]. Taking these figures into account, it would appear that it is not unreasonable to expect more substantial savings and benefits considering the increased Irish policy initiatives for wind technology currently being experienced in Ireland. A lack of empirical data on the effect of short-duration wind variation may contribute to the conflict between estimated benefits of wind turbine generated power and actual benefits. A predicted financial appraisal by Kose et al. [28] of a 6 MW wind farm claimed to have a payback period (PP) of 6.44 years but this value was calculated using modelled data and may or may not be wholly accurate. Empirical research by Kealy [29] on a 10 kW three-phase wind turbine found a payback period of 23 years using real data read on-site from the turbine output indicator. This actual data calculation is in contrast to many predicted calculations so caution needs to be applied when SME’s are embracing wind turbines for CSR purposes. In fact, in that research the owner of the wind turbine did not see any significant reduction in the amount of imported energy units, kWh’s, after the turbine was installed [29]. Another empirical piece of research by Kealy et al. [30] investigated the output of a 3.5 MW wind farm in Ireland and found satisfactory outcomes in terms of the capacity factor and the number of kWh units produced annually. However, the annual kWh energy output from the wind farm, 9,808,318 kW h’s, were metered digitally and fed directly into the National Grid (38 kV Sub-station) and there was no further independent research to find out of this amount actually displaced the number of kWh units from traditional fossil-fuel sources. This lack of empirical research is worrying and is stifling intellectual debate on the issue. It may be that currently in the national, Irish, narrative, there appears to be a ‘lack of intellectualism’ and a significant ‘group-think’ approach on many issues within Irish society [31], this may possibly be a restricting factor in the debate surrounding the wind energy industry. While influential organisations promote debate, surely more detailed, independent, research needs to be carried instead of calls for ‘consensus-seeking’ conversations and listing corporations who have spent millions of Euro investing in wind turbine projects [32] without an appraisal of these projects. Independent research is needed to make claims about turbine installations and this research can contribute to that debate.

Types of Wind Energy Systems: One of the problems associated with wind generated power is the random nature of the power output due to the random nature of wind speed and direction. The output power variations are a function of short-term wind speed variations [33]. Long duration wind variations cause problems e.g. congestion and reliability of the system, for the network operators who can put in place established strategies like generation forecasters, dispatch and contingency analysis, and real-time control. Long duration wind variations are generally in the hour or half-hour time frames. By contrast, turbulence and gusts are examples of short duration wind variations, variations in the wind velocity from 10-min averages, the effects of which are more difficult to observe. Research by Roy [34] sought to estimate the standard deviation of power output by a wind turbine generator in the presence of short duration wind variations. The author uses the two-parameter Weibull statistics as a description for wind variations around stable mean values. The Weibull probability distribution function uses the quadratic relationship between wind power and wind speed. The short duration output power and the output power variability are estimated using the generally available turbulence intensity measure. Turbulence intensity is the ratio of the wind speed standard deviation to the mean wind speed, determined from the same set of measured data samples and taken over a specified period of time (I.S. EN 61400-1: 2005). Research by Lin et al. [35] sought to quantify these variations in wind turbine power output using field-measured wind power output data, the data being obtained using 1-min average data. Four different types of wind generators were analysed in the research by Lin et al. [35]:

- Type 1: Induction Generator with fixed rotor resistance, fixed speed
- Type 2: Induction Generators with variable rotor resistance, variable speed
- Type 3: Double-Fed-Induction-Generators (DFIG)
- Type 4: Generators with full power converters

Interestingly research by Boutsika and Santoso [17] conclude by stating that the DFIG type of wind turbine (Type 3) has room for improvement when assessing wind power variability, and a full power converter (Type 4) may be a better option.

3. Methodology

3.1. Case study methodology

A case study methodology was chosen on this singular business entity because it was felt that it allowed the researcher to investigate the case in depth and within its real-world context while making use of the researchers’ technical and business background/experience (Electrician, B. Eng in Electronic Engineering, and PG Dip in Management and Marketing) in order to collect the data safely and accurately for the study. The single business case study is selected because it was also felt that it
reflects many socially-responsible SME’s in Ireland and it pro-
vided the researcher with an opportunity to observe and analyse
the effect on stakeholders of investing in a 300 kW on-site wind
turbine. The Small-Medium-Enterprise (SME) upon which this
research is based had undertaken to participate in sustainability
initiatives and as part of their CSR efforts have installed a 300 kW
wind turbine at a capital cost of €280,000. Quantitative methods
were used to collect and analyse the numerical data over a
protracted period of time. The resulting data is presented using
tables and graphs, and statistically analysed to describe the
central tendency and the dispersion of the data. The Microsoft
Excel and IBM SPSS Statistics software is used for data analysis. In
order to ensure rigor in this case study, data was gathered from
multiple sources. This data includes company sustainability re-
ports, electricity utility bills, digital meter indicators and
analogue (Rotating Disc) meter indicators. The evaluation of the
evidence from these multiple sources is triangulated to confirm
and corroborate the findings. Reliability of the data is assured by
measuring the power output from the turbine on a number of
site visits incorporating a range of wind speeds. The instrument
used to measure power output is a new high-quality instrument.
Measurement validity is assured as the measuring instrument
(Fluke 1735 Power Logger) is designed to measure power
flow and quality on a range of electrical systems. Reliability of the
Rotating Disc Meter (RDM) was tested before and after the in-
strument was connected to the turbine. The RDM was connected
on an electrical system with a sealed calibrated fixed utility
meter (Fig. A1) and the results compared. The RDM consistently
showed a 98% accuracy rate when validated with the Electricity
Supply Board (ESB) meter reading.

The SME upon which this case study is carried out is based in
rural Ireland. It operates in the food industry and the company
has grown significantly since its inception in the late 1970’s. Full
access to all areas was permitted to the researcher during the
data collection stage. A number of site visits were carried out
over a protracted period of time. On each visit, energy meter
readings from the digital meter and the electromechanical
rotating disc meter were noted and recorded while on five
particular site visits relevant data was collected using the Fluke
Power Logger.

3.2. Instrumentation

The Fluke 1735 Power Logger is used to obtain quantitative data
relevant to the power output of the turbine. The Power Log Version
V4.3.1 software is used in conjunction with the meter in order to
obtain data for this research. The Fluke meter instantaneously
measures and stores voltage, current, and power factor data on
connected loads (actual measurements) and outputs a value at half
second intervals. The meter calculates minimum, average and
maximum values within the half-second period. The generated
interval data is used to process values for mean, standard deviation
and ramping (or rate-of-change) of wind turbine output power. The
power factor is measured using a zero-crossing analysis of the
voltage signal compared with the zero-crossing of the current
signal. The power and energy values are subsequently calculated
using the measured voltage, current and power factor values. A
sample of the power factor data is shown in Fig. A2, under low wind

![Diagram of Main Electrical Distribution Board](image-url)
speed conditions. When the measured power factor indicates a negative value, this indicates that power flow is from the installation (utility) to the turbine. When the power factor value is a positive value, this indicated that power flow is from the turbine to the installation. The power directional arrows printed on the CT clamps point from the turbine to the installation. The discrete data is recorded at half-second intervals where the Fluke meter has a storage capacity of 36 min, giving a total number of 4320 individual cases. Data is transferred from the Fluke meter to the researchers PC via USB link.

The flexible nature of the inductive approach utilised in this study allowed the researcher to observe patterns associated with the number of electrical energy units produced by the turbine as prescribed by the digital indicator (Digital Energy Meter in Fig. A3). The numbers simply did not add up. A decision was made to insert a second energy meter in series with the digital indicator to check for accuracy. This was a torque-operated three-phase electromechanical rotating disc meter which was used to carry out the second test on the number of kWh energy units generated by the wind turbine (Rotating Disc Meter in Fig. A4) for validation purposes. The rotating disc is acted upon by a set of voltage and current coils, setting up two magnetic fields. The interaction between the induced magnetic fields set up a force (driving torque) which is exerted on the disc in proportion to the product of the instantaneous voltage, current and power factor values. A permanent magnet mounted beside the two discs allows for an opposing force to be felt on the disc resulting in the disc rotating at a speed that is proportional to the power, or rate of energy, being used in the load. The number of rotations of the disc is therefore proportional to the power, or rate of energy, being used in the load. The expectation was that these 600,000 carbon-neutral kWh units would displace the same number of units normally supplied by the National Grid, much of which is generated by fossil-fuel burning plants, emitting much Green-House Gases (GHG) into the atmosphere in the process. The schematic diagram of the installation is shown in Fig. 2.

The Embedded Generation Interface Protection (EGIP) relay is used to check that all the conditions are met to safely embed the two supplies together. The 300 kW-rated turbine produced 460,842 kW h units of electrical energy in 2015 according to the Digital Meter indicator in Fig. A3. This gives a capacity factor of 17.53%. When the SME purchased the turbine and installed it at the end of 2013 the turbine supplier stated that it would deliver half of their electricity units per annum, equating to approximately 600,000 kW h units of electrical energy provided by the wind turbine. The expectation was that these 600,000 carbon-neutral kWh units would displace the same number of units normally supplied by the National Grid, much of which is generated by fossil-fuel burning plants, emitting much Green-House Gases (GHG) into the atmosphere in the process. The schematic diagram of the installation is shown in Fig. 2.

The Embedded Generation Interface Protection (EGIP) relay is located to the right of the schematic diagram in Fig. 2. All of the tests are carried out between the EGIP relay and the Main Distribution Board. Renewable energy data from the system shown in Fig. 2 is collected by the SEAI. At the beginning of each calendar year the SEAI, under the guise of the Energy Policy Statistical Support Unit, contact businesses with embedded/autoproducting wind turbines and request information on the number of energy units generated by the turbine in the previous year and the size of the turbine in kW. The SME is also asked about the number of units used on site and the number of remaining units exported to the national grid. The information is essential for Ireland to meet its international reporting obligations under the European Energy Statistics Regulation of 2008, No 1099. Regulation (EC) No 1099/2008 of the European Parliament and of the Council establishes a common framework for the

<table>
<thead>
<tr>
<th>Dates (from date to date)</th>
<th>Digital meter kWh indicated</th>
<th>Rotating disc meter kWh indicated</th>
<th>Rotating disc % of digital value</th>
</tr>
</thead>
<tbody>
<tr>
<td>26-Nov-15 to 28-Nov-15</td>
<td>4215</td>
<td>2312</td>
<td>54.9%</td>
</tr>
<tr>
<td>28-Nov-15 to 30-Nov-15</td>
<td>5191</td>
<td>2968</td>
<td>57.2%</td>
</tr>
<tr>
<td>30-Nov-15 to 2-Dec-15</td>
<td>7648</td>
<td>4456</td>
<td>58.3%</td>
</tr>
<tr>
<td>2-Dec-15 to 3-Dec-15</td>
<td>87</td>
<td>56</td>
<td>64.4%</td>
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<td>3-Dec-15 to 7-Dec-15</td>
<td>20,210</td>
<td>12,016</td>
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<td>13,787</td>
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<td>4520</td>
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<td>12,544</td>
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<tr>
<td>21-Dec-15 to 31-Dec-15</td>
<td>22,997</td>
<td>13,400</td>
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</tr>
<tr>
<td>31-Dec-15 to 1-Jan-16</td>
<td>806</td>
<td>456</td>
<td>56.6%</td>
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<tr>
<td>1-Jan-16 to 15-Jan-16</td>
<td>8329</td>
<td>4760</td>
<td>57.2%</td>
</tr>
<tr>
<td>15-Jan-16 to 2-Feb-16</td>
<td>58,123</td>
<td>34,968</td>
<td>60.2%</td>
</tr>
<tr>
<td>Overall</td>
<td>Total</td>
<td>Total</td>
<td>Overall</td>
</tr>
<tr>
<td>26-Nov-15 to 2-Feb-16</td>
<td>167,346</td>
<td>98,744</td>
<td>59%</td>
</tr>
</tbody>
</table>

Field around the generator stator is 1500 Revolutions/Minute (RPM). The speed of rotation of the generator must be above this value for generator action to take place. Because the turbine supplies the clients load in parallel with the National Grid, an Embedded-Generator-Interface-Protection (EGIP) relay is used to check that all the conditions are met to safely embed the two supplies together. The 300 kW-rated turbine produced 460,842 kW h units of electrical energy in 2015 according to the Digital Meter indicator in Fig. A3. This gives a capacity factor of 17.53%. When the SME purchased the turbine and installed it at the end of 2013 the turbine supplier stated that it would deliver half of their electricity units per annum, equating to approximately 600,000 kW h units of electrical energy provided by the wind turbine. The expectation was that these 600,000 carbon-neutral kWh units would displace the same number of units normally supplied by the National Grid, much of which is generated by fossil-fuel burning plants, emitting much Green-House Gases (GHG) into the atmosphere in the process. The schematic diagram of the installation is shown in Fig. 2.

4. Results

4.1. Plant overview

The turbine under test is a Type III Double-Fed-Induction-Generator (DFIG) type installed at the end of 2013. It has a three-phase 690 V output switched to the National Grid through Thyristor switching devices. The rotational speed of the magnetic
production, transmission, evaluation and dissemination of comparable energy statistics in the European community. This framework relies on suitable qualified personnel in participant SME’s to carry out the task accurately. In this case study, the 300 kW turbine produced 460,842 kW h units of energy in 2015 according to the digital meter in Fig. A3. The Electricity Supply Board (ESB) utility supply meter shown in Fig. 2 is calibrated to measure both exported units and imported units, and indicated that 27,828 kW h units of energy were exported in 2015 meaning that the remaining units 433,014 kW h units were used on site by the SME. The larger non-embedded wind farms are metered at the grid interface by either ESB Networks or Eirgrid where the turbines are providing energy directly into the National Grid. The way in which it is intended to reduce GHG emissions is that for every kWh unit of electrical energy produced by the carbon-neutral wind turbine, there is a displacement of a unit of electricity energy which would otherwise be supplied from the National Grid, with a substantial portion of the same currently being derived from fossil fuel. The burning of fossil fuel sufficient to generate one unit of electrical energy (kWh) produces 456.6 g of CO2 [26] which is emitted into the atmosphere.

4.2. SME sustainability reporting

The company in this research report to the Bord Bia ‘Origin Green’ reporting framework as part of their CSR strategy. They signed up to the sustainability programme which helps them to voluntarily achieve measurable sustainability targets — reducing environmental impact, serving local communities more effectively and protecting the local natural resources (http://www.origingreen.ie/about/origin-green-promise/). The plans are verified by an independent third-party agency and monitored on an annual basis. Some of the initiatives recommended by the sustainability charter include the investment in renewable technology and also the reduction in GHG emissions. It was predicted that the installation of the wind turbine at the end of 2013 would tick the ‘renewable energy’ and ‘GHG emissions’ boxes. Table 2 indicates benchmarks for the number of kWh energy imported units compared with the number of tonnes of product produced in the factory. Table 1 shows the Origin Green benchmark for 2011, 2012, 2013, 2014, and 2015. From the values in Table 1, it is clear that the business continues to grow, in terms of tonnage product output. However, the number of kWh energy units also continued to rise during this period. There is no evidence to suggest that the SME are ‘saving’ importing 460,842 kW h units of electrical energy as stated in section 4.1 of this report. Of this value, 27,828 kW h units of energy were exported to the national grid and the remaining number of generated units (433,014) was alleged to be used on site by the connected equipment.

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**Fig. 3.** Power Output on 23-Sept-15 with a 10-min average wind speed of 6.4 m/s.

**Fig. 4.** Power Output on 22-Oct-15 with a 10-min average wind speed of 7.3 m/s.

**Fig. 5.** Power Output on 10-Nov-15 with a 10-min average wind speed of 11.4 m/s.
of the central tendency (among which is the mean) the exploratory data analysis methods allowed for the calculation of the mean value for the data shown in Fig. 3 is 15.816 kW. The mean value for the data shown in the 36-min period shown in Fig. 3 is 15.818 kW. This means that the average amount of deviation from the mean. The standard deviation reflects the degree to which the values in a distribution differ from the arithmetic mean. It is usual practice to present the standard deviation at the same time as the mean, since it is difficult to determine the meaning in the absence of the mean. The standard deviation for the data shown in Fig. 3 is 15.818 kW. This means that the average amount of deviation from the 7.853 kW average power output value is 15.816 kW. The ‘coefficient of variation’ is a measure of dispersion of a probability distribution or frequency distribution and is defined as the ratio of the standard deviation to the mean. The coefficient of variation for the data shown in Fig. 3 is calculated as 201%. The mean value for the data shown in the ‘Turbine Output in Watts’ Fig. 4 is 26.3 kW. The duration of the test is 36 min and was carried out on Thursday 22nd October 2015 with a 10-min average wind speed of 7.3 m/s. The Wattage output power value is changing very rapidly as can be seen from Fig. 4. A sample of the source data used to generate Fig. 4 is presented in Table 4 to calculate the rate-of-change.

Table 4
Indicating difference of turbine power output over a 1 min interval period (rate-of-change).

<table>
<thead>
<tr>
<th>Time</th>
<th>Output power</th>
<th>Time</th>
<th>Output power</th>
</tr>
</thead>
<tbody>
<tr>
<td>30:20.500</td>
<td>–2.571 kW</td>
<td>31:20.500</td>
<td>82.862 kW</td>
</tr>
<tr>
<td>30:21.000</td>
<td>–5.990 kW</td>
<td>31:21.000</td>
<td>89.417 kW</td>
</tr>
<tr>
<td>30:21.500</td>
<td>4.861 kW</td>
<td>31:21.500</td>
<td>84.923 kW</td>
</tr>
<tr>
<td>30:22.000</td>
<td>0.878 kW</td>
<td>31:22.000</td>
<td>94.655 kW</td>
</tr>
<tr>
<td>30:22.500</td>
<td>4.767 kW</td>
<td>31:22.500</td>
<td>94.561 kW</td>
</tr>
<tr>
<td>30:23.000</td>
<td>14.239 kW</td>
<td>31:23.000</td>
<td>94.624 kW</td>
</tr>
<tr>
<td>30:23.500</td>
<td>6.900 kW</td>
<td>31:23.500</td>
<td>92.177 kW</td>
</tr>
<tr>
<td>30:24.000</td>
<td>7.213 kW</td>
<td>31:24.000</td>
<td>97.446 kW</td>
</tr>
<tr>
<td>30:24.500</td>
<td>11.698 kW</td>
<td>31:24.500</td>
<td>86.124 kW</td>
</tr>
<tr>
<td>30:25.000</td>
<td>4.202 kW</td>
<td>31:25.000</td>
<td>95.784 kW</td>
</tr>
<tr>
<td>30:25.500</td>
<td>7.558 kW</td>
<td>31:25.500</td>
<td>84.525 kW</td>
</tr>
</tbody>
</table>

In addition to being interested in the mean (average) value for a distribution of values, this research is also interested in the amount of variation shown by the distribution i.e. the extent to which the data values are spread around the mean. This is called ‘dispersion’ and it is a measure of how widely spread a distribution is. While two different data sets may exhibit the same mean value, how widely spread out they are may be different. The most commonly used method of expressing the diversity of a data set is the ‘standard deviation’. The standard deviation calculates the average amount of deviation from the mean. The standard deviation reflects the degree to which the values in a distribution differ from the arithmetic mean. It is usual practice to present the standard deviation at the same time as the mean, since it is difficult to determine the meaning in the absence of the mean. The standard deviation for the data shown in Fig. 3 is 15.818 kW. This means that the average amount of deviation from the 7.853 kW average power output value is 15.816 kW. The ‘coefficient of variation’ is a measure of dispersion of a probability distribution or frequency distribution and is defined as the ratio of the standard deviation to the mean. The coefficient of variation for the data shown in Fig. 3 is calculated as 201%. The mean value for the data shown in the ‘Turbine Output in Watts’ Fig. 4 is 26.3 kW. The duration of the test is 36 min and was carried out on Thursday 22nd October 2015 with a 10-min average wind speed of 7.3 m/s. The Wattage output power value is changing very rapidly as can be seen from Fig. 4. A sample of the source data used to generate Fig. 4 is presented in Table 4 to calculate the rate-of-change.

Table 3
Statistical analysis of turbine power output.

<table>
<thead>
<tr>
<th>Date</th>
<th>10-Minute average wind speed</th>
<th>Average output power (36-min)</th>
<th>Minimum output power (36-min)</th>
<th>Maximum output power (36-min)</th>
<th>Standard deviation</th>
<th>Coefficient of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>23-Sept-2015</td>
<td>6.4 m/s</td>
<td>7.85 kW</td>
<td>–23.1 kW</td>
<td>76.4 kW</td>
<td>15.8 kW</td>
<td>201%</td>
</tr>
<tr>
<td>22-Oct-2015</td>
<td>7.3 m/s</td>
<td>26 kW</td>
<td>–16.7 kW</td>
<td>126 kW</td>
<td>23 kW</td>
<td>88%</td>
</tr>
<tr>
<td>5-Nov-2015</td>
<td>2.5 m/s</td>
<td>–0.02 kW</td>
<td>–0.9 kW</td>
<td>0.063 kW</td>
<td>0.058 kW</td>
<td>–290%</td>
</tr>
<tr>
<td>10-Nov-2015</td>
<td>11.4 m/s</td>
<td>114 kW</td>
<td>0.157 kW</td>
<td>272 kW</td>
<td>52.5 kW</td>
<td>46%</td>
</tr>
<tr>
<td>18-Nov-2015</td>
<td>12.1 m/s</td>
<td>55 kW</td>
<td>–31 kW</td>
<td>254 kW</td>
<td>49 kW</td>
<td>89%</td>
</tr>
</tbody>
</table>

The data from the Fluke electric power meter was downloaded to the IBM SPSS (Statistical Package for Social Science) Statistics software. The SPSS package and the (0.5 s) interval data were used to generate the following graphical representation of the data (Figs. 3–6). On five site visits on five different days (and under different wind conditions), data was gathered during a 36-min period and the analytical results of these tests are summarised in Table 3.

Descriptive statistics using the IBM SPSS software enabled mathematical calculations to be carried out on the data. Three of the exploratory data analysis methods allowed for the calculation of the central tendency (among which is the mean value), the dispersion of the data, and the coefficient of variation. The arithmetic ‘mean’ is a method for measuring the average of a distribution. The mean value of the power output for the 36-min period shown in Fig. 3 is 7.853 kW (using the SPSS software on the 4319 cases used to generate the graph). The test was carried out during a 36-min period between 10.11 a.m. and 10.47 a.m. on Wednesday 23rd September 2015. Some of the power output values in Fig. 3 indicate negative values i.e. below the 0-kW line. At these negative values, the turbine is acting similar to an electrical (motor) load with the subsequent energy being imported through the Utility Supply Meter (Fig. 2) adding to the cost of the imported electricity bill for the company.

Figure 6. Power Output on 18-Nov-15. Not very windy at the start but wind speed increased rapidly during the 36-min test period.

### 4.3. SPSS graphs and statistical analysis

The data from the Fluke electric power meter was downloaded to the IBM SPSS (Statistical Package for Social Science) Statistics software. The SPSS package and the (0.5 s) interval data were used to generate the following graphical representation of the data (Figs. 3–6). On five site visits on five different days (and under different wind conditions), data was gathered during a 36-min period and the analytical results of these tests are summarised in Table 3.

Descriptive statistics using the IBM SPSS software enabled mathematical calculations to be carried out on the data. Three of the exploratory data analysis methods allowed for the calculation of the central tendency (among which is the mean value), the dispersion of the data, and the coefficient of variation. The arithmetic ‘mean’ is a method for measuring the average of a distribution. The mean value of the power output for the 36-min period shown in Fig. 3 is 7.853 kW (using the SPSS software on the 4319 cases used to generate the graph). The test was carried out during a 36-min period between 10.11 a.m. and 10.47 a.m. on Wednesday 23rd September 2015. Some of the power output values in Fig. 3 indicate negative values i.e. below the 0-kW line. At these negative values, the turbine is acting similar to an electrical (motor) load with the subsequent energy being imported through the Utility Supply Meter (Fig. 2) adding to the cost of the imported electricity bill for the company.
output over a 1 min period, the power output value at 30:24.000 is 97.446 kW. This gives a rate-of-change power output value at 30:24.000 is 90.233 kW over a 1-min period. Other rate-of-change power output values appear consistent with these examples. At the beginning of the test period for the data in Fig. 6 (10.02 a.m.), the 10-min average wind speed was 6.5 m/s. The wind speed quickly increased and at the end of the 36-min test period (10.38 a.m.) the 10-min average wind speed had increased to 12.1 m/s. The increase in power output due to the increase in wind speed is demonstrated in Fig. 6. A summary of the statistical analysis for each of the five site visits and test data is shown in Table 3. This summary is for the data shown graphically in Figs. 3–6. The low value of average output power in Table 3 for the data retrieved on 18th November 2015 (even though the 10-min average wind speed ends up at 12.1 m/s) is because data is averaged over the complete 36-min period. Note from the graph in Fig. 6, that the 10-min average wind speed at the beginning of the test is just 6.5 m/s.

5.4. Comparison of kWh energy units indicated on the digital energy meter with those indicated on the rotating disc energy meter

The Three-Phase electromagnetic rotating disc meter (RDM) and connections are shown in Fig. A4 in the Appendix. Site visits on each of the dates shown in Table 1 allowed the comparison of the number of kWh energy units produced by the turbine as indicated by the digital meter (DM) indicator and the rotating disc meter indicator. Ideally, these should be the same value as they are measuring exactly the same energy signals as shown in Fig. 2.

A picture of the Digital Meter located in the turbine tower is shown in Fig. A3. The push buttons on the front of the panel allow scrolling of the parameters associated with the turbine (in monitoring mode). The Digital Meter display in Fig. A3 and the Rotating Disc Meter in Fig. A4 are the instruments on which the values in Table 1 are based. There is a significant difference between the Digital Meter reading and the Rotating Disc Meter. The RDM only indicates 59% of the DM value so the error between the two readings is 41%. The Rotating Disc Meter was checked on a number of occasions in a controlled setting before and after this case study was carried out for validation purposes and the accuracy of the meter consistently indicating a value of 98%. The validation/test arrangement is shown in Fig. A1.

5. Discussion

5.1. GHG emissions

One of the purposes of the SME embracing this wind turbine project was to reduce GHG emissions. Table 5 indicates that in this case the investment has not had the desired effect on GHG emissions. Note that the SME importing 1 kW h of electrical energy from mainly fossil-fuel generators accounts for the emission of 456.6 g of CO2 [26] into the atmosphere. The SME has seen a constant rise in CO2 emissions over the past five years and the installation of the wind turbine did not thwart this trend. In 2015 there was 685.2 Tonnes of CO2 emitted into the atmosphere due to operations requiring imported electrical energy from the National Grid. As can be seen from Table 5 (and Table 2), the number of kWh imported units continues to rise. The kWh/Tonne benchmark values in Table 2 are actually getting worse because in 2015 it required 20.90 kW h units of imported energy to produce one Tonne of product while in 2014 it required 19.04 kW h units of imported energy to produce the same output (one Tonne). This deterioration in the energy benchmarks should have raised a ‘red flag’ for the SME and also for the government body charged with governance of the sustainability reporting mechanism but it appeared not to do so. It is clear from the data presented in Table 5 that the DFIG turbine in this case is not an economically viable alternative to fossil-fuel driven electrical generators, as the number of kWh units imported from the mostly fossil-fuel driven National Grid continues to rise, unabated.

5.2. Highly dispersant power output values

The digital output reading in the turbine tower appears to over-state the number of kWh energy units produced by the turbine by a significant amount, approximately 41%, compared to the analogue electromechanical rotating disc reading. The fast changing, highly dispersant power output signal is sampled at regular intervals to digitally calculate the energy and it appears that it is not calculating this value accurately. A look at the energy benchmarks in Table 2 would appear to confirm the fact that the SME is not saving 460,842 kW h units of electrical energy annually due to the wind turbine contribution as shown by the digital energy indicator located in the turbine tower. The rotating disc electromechanical kWh energy meter installed by the researcher indicated a significant reduction in this digitally-claimed output. This RDM is designed in such a way that a force (driving torque) is exerted on the disc, the speed of which is proportional to the instantaneous value of voltage, current and power factor in the circuit. It appears that the promised/expected/perceived reduction in CO2 emissions due to the installation of this wind turbine continues to rise in 2015 and in 2014. It is clear from the data presented in Table 5 that the DFIG turbine in this case is not an economically viable alternative to fossil-fuel driven electrical generators, as the number of kWh units imported from the mostly fossil-fuel driven National Grid continues to rise, unabated.

5.3. Statistics associated with the output from the wind turbine

Regulation (EC) No 1099/2008 of the European Parliament [36] is an important tool for evaluating energy statistics within each

<table>
<thead>
<tr>
<th>Year</th>
<th>kWh units imported</th>
<th>Tonnes of CO2 emitted</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>723,160</td>
<td>330.2</td>
</tr>
<tr>
<td>2012</td>
<td>921,578</td>
<td>420.8</td>
</tr>
<tr>
<td>2013</td>
<td>1,226,945</td>
<td>560.2</td>
</tr>
<tr>
<td>2014</td>
<td>1,377,185</td>
<td>628.8</td>
</tr>
<tr>
<td>2015</td>
<td>1,500,588</td>
<td>685.2</td>
</tr>
</tbody>
</table>
member state. In this framework article 6 gives guidelines on quality assessment and reports and states explicitly that member states shall ensure the quality of the data transmitted. In this case study, the quality of the data transmitted is questionable. The governmental body tasked with this quality assessment needs to do more in order to improve these very valuable statistics. The EU Directive 2009/28/EU article 14 [37] states that member states must make available information on the net benefits of generating electricity from renewable sources. This information is to be provided by either the supplier of the wind turbine or by the national competent authorities. The author of this research suggests a much greater governance and regulation in the wind energy industry from national authorities, as the equipment supplier in this case overstated the benefits of this wind turbine. This may be down to a number of factors, among which may be (i) limited previous empirical results (ii) lack of specialist knowledge in the area (iii) desire to make profit by supplying the turbine. The national authorities must ensure that academia is contributing to the raising of corporate social responsibility awareness by training personnel in this sphere. This lack of governmental guidance is stated by Andrade and Puppim de Oliveira [19] as one of the reasons in the failure to lower GHG emissions. Questions must be asked as to the effectiveness of the United Nations in governing and policing the global energy strategies among member nations. Perhaps it is time for a new global governance body in the area of GHG emissions, a body guided by an accurate and rigorous empirical field research data which would have the power to ensure that policies are being implemented in a truthful and effective way.

6. Conclusions

In this case at least it is clear that government energy policy failed to achieve its goal, namely to reduce the SME Green-House-Gas emissions by the installation of a wind turbine as a ‘green’ alternative provider of electricity energy. The SME in this study did not significantly reduce the number of imported kWh electrical energy units purchased via the National Grid. Subsequently, the initiative did not reduce its CO₂ (GHG) emissions as the Irish government strive to meet EU binding emission targets. Worryingly, the research highlighted a flaw in the sustainability reporting mechanism and the governance associated with such a process. The benefits of the turbine were greatly overstated and the erroneous readings went undetected in spite of a plethora of state bodies having access to the data.

The only stakeholder who appeared to have benefitted from the project is the turbine supplier who got paid in full from the SME for providing the turbine. These research findings should serve to inform academics and practitioners in the alternative energy sphere of the dangers of ‘group-think’ mentality that currently exists in the Irish narrative. Things may not be always as they seem or as others claim. Rigorous research and accurate data collection by suitable qualified persons in the field needs to be conducted and disseminated in order to inform practices and policies. For wind turbine providers to develop their businesses in a sustainable manner, they must provide an improved product or service than was provided for the SME in this study. This study also provides managers and business owners with informed and independent data by which to question and critique the benefits of such future investments and make better, and more profitable, decisions.

Appendix
Fig. A3. Three-Phase Digital Energy Meter (DM) in Main Panel at base of turbine tower.
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Fig. A4. Three-Phase Rotating Disc (analogue) Energy Meter (RDM) in EGIS Relay Panel in Main Electrical Switch-room.

References


