Snapshots of Doctoral Research
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'Knowledge is power' — making sense of wind farm data

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Introduction

The Irish wind energy sector is booming. In 2012, Irish wind farms supplied enough energy to provide about 15% of Ireland's electricity demand and power 1.12 million households. In March 2014, The Irish Wind Energy Association (IWEA), an organisation committed to the promotion of wind energy in Ireland, highlighted a planned €7 billion investment in the sector, with a confirmed project pipeline of over 180 new wind schemes. According to a recent TCD/ESRI report, this will bring the total number of jobs in the sector from 3,400 at present to over 8,400 and see a doubling of production of clean, indigenous, renewable energy.

The modern wind turbines, which will be rolled out as part of these new schemes are a far cry from the turbines installed over four decades ago at the first commercial wind farm, constructed in 1980 on Crotched Mountain, New Hampshire, USA. A modern turbine such as the Vestas V167 offshore wind turbine would tower above those early wind turbines. The V167, standing at 187 meters is seven meters taller than London's Gherkin building and has a rotor diameter of 164 meters, into which you could comfortably fit the London Eye. Back in 1980, in New Hampshire, it would have taken a wind farm of over 266 of these early turbines to match the generating capacity of a single V167.

Modern wind turbines like the V167, are not merely big machines, they are also complex and robust machines. Unlike traditional power plants, which operate in controlled environments inside large bespoke plants, wind farms are increasingly found in remote locations like on the side of mountains or out at sea. They have to be able to operate in a range of challenging environmental conditions, such as in high winds in stormy weather, severe turbulence due to complex terrain, and ice and snow in cold climates. Given these challenges, a relevant question is, how much does it cost to build and run a wind farm, and how does this cost compare to the cost of building and running traditional power plant?

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Table 1: U.S. Energy Information Administration (2013) LCOE cost types descriptions

Cost Type	Description
Capital	Costs associated with building the plant
Operation and Maintenance (O&M)	Costs associated with running the plant
Transmission	Costs associated with delivering the energy to the customer
Fuel	Costs of fuel

The cost of wind energy

One accepted method of calculating the costs associated with generating electricity is known as the levelised costs of energy (LCOE). LCOE measures and compares costs across different sources of generation and is calculated by dividing the total lifetime cost of a generating plant by the total value of electricity generated, and is usually expressed in units of currency per megawatt hour ($/MWh.)

A study by the U.S. Energy Information Administration in 2013 calculated LCOE for a range of power plants over an expected operating lifetime of 30 years. The study broke out costs into the following four categories:

The chart shown in figure 1 shows a comparison of five power plant types. The U.S. Energy Information Administration report contains information on a wide variety of plant types, however a subset of just five plant types are presented here for the sake of clarity.

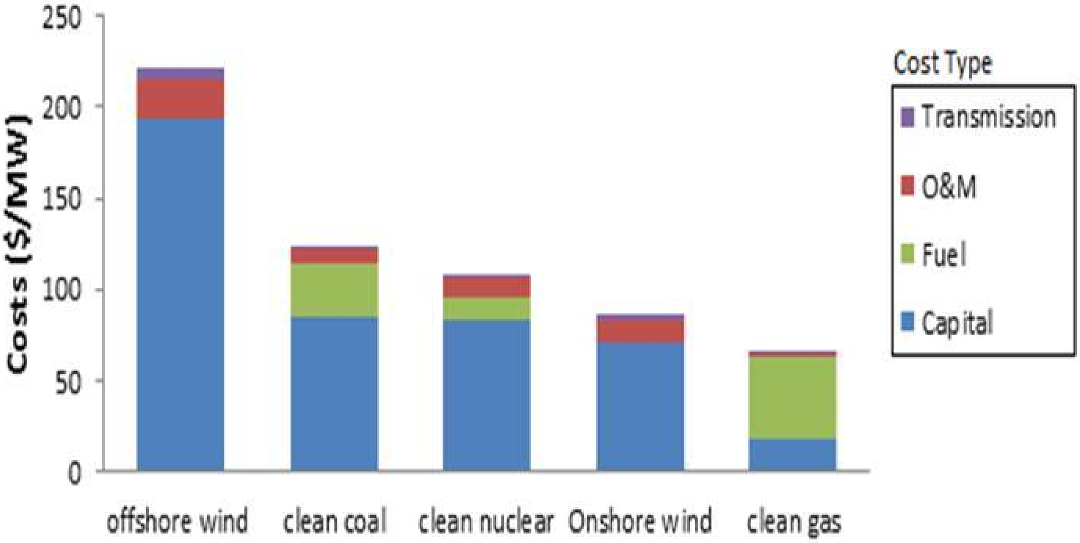

Figure 1: U.S. Energy Information Administration in (2013) LCOE cost breakdown

We can see from figure 1 that the two biggest cost categories are capital costs and fuel costs. It should be said that newer technologies often have higher capital costs, which generally fall over time, benefiting from economies of scale, and improvements in technology. Fuel costs vary, but given the non-renewable nature of most fuels, one may expect the cost to increase given sufficient time.

The final two cost categories are Operation and Maintenance (O&M), and transmission costs. Transmission costs are the lowest cost category and O&M costs are the third most significant cost category. O&M costs include service and maintenance of the assets as well as the cost of replacing and upgrading, failed or underperforming components. Information is essential for managing O&M costs. Having access to better information about how a wind farm is behaving helps operators make better O&M decisions, which lead to improved plant reliability and ultimately lower costs. Making sense of wind farm data, and enabling wind farm operators to better manage O&M costs are one of the aims of this research project.

Wind farm data

Systems which manage wind farms often generate very large volumes of data. It is not uncommon for these systems to report a single issue multiple times, making the task of counting issues and their associated equipment failure times, complex and labour intensive. Issues are often reported in ambiguous and unintuitive language. If issues are classified, it is usually to a coarse proprietary classification system which is of little or no use when counting issues, particularly when tabulating issues across multiple vendors.

It is often the case that there is a very loose coupling between the data produced by machines (like alarms and events) and data produced by humans (like maintenance and service reports). It is not uncommon for records of work, undertaken to maintain or improve the assets, to be either poorly recorded, e.g. as unstructured written reports, or not recorded at all. This means that attempting to automatically analyse data for correlations between alarms and events, and maintenance activities, is difficult if not impossible.

Finally, there is a wealth of information around the boundaries of wind farms that have a significant role in helping to placing machine data in the correct context. For example, information about the location of assets in the wind farm (longitude/latitude, altitude, etc.), data on component failure rates, relationships between assets (operational dependences on some other asset, like a substation), etc. This information often only exists in the heads of experienced experts, is difficult to formally capture and can be lost when key personal leave the organisation.

The research project

The aim of the research project is to improve the accuracy and reliability of wind farm data, and to build a computer based system that will make better sense of wind farm data.

There are two stages to the project:

1. Knowledge capture and transfer
2. Expert system implementation

The first stage, 'knowledge capture and transfer', involves collecting relevant wind farm data and organising it into a format that can be effectively processed by software. This process involves identifying and defining important wind farm concepts (e.g. Turbine, component, alarm, time, service-report, cost, etc.) and also the important relationships between concepts (e.g. Alarm X *affects* turbine Y). The data will be modelled in an ontology, which is a semantic framework for organising information.

Ontologies facilitate three important properties for defining knowledge. Firstly, they allow for new information to be easily added in a structured, formal and connected fashion. Secondly, they ensure that the data set is of good quality, as ontologies facilitate the automatic checking of data consistency rules. Thirdly, ontologies facilitate the sharing of information between systems, between humans, and between humans and systems.

The data in the ontology will be described along three dimensions: thematic, spatial and temporal. The thematic dimension describes some quality of the data (Turbine X *isAffectedByAlarmCode* YYY). The spatial dimension describes where the event occurs (Turbine X is located at coordinates XXX). The temporal dimension describes when the event occurs (Alarm X occurred today).

The second stage, 'expert system implementation' involves designing and implementing a computer system that emulates the decision-making ability of a human expert, and can use the wind farm ontology to make better sense of the data, by inferring new, useful and meaningful facts about the wind farm. A simple illustrative example is, if the ontology knows that Turbine A has a Component B, and Component B is affected by Alarm C. The ES will be able to infer that Turbine A is also affected by Alarm C even though the system was not explicitly told about the connection between Turbine A and Alarm C.

The ES will also offer a query engine which acts rather like a search engine. The difference is that this query engine will have some semantic knowledge about the concepts and relationships in the ontology. So for example it will 'know' what a turbine is, and it will be able to traverse the network of connected turbine concepts (e.g. Alarm, components, etc.). In this way it will be possible to 'ask' the ES some sophisticated questions. An example of a query is:

> "Find all turbines that have alarms for the generator component where these alarms occurred after a maintenance activity."

The query engine will be able to discover related maintenance activities because both alarms and maintenance activities will be related through the temporal domain (i.e. Time).

The ES will provide wind farm operators with a rich framework for querying wind farm data in an intuitive and sophisticated fashion. This will lead to the discovery of new patterns of behaviour in the wind farm data, which will result in a more nuanced understanding of the wind farm. This in turn will allow wind farm operators to better manage their assets and will lead to lower O&M costs and improve plant reliability.

The Irish Wind Energy Association (IWEA) has highlighted over 180 new wind schemes planned for Ireland alone. The long-term viability of these projects will depend on how well costs can be managed. This research project will deliver a set of patterns for formally capturing wind farm knowledge along with software capable of querying wind farm knowledge in a connected and semantically aware fashion. These two things taken together will help wind farm operators discover important patterns hidden in the morass of wind farm data and assist with the important goals of lowering O&M costs and achieving higher plant reliability.

In Summary

Wind turbines are large, complex machines which have to operate in increasingly challenging environments. The systems which manage wind farms often produce poor or incomplete operating and maintenance records. Unlike traditional generating plants which are housed in climate controlled complexes, wind turbines are affected by a range of external conditions, like cold weather, high winds, turbulence from complex terrain, etc.

This project will provide a robust semantic framework which will enable all relevant wind farm information to be captured and organised in a formal structured fashion. This knowledge-base can then be queried by a computer based ES which will unlock the hidden knowledge of the wind farm, by providing a means to explore the data in a much more connected fashion. Having better information for a wind farm will help wind farm operators make informed, evidence based decisions about how to operate the assets, which will improve reliability, lower costs and in turn increase the viability and sustainability of the wind energy sector.

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