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# A review and analysis of renewable energy curtailment schemes and Principles of Access: Transitioning towards business as usual



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## HIGHLIGHTS

- Literature review of Principles of Access.
- Detailed case study analysis of Principles of Access in ANM projects.
- Quantitative analysis of different Principles of Access.
- Proposed business models for ANM as business as usual.

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## ABSTRACT

In the last decade, the EU has driven forward the development and connection of renewable power sources across Europe. This has changed the way in which distribution networks operate, moving from a passive system, to a more active system where generation and demand are located closer together with system states being more complex and variable. Increased penetration of renewable generation into distribution networks is presenting a number of challenges to Distribution Network Operators (DNOs) including the provision of network access in capacity constrained networks. The introduction of Active Network Management (ANM) is enabling an increase in renewable generation connections through enhanced network access in otherwise 'full' networks.

This paper presents a way in which DNOs might move towards Business as Usual (BAU) arrangements for ANM schemes. It is necessary to determine the curtailment arrangements, or Principles of Access (PoA), and from this estimate generation access under ANM and the flow of services and money for different scenarios. In this paper, a comprehensive literature review, detailed case study evaluation on early ANM schemes, quantitative curtailment assessment for different PoA and a qualitative analysis of business models for different ANM PoA is presented in turn with conclusions drawn from these three approaches.

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## 1. Introduction

The European Union (EU) is currently in the process of moving towards 'greener' technologies with a drive to encourage the adoption of renewable energy technologies. The threat of climate change is a global concern and the EU governs a significant degree of energy policy in the United Kingdom through directives which are applicable to all EU member states.

EU Directive 2009/28/EC (The European Parliament and the Council of the European Parliament, 2009) sets renewable energy targets for all member states to achieve by 2020 in overall energy production and transport. The targets state that 20% of energy generated in the EU and 10% of energy used in transport should be from renewable means. The directive requires member states to set their own personal targets; these must however be consistent with 2009/28/EC.

UK Government targets outlined in the UK Government Low Carbon Transition Plan (HM Government, 2009) state that around 30% of electricity will be generated from renewable energy sources by 2020. The Scottish Government has also set its own ambitious targets, aiming for 100% of electrical demand to be met from renewable energy by 2020 (Scottish Government, 2011).

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To encourage the connection of renewables, a number of incentives were introduced by the UK Government including the Feed-in Tariffs (FITs) (Ofgem, 2013b) and Renewable Obligation (RO) (Ofgem, 2013c).

The RO is the most significant incentive for renewable generation development in the UK, where generators are rewarded Renewable Obligation Certificates (ROCs) for each MWh of energy produced by renewable energy sources.

The value of ROC has an important impact on the price paid to the renewable generator for electricity produced. The ROC price is set at a fixed rate for each year, while the market price of electricity fluctuates, and the long term value of the PPA is typically lower than the average market rate (Cornwall and Littlechild, 2008)

The number of ROCs awarded varies depending on the technology, namely to encourage investment in less developed technologies (Department of Energy and Climate Change and Ofgem, 2013). The value of ROCs is set by Ofgem each year and will change over the years in line with the Retail Price Index (RPI). An example of ROC prices can be found online at the e-ROC website (e-ROC, 2013). The current Electricity Market Reform (EMR) (Department of Energy and Climate Change, 2011) will introduce Contracts for Difference (CfDs) and these will replace ROCs by 2017. The aim of CfDs is to remove the long term exposure of low carbon technologies to volatile electricity prices. CfDs ensure that generators receive payments for energy produced at a fixed price, known as the 'strike price'. If the electricity price is lower than the strike price, low carbon generators will receive a top-up payment to make up the difference from suppliers. However, if the electricity price is higher than the strike price, then low carbon generators must pay back the difference.

Feed in Tariffs (FITs) apply to any generators smaller than 5 MW and the rates vary depending on the size of installation and the technology used. FIT prices are set by Ofgem each year. Prices for the 2013/2014 period are available on the Ofgem website (Ofgem, 2013d).

At transmission level, Connect and Manage was introduced by National Grid (2009) with the aim of facilitating the connection of new renewable generation to the transmission system. Connect and Manage allows all new generators, regardless of size or type, to connect to the network by simply carrying out the required local upgrades (around the point of connection) without waiting for any wider transmission network upgrades that might be required. Connect and Manage also applies to large embedded generation (greater than 50 MW) on the distribution network. Through the introduction of Connect and Manage, applications from renewable generators for connection to transmission and distribution networks have increased (National Grid, 2011).

At distribution level, the increase in Distributed Generation (DG) connecting led to a change in the behaviour of the distribution network (CIGRE Working Group C6.09, 2011). Traditionally, distribution networks were designed to transport electricity from transmission grid connection point down through to lower voltages and eventually to demand customers. However, with the connection of DG the location of generation is now closer to demand, and in some cases the direction of power flow may be reversed i.e. more electricity is generated in the distribution network than is required by demand and will therefore flow up to transmission level.

Legislation at EU and UK levels has provided the stimulus and incentive to develop renewables, but there are three sets of issues which can sometimes restrict the connection of renewable generation to the power system. These include:

1. Network issues which focus on local issues such as lack of capacity on the network to enable new connections, and also control of voltage and reactive power levels on the network.

2. System issues which can include security of supply, back up reserve and system balancing. Systems which are overloaded with new generation may have difficulty in balancing generation and demand.
3. Market issues such as the subsidies, compensation for curtailment, use of system charging, and electricity pricing.

Currently, solutions are being developed to these three issues, and ANM is emerging as a serious contender for solutions to the first of these problems i.e. better control of network and enabling additional generation to connect.

A number of definitions for ANM were defined by a CIGRE working group report (CIGRE Working Group C6.11, 2011). The authors define ANM as the control of power, voltage and frequency within a network through the use of remote control and communication technologies.

ANM schemes allow the increased connection of renewable generation (Currie et al., 2007) to the distribution network. In order to do so, there may be some curtailment of renewable generators required. For the purpose of this paper, curtailment can be defined as the reduction of output of wind generation to an output level lower than current availability of the generators.

While this suggests curtailment has a negative effect on wind, it is in fact a positive result for wind farms connecting to constrained networks. Without ANM and the curtailment of wind generation during certain time periods, the generators would not have been able to connect to the network without costly and time consuming upgrades. (Currie et al., 2010)

This paper is structured as follows. In Section 2, examples of curtailment practices are presented and Principles of Access (PoA) which have been collected as part of a literature review and are assessed against a list of criteria, and the advantages and disadvantages discussed. Section 2.2 presents case studies of ANM schemes which have applied PoA and the cost of the ANM scheme is compared with traditional reinforcement costs. In Section 3, a quantitative analysis of different PoA is carried out using constraint management techniques. Section 4 goes on to discuss the 'Business as Usual' (BAU) case for ANM schemes and demonstrates how a DNO might recover the costs associated with the ANM installation when they are no longer funded through innovation funds such as the Low Carbon Network Fund. Finally, Section 5 contains concluding remarks on how DNOs might move towards BAU with ANM schemes that apply PoA to curtail generation.

## 2. Materials and methods

### 2.1. Principles of Access

PoA for wind generators in ANM systems is a relatively new field of research. In order to gain an understanding of PoA, it is appropriate to look to transmission systems to build on previous learning. At transmission level, short-term access trading (Shaaban and Bell, 2009) is a method identified as a possible short-term solution to the problem of transmission access rights to integrate renewable generation. The principle works by trading generation capacity between renewable generation and conventional generation in particular transmission network zones to make efficient use of renewable generation whenever possible. For example, when wind conditions are good then access rights can be traded from a conventional generator who has firm access rights to the wind generator with non-firm rights. Trading could also take place during planned outages of the conventional generator or during periods when wind conditions are poor. DC power flow analysis is used to determine which generators can trade access rights

between each other. Difficulties in trading agreements may arise because of generator size. Wind farms may need to buy more access rights than they require because it may not be possible for the generator which the wind farm is trading with to reduce output by the required amount. The scale of this issue depends on trading partner size and technical specification of the generation.

A study by Rogers et al. (2010) and Fink et al. (2009) has identified methods of curtailment on international transmission systems. Xcel Energy in the United States provides transmission services for eight Western and Midwestern states. There are two regulatory bodies which take care of the curtailment procedures for this group of states. Firstly, Northern States Power and South-western Public Service curtail wind turbine generators on a rotational basis when required. Public Service of Colorado (PSCO) has made contracts with certain generation plants to curtail a set amount per year on an as-needed basis. If additional curtailment is required then curtailment operates on a rota basis. With regards to compensation, Northern States Power pays a price per kWh for both fixed and variable costs of generators. PSCO will pay the price per kWh for energy and production tax (the US version of ROCs) on any additional curtailment outside of the contracted amount.

In Spain, there are two methods of curtailment. Firstly, there is programmed curtailment where decisions are made before the day-ahead market is closed. Secondly, there is a real time market. Curtailment instructions are sent out from the system operator to the wind generators via the Control Centre for Renewable Energies and the Generation Control Centres (GCC). All wind power greater than 10 MW must be connected to the GCC. Analytical models are used to determine the need for curtailment. All real-time curtailment receives compensation of 15% of the wholesale price for each hour which is multiplied by the theoretical production based on the wind forecasts.

The above international examples demonstrate effective methods of wind curtailment; however in order to implement the above in distribution networks, some changes may be required due to generator size and differences in roles of distribution and transmission system operators. There are several examples of curtailment management strategies at distribution level and these are discussed below.

In several of the existing, early deployed ANM schemes, the current method of curtailment is 'Last In First Off' (LIFO). This means that the first non-firm generator unit (NFG) to sign a contract is always the last NFG to be curtailed. While this is an easy method to administer it does not provide the optimal use of resources and in some cases can lead to generators being needlessly curtailed depending on specific network conditions. LIFO is the approach used in the Orkney ANM scheme (Currie et al., 2010), and the one which will be applied in the Northern Isles New Energy Solutions (NINES) scheme on the Shetland islands (Gill et al., 2013).

A study by Currie et al. (2011) has identified a number of possible contractual arrangements which could be applied to curtailment schemes. Based on an initial assessment of the PoA options against set criteria which considered the technical, commercial and regulatory strengths of each approach (EIRGRID, 2011), LIFO and Market Based approaches are noted as the most feasible PoA.

Recent work carried out by UK Power Networks has discussed potential PoA for their 'Flexible Plug and Play' network development (Baringa Partners and UK Power Networks, 2012). A literature review of national and international case studies was carried out (Anaya and Pollitt, 2012) and a number of options for managing NFG including LIFO, market based and a pro rata approach was considered.

The report assessed a number of PoA options based on five assessment criteria. These include network efficiency, certainty,

simplicity, fairness, and learning. The PoA considered for the FPP project involved a number of variations on LIFO and Pro-rata curtailment. The restrictions upon the selection included timing, and having to work within the current regulatory framework. The final choice for PoA was a Pro-Rata PoA with a cap on the volume of capacity able to connect (Laguna Estopier et al., 2013). The generation capacity cap was determined by calculating the point at which the total generation curtailment cost over the lifetime of the generator was equal to the cost of required network reinforcements. Beyond this cap, generators would be curtailed based on a LIFO PoA. All existing connections will not be affected by new PoA rules.

A combination of PoA such as pro rata and market-based could provide a practical solution for many curtailment strategy approaches in ANM schemes however more research is required into the impact and behaviour of potential market arrangements for distribution networks.

The PoA studied in this paper have been identified in the literature review presented above and is not an exhaustive list of possible arrangements. In this paper, PoA are grouped into non-market and market arrangements to highlight the level of control which the system operator and NFG have over curtailment levels.

In order to critically assess PoA, a number of assessment criteria are developed from existing criteria found in the literature (Currie et al., 2011; EIRGRID, 2011; Bell et al., 2011). These criteria will be used to assess the PoA discussed in the following sections. It is suggested by the authors that a suitable PoA should:

1. Support safe, secure and reliable power system operation.
2. Encourage efficient investment and operating decisions by the distribution companies, generators and consumers such that the overall cost of electricity is minimised.
3. Not present undue barriers to the utilisation of low carbon electricity.
4. Be fair, equitable and transparent.
5. Be robust against future generation, demand and network changes.
6. Be practicable.
7. Be as simple as possible to achieve the objectives, and no simpler.
8. Not have an unduly negative impact on existing connection agreements.
9. Gain sufficient support of stakeholders to allow implementation.
10. Allow investors to be able to estimate, with sufficient confidence, future income and expenditures in order to secure investment from financial backers.
11. Comply with all Generator technical standards and network design standards.

#### 2.1.1. Non-market arrangements

Non-market arrangements use predetermined rules to curtail NFG. These rules are decided by the DNO and NFG must adhere to these rules in order to connect to the network. Non-market arrangements are simple for the DNO to implement as no changes to current rules and regulations are required.

*2.1.1.1. Last n First Out (LIFO).* Under this method, the first NFG to be curtailed under a constraint event is the chronologically last NFG to connect to the network or added to an ANM scheme. Adding a new NFG connection to the LIFO priority list (in the position of least priority) does not alter the priority position of existing NFG. This approach is consistent, transparent and easy to implement within the current UK regulations. However, this method would not necessarily be the best way of fully utilising

the available network capacity or the available renewable generation. For example, the lowest priority generator may be located furthest from the constraint which would result in a higher volume of curtailment required when compared with a generator located closer to the point of congestion. As the number of NFG increases, the Capacity Factor (CF) for those at the bottom of the priority list may begin to approach unacceptable levels, and discourage any new NFG connections.

**2.1.1.2. Pro Rata.** The pro rata method divides the required curtailment equally between all NFG contributing to a network constraint. The total amount of curtailment would be shared by each of the NFG based on the ratio of rated or actual NFG output to total required curtailment. Implementing this method would grant equitable access for multiple NFG. However, it is difficult for the DNO to calculate the long term volumes of curtailment of this method since, as more NFG is connected, the level of curtailment of each NFG, including those already connected with NFG contracts, will increase. To some extent, this can be solved by setting a cap on the level of generation which can be connected to a particular network location without the network being reinforced. This then gives a minimum CF which allows generators to calculate return on investment.

**2.1.1.3. Shedding rota.** This method curtails NFG based on the order specified in a predetermined rota. This rota could be changed on a daily, weekly or monthly basis using the network operator's discretion. As the level of generation connected under a rota arrangement increases, the level of curtailment may increase however the length of time spent at the bottom of the priority stack would decrease. This uncertainty could be eased if the DNO were to set a cap on the amount of generation that can connect to the network, thus calculating a minimum CF that each NFG might experience.

**2.1.1.4. Technical best.** This PoA curtails the NFG in order of size of contribution to the prevailing constraint or based on which generators are most effective (in power systems terms) in relieving the constraint. In general, this would vary for different types of constraints and network configurations. This approach would ensure a minimisation of the volume of energy curtailed and the most efficient operation of the network. This approach may discriminate against certain NFG based on their location and capacity; however it could also encourage the DNO to upgrade the network at an earlier date.

**2.1.1.5. Greatest carbon benefit.** This method aims to minimise the carbon emissions associated with actively managed networks by curtailing NFG which will result in the greatest reduction in CO<sub>2</sub> emissions. Based on a carbon metric such as CO<sub>2</sub>/MWh per generating unit the network operator could prioritise NFG in the curtailment scheme. Generators could be grouped into a number of different ranges of CO<sub>2</sub> emissions, similar to ROC banding. If the group of NFG all has similar CO<sub>2</sub> emissions then this method could be combined with a second POA e.g., pro rata or LIFO to apply curtailment. There may be difficulties in the calculation of true carbon emissions of each generation in a clear, open and fair manner.

**2.1.1.6. Most convenient.** This method allows the system operator to curtail the generator they know to be the most convenient i.e. easiest to implement and most effective for relieving network constraints. There may be unfair discrimination against certain types of generators based on location, control room preference and size of generator. The assessment may also be influenced by

system operator preference which raises issues regarding fairness and transparency.

**2.1.1.7. Generator size.** This method curtails the largest generator that is contributing to a constraint first, where size refers to output at time of constraint. This method has the advantage of easing network congestion quickly by regulating or removing the largest NFG first. This PoA could be deemed unfair, and may discourage efficient investments from developers e.g., reluctance to install larger generating units.

## 2.1.2. Market arrangements

Market Arrangement type PoA use some form of constraint market with a bidding system to determine the curtailment order of NFG.

Market PoA do not impact on existing connections (assuming they have a firm connection and their rights are 'grandfathered') and, in principle, is sustainable for future network developments. In addition, there is potential to extend the market to existing firm connected generators should they choose to participate.

These approaches will require the largest change from existing practice in distribution networks, and require the development of market rules and structure under which the generators could operate. This will require a large input from all bodies involved – generators, system operators, regulators, etc. and a potentially complex set of market procedures.

**2.1.2.1. Curtailment market.** A curtailment market might take the form of generators submitting bids on an annual, quarterly, monthly or daily basis in which they indicate their willingness to curtail. In a perfect market, this bid would be equal to the price the NFG would have received had they been allowed to generate during the constraint period. The system operator will always aim to clear the constraint with minimum cost to the system i.e. the lowest bids will be curtailed first. Compensation might be paid-as-bid, reflect the curtailment market clearing price, or be a fixed price e.g., a percentage of the price of wholesale electricity during that particular period. This option gives control to generators to submit bids which reflect their desire to remain connected and could encourage participation from existing firmly connected generation. However a new market system would need to be established and it may require large changes to the distribution and grid codes.

This section has provided an extensive literature review of the area of curtailment management strategies and PoA in ANM schemes. By looking at examples at both transmission and distribution level it is possible to develop a list of potential PoA arrangements for consideration in ANM schemes for the future. The next section will look at projects which have applied PoA to their own ANM schemes and discuss the cost of the projects when compared with conventional network reinforcement solutions.

## 2.2. Principles of access case studies

The following case studies have applied PoA to NFG connecting to a distribution network within an ANM scheme. The case studies highlight the benefits and problems faced with the different PoA and also how these arrangements are implemented in terms of contractual arrangements and the costs of the project compared to traditional network reinforcements. The UK is currently at the forefront of trials of ANM, so only one example from outside the UK, is included in the review below. More examples of curtailment strategies exist at transmission level as discussed in [Section 2.1](#), and many of these are documented in ([Rogers et al., 2010](#)).

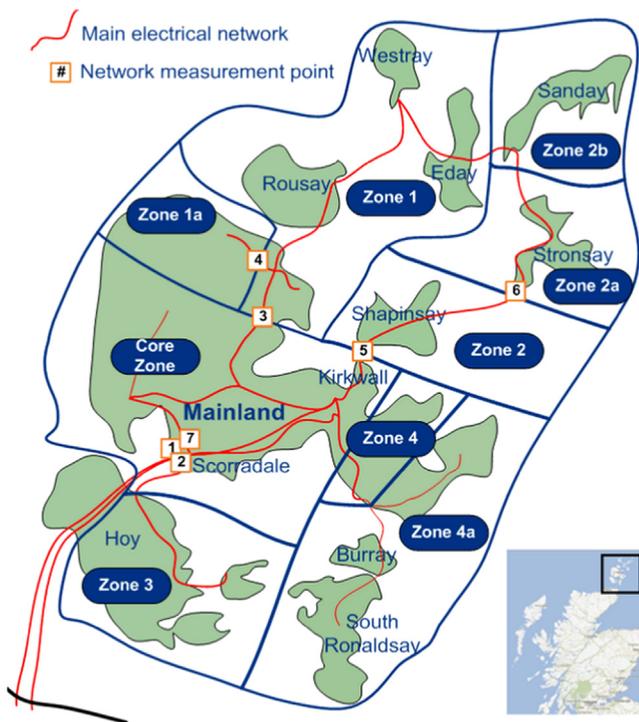


Fig. 1. Orkney distribution network with zone boundaries (Scottish and Southern Energy Power Distribution, 2013).

### 2.2.1. Orkney ANM scheme

The ANM scheme on the Orkney Islands is the first of its kind in the UK. A number of papers (Currie et al., 2004, 2006, 2007, 2010; MacDonald et al., 2008) have detailed the research and development of the Orkney ANM scheme.

A LIFO arrangement is currently being used on the Orkney ANM scheme. When curtailment is required, the ANM controllers will send trim/trip signals to generators behind the constraint in the order determined by the LIFO priority stack (Currie et al., 2007). Generators at the bottom of the stack will be first to curtail. The network is divided into 'constraint zones' with each zonal boundary being a constraint point, as shown in Fig. 1.

The system is managed in real-time via the use of a Programmable Logic Controller, which receives measurements of power and current, and uses private or public radio links to communicate commands to generators. In addition to ANM solutions, several reactive compensation devices and shunt reactors have been installed to resolve local voltage rise problems at specific locations on the Orkney network.

A report produced by KEMA (2012) on the Orkney ANM scheme highlights the project successes and problems encountered during the creation of the ANM scheme. The total cost of the ANM scheme to date has been approximately £500,000. Generation developers remained interested in connecting to ANM scheme regardless of projected curtailment figures, most likely due to high CFs when compared with mainland GB.

The Orkney ANM project was implemented as an alternative solution to network reinforcements. These reinforcements would have been in the form of a new 33 kV subsea cable linking Orkney to mainland GB grid, which would have cost an estimated £30 m. Regardless of the construction of the subsea cable, there would still be local constraints on the network which would require some form of constraint management of exporting generation. From inception as a research project, the Orkney ANM scheme took 6 years to reach operational stage (2003–2009). This lengthy period was the result of advanced modelling required for generators, extensive testing, and external factors such as planning consent and construction work for the first generators.

The Orkney ANM scheme is based on a locally centralised architecture with network and generation output measurements communicated back to a central processing unit sited at the operational hub for the Orkney power network. Control instructions are calculated there and communicated out to controlled generating units. The necessary SCADA and Distribution Management System interfaces, communications links with watchdogs and local fail-safes are integral to this architecture.

One of the key early lessons learned from the Orkney ANM Scheme was the importance of communication systems. The communications for each curtailable site was the responsibility of the generator. There were problems with NFG who used existing lower frequency radio links or leased copper wire links. When the communication links between generators and network are down the generators are automatically issued a zero set-point to prevent any network problems. As a result of initial unreliability of some of the communication links, there were higher levels of curtailment for some generators.

Another key lesson learned involved the inclusion of micro-scale wind generation in the Orkney ANM scheme. Initially, only wind generation greater than 50 kW capacity was installed with monitoring and communication equipment required for curtailment instructions from the ANM scheme. While this was justified from a financial viewpoint (i.e. the smaller generators had less funds available to pay the cost of installing monitoring and communications equipment) it has resulted in a large volume of micro-generation 'eating' into the capacity of larger generators in the LIFO stack which has led to higher levels of curtailment for those larger generators. The impact of individually curtailing a single sub-50 kW machine will have little impact on network constraints, therefore in order to prevent further increase to curtailment of existing NFG as the level of new sub-50 kW generation increases, the second generation ANM system for Orkney will include control of micro-generation clusters. On/off controls will be issued to control group clusters to manage network constraints. These simplified controls will reduce the cost of the controller required for ANM participation and existing communication will be utilised to keep the costs of ANM scheme low for small sub-50 kW generators (Foote et al., 2013).

### 2.2.2. Shetland ANM integration

The electricity network in the Shetland Isles is composed of three main 33 kV circuits connecting three large scale generating sites and outward to primary substations supplying demand at 11 kV and low voltages level. The Shetland network is not connected to the mainland GB grid. A number of network issues have thus far prevented more than 3.6 MW of wind connecting to the network (Gill et al., 2013).

Funded by the Low Carbon Network Funds (LCNF), Scottish and Southern Energy (SSE) and Strathclyde University, the NINES project is researching ways to increase and optimise the amount of renewable energy flowing on the island network (Scottish and Southern Energy Power Distribution, 2012). Better management of the Shetland network, through demand side management and ANM systems will allow an increase in the level of renewable energy able to connect and decrease the volume of fuel burned by conventional generation on the island.

The NINES scheme will operate a LIFO PoA for the curtailment of all NFG connecting to the system. Micro-generation will be included in the ANM scheme, therefore avoiding issues experienced by the Orkney ANM scheme, discussed in Section 2.2.1.

The cost of the NINES scheme is estimated to be around £33.54 m (Ofgem, 2013a) and this includes the ANM scheme, domestic demand side management, a district heating system and a 6 MWh battery. Network reinforcement solutions which

**Table 1**  
Table of FPP connection costs vs. typical connection costs (UK Power Networks, 2012).

Project	Capacity (MW)	Typical connection offer (m)	FPP budget estimate (k)	Savings (%)	Status
Gen A	5	£1.2	£570	53	Accepted FPP Opt in offer
Gen B	0.5	£1.9	£400	79	Accepted FPP Opt in offer
Gen C	10	£4.8	£500	90	Accepted FPP Opt in offer
Gen D	7.2	£3.5	£700	80	Accepted FPP Opt in offer
Gen E	2.5	£1.9	£170	91	Accepted FPP Opt in offer
Gen F	1	£2	£300	85	Pending

would require the construction of a subsea cable to connect to the mainland GB network would cost in the region of £300 m (TNEI Services Limited, 2007).

### 2.2.3. Flexible Plug and Play ANM implementation

The Flexible Plug and Play (FPP) project is one of the Tier Two LCNF projects awarded funding in 2012 (Central Networks, 2005), and is trialling new commercial solutions for connection of renewable generators. Through the introduction of ANM technologies and PoA, UK Power Networks hope to fast-track the connection of renewable generation and reduce the cost of connections. The alternative is a lengthy delay while network reinforcements are carried out or a high connection cost to generators in order to connect at a neighbouring grid connection point or at a higher voltage level.

A comparison of connection costs is shown in Table 1. Significant savings are shown for generators wishing to connect to the network by introducing the non-firm connection option under the FPP connection scheme.

A Pro-Rata PoA is applied to the FPP project, as it was shown to provide higher long term CFs for NFG when compared with LIFO, as long as a cap was set on the maximum level of NFG which could connect to the network. Once this cap is reached, LIFO will be applied to subsequently connecting NFG.

The cost of the FPP ANM scheme is approx. £6.7 m (total funding awarded by Ofgem) which compares to reinforcement costs i.e. upgrading the transformer, of £15.3 m (UK Power Networks, 2012). One consideration for the future of the network is that as the level of connected NFG increase, thermal constraints could be created in some areas of the network. In this case, new curtailment zones are created. At the present time, curtailment is based around a constraint at the grid connection point and connection agreements with generators will have this constraint written in to the contract. With new constraint locations, the question arises as to how curtailment might be allocated and if CFs might be reduced to a value lower than previously guaranteed by the DNO. This refers to issues regarding the level, to which DNO must guarantee certain CFs in ANM schemes, and should a level be exceeded then what level of compensation should be provided.

### 2.2.4. Belgian east loop ANM programme

The Belgian transmission and distribution operators, Elia and ORES, are experiencing increasing network constraint on generation connection and operation in the south east region of Belgium. The transmission system was initially designed to meet lower rural demand, but with increased connection of wind and other DG in the region, the 70 kV transmission lines are now at their thermal limits due to reverse power flows.

In order to allow the connection of further renewable generation in the region, Dynamic Line Rating and non-firm connection agreements will be used. The scheme will apply a pro rata

approach to curtailment, where curtailment is proportional to the output at the time of the constraint. (Durieux et al., 2011).

The Dynamic Line Rating scheme was installed and trialled by Ampacimon (Schell et al., 2012) and provides additional headroom for new non-firm connections on the network. The introduction of these ANM strategies will allow prompt connection of renewables in the area, however a full scale trial has still to take place and cost of the ANM project are not currently available in the literature.

This section has provided a review of four ANM schemes which are implementing PoA.

The following section gives results from a numerical analysis of different PoA methods.

## 3. Results

### 3.1. Analysis of Principles of Access

In order to compare the impact of different PoA, a quantitative analysis was carried out using a power flow constraint ANM technique. This example applies the PoA within the constraint analysis to compare the impact of LIFO, pro rata and rota arrangements on NFG CFs. Relevant demand and generation data for the case study network is used to identify periods of constraints, and then apply PoA to the 11 NFG connected to the network. The PoA are applied using the cost functions in the OPF model i.e. the generator with lowest priority will be assigned the highest OPF costs in order to ensure it is curtailed first. This is similar to the method proposed by Dolan et al. (2012). The Constraint Analysis Process is shown in Fig. 2.

The results shown in Fig. 3 demonstrate the change in CF for 11 NFG behind a single constraint in a real example network. Generator A is top of the priority list i.e. last to curtail under LIFO. Under a rota arrangement, the priority order is changed every 24 h. Under a pro rata arrangement, the curtailment is shared between all non-firm generators depending on output at the time of curtailment. The CFs have been calculated for a typical full year of half hour trading periods.

The results demonstrate that while LIFO allows NFG at the top of the priority list to only experience a small change in CF, the rota and pro rata arrangements result in more of a levelised CF across all NFG generators. This highlights the important issues of fairness and legacy rights.

The quantitative analysis provides a comparison for different PoA in ANM schemes. Depending on the location and type of constraint, different PoA may be suited to different network topologies and configurations however the overlying conclusions from this analysis suggest that while LIFO may be the most straight forward PoA to implement, it does not result in the best CF for the majority of NFG connected to the network.

In the next section we will carry out a qualitative analysis on the way in which DNOs can recover the costs of ANM schemes when compared with the methods used to recover the costs of traditional reinforcements.

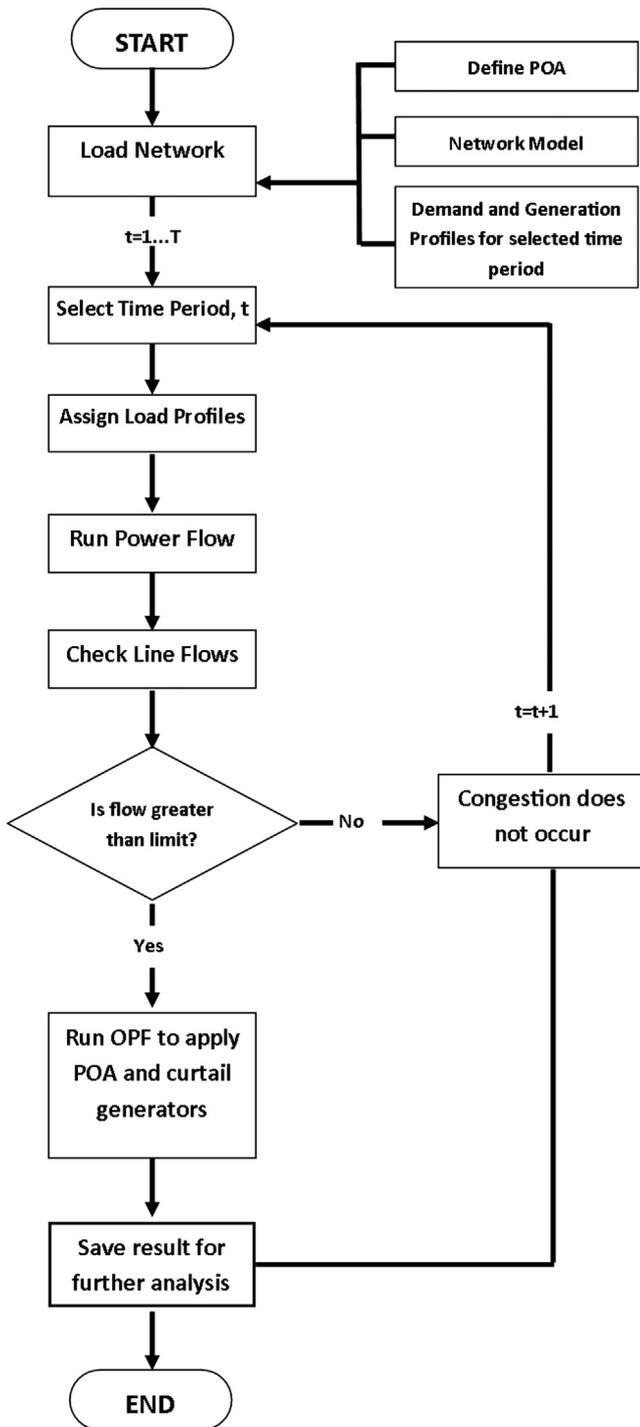


Fig. 2. Constraint analysis modelling process.

#### 4. Discussion

##### 4.1. Business models for 'Business as usual' deployment of ANM

As discussed in Section 3 the costs of ANM schemes have been shown to be lower than traditional network reinforcements. However the mechanism by which costs are recovered and allocated to stakeholders by network operators is yet to be defined. This section provides a qualitative analysis of the costs and payment mechanisms and will outline two potential business models for 'Business as Usual' deployment of ANM schemes.

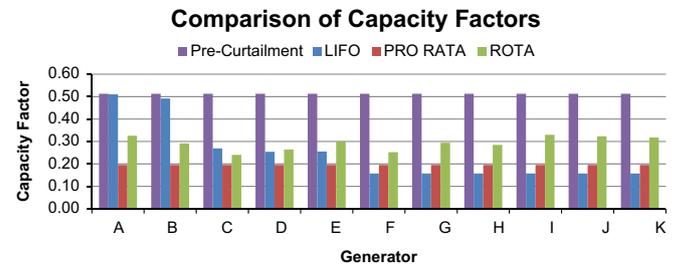


Fig. 3. Graph showing the changes in CFs for different PoA on Wind Generators.

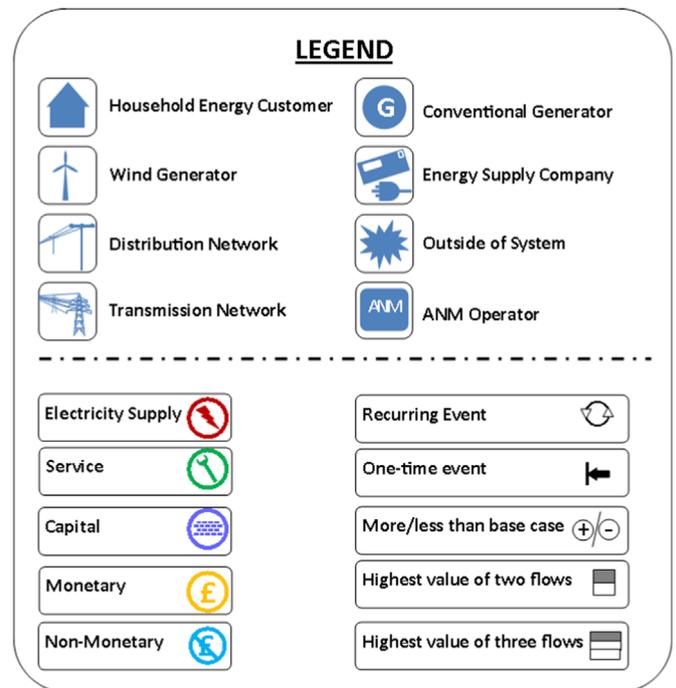


Fig. 4. Legend for business models in Figs. 5 and 6.

Currently, the costs of network reinforcements are recovered through a combination of connection and use of system charging depending on the voltage level of the connection (National Grid, 2012b). To date, the cost of ANM schemes have received funding through network research and development funds, and schemes such as Registered Power Zone (RPZ) (Ofgem, 2012a) and LCNF (Ofgem, 2012b). As ANM schemes become a 'business as usual' (BAU) option, a mechanism by which the network can recover the costs of installing, operating and maintaining an ANM system must be established.

One way of demonstrating a complex business model is through the use of a visual aid. Business models developed by Environmental Change Institute at University of Oxford (2011) have been used as the format for the diagrams in Figs. 5 and 6. The models help to demonstrate the flow of money and services between actors in the business model, as well as highlight complexities and critical relationships. These models suggest one method of recovering the costs of an ANM scheme; however, there are many variations which could be determined as best practice for different DNO and ANM schemes.

The legend for the business models in Figs. 5 and 6 is shown below in Fig. 4. The list of actors is not exhaustive, and additional actors may include aggregators, regulators and contractors (for installation of equipment).

Currently, the ANM Operator is an actor who provides ANM equipment, installs and maintains ANM equipment and manages

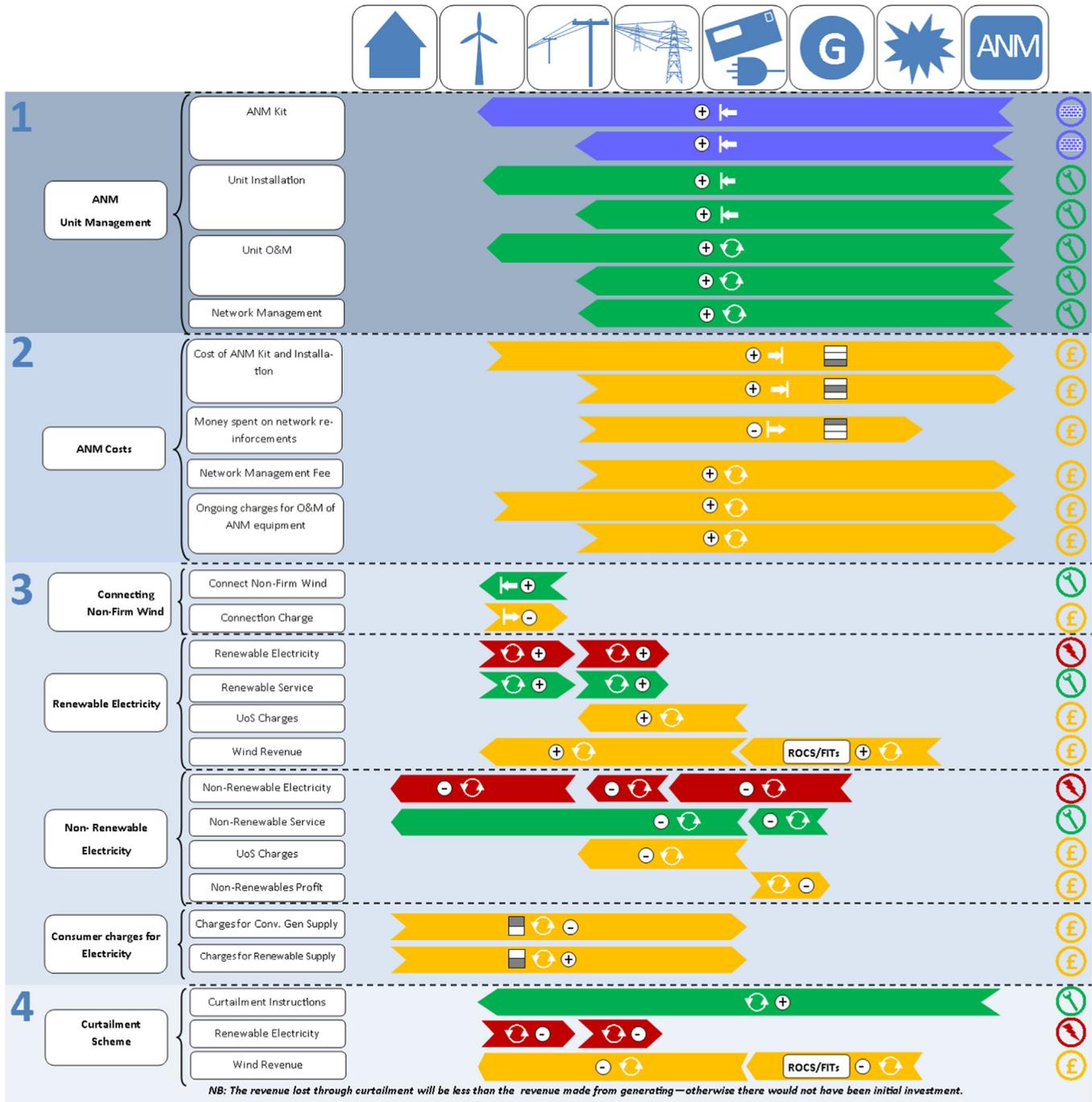


Fig. 5. Business model of ANM scheme operating non-market PoA based on models developed by SuperGen HiDEF distributed energy modelling project (Environmental Change Institute at University of Oxford, 2011).

the ANM scheme. There is potential for each of these roles to be carried out by different contractors in the future, or for the DNO to take upon the role of ANM operator.

The base case against which all flows are compared is a standard network configuration, without the inclusion of any network management or incentives to encourage renewable energy. Most domestic electricity users source power from vertically integrated suppliers and large centralised generators. The base case network is currently at full capacity and the DNO would like to allow renewable generation to connect as soon as possible. The standard way of doing this, would be to pay for network upgrades i.e. upgrading transformers, overhead lines, etc.

#### 4.2. Non-market ANM scheme

The model shown in Fig. 5 demonstrates the flow of money and services between key stakeholders in an ANM scheme applying a non-market PoA such as LIFO. It proposes that the cost of ANM management and installation of shared network equipment be recovered through Distribution Network Use of System (DNUoS) charges, similar to the way in which network reinforcements are recovered. A more detailed description of Fig. 5 is given below.

In strand one of the Fig. 5 the ANM equipment is provided and installed by the ANM actor. They also manage the network and provide operation and maintenance (O&M). In strand two, the cost

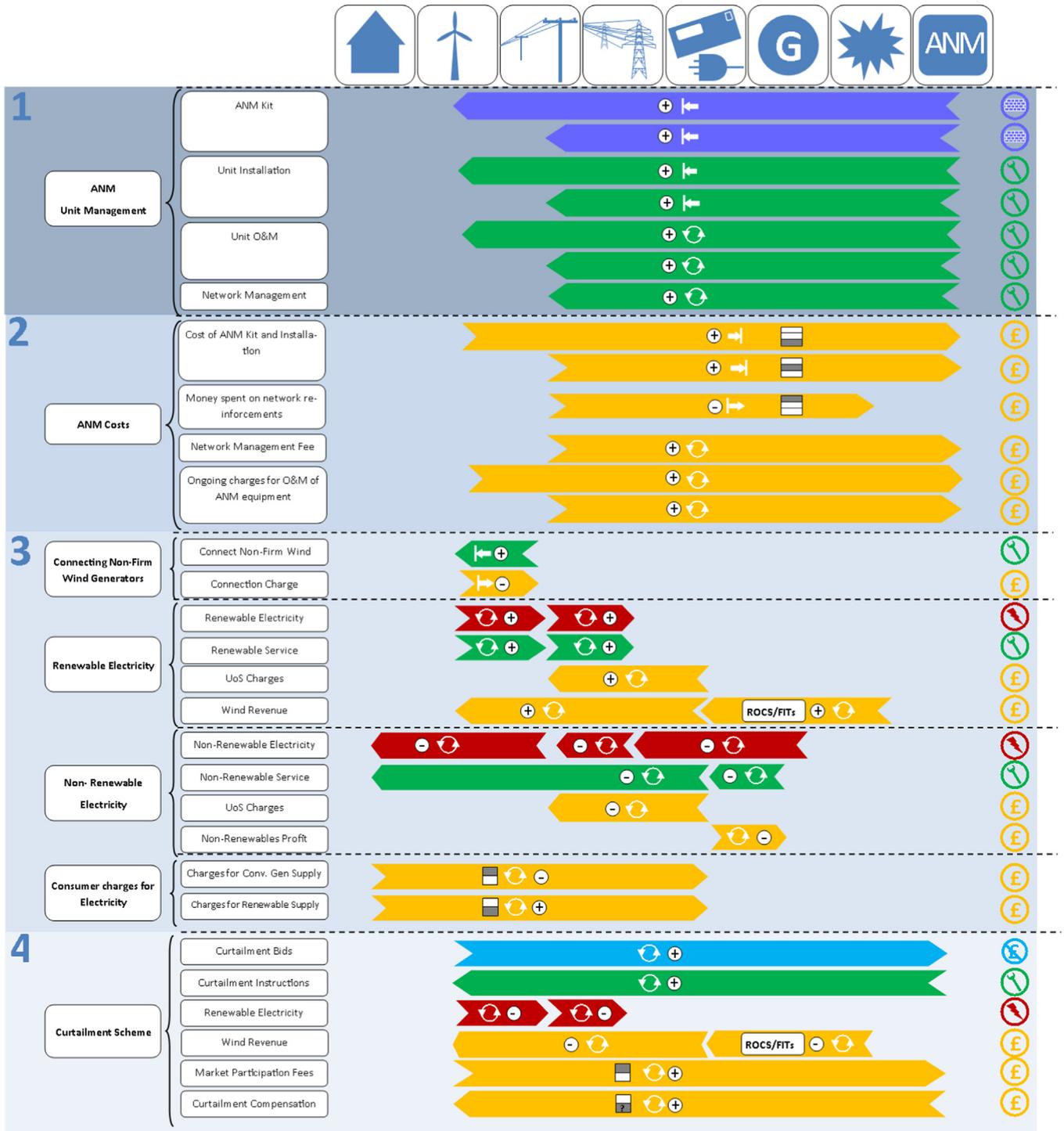


Fig. 6. Business model of ANM scheme operating a market PoA based on models developed by ECI (Environmental Change Institute at University of Oxford, 2011).

of ANM equipment is paid for by the NFG owner and the DNO. The NFG owner costs for connection charge and ANM equipment is lower than the connection charge under a traditional arrangement, which would include both shallow and a proportion of deep connection upgrade work.

Strand three highlights the changes in types of generators used and how this is passed on to customers through DNUoS charging. The installation of an ANM scheme on the network allows more generation to connect to the network under a non-firm connection. The increase in renewable generation reduces the volume of

electricity provided by conventional generating methods. There will be a portion of the DNUoS charge for the NFG which will account for central ANM equipment and management; this however, is lower than costs which would be attributed to the generator if deep network reinforcements were carried out.

Finally, strand four deals with the curtailment of NFG. This is managed by the ANM operator. As a result of curtailment, there is a reduction in export of renewable energy, and therefore a reduction in revenue and profit made by generators from ROCs or FITs when compared with firm connected generation. The

curtailment of wind power will be a result of one, or possibly more of the reasons listed in Section 1 (e.g., frequency or voltage limits, network stability or thermal constraints).

In addition to the basic recovery of costs for the construction, operation and maintenance of the ANM scheme, there is the option to create ancillary services by incentivising domestic Demand Side Management (DDSM). The installation of storage devices in the homes of domestic customers is being trialled by SSE for the NINES project (Scottish and Southern Energy Power Distribution, 2012). As part of this project, SSE are also required to develop a sustainable business model to incentivise the uptake of storage devices in the homes of domestic customers and a mechanism through which to distribute the incentive.

#### 4.3. Market ANM scheme

Similar to Fig. 5, the business model proposed in Fig. 6 demonstrates the flow of money and services between stakeholders in an ANM scheme applying a Market PoA e.g., where generators submit bids and are curtailed based on the value of the submitted bid. The first three strands of Fig. 6 match those of Fig. 5 therefore the same logic and processes apply.

In strand four of Fig. 6, the diagram proposes a method of recovering the cost of running a curtailment market. The non-firm generators submit curtailment bids via an aggregator on a regular basis, which could be hourly, daily, weekly, monthly, etc. – depending on system operator preference. This value (£/MWh) gives an indication of the desire to be curtailed. This value is likely to reflect the value of lost ROCs or FITs and possibly additional running costs such as O&M and repayment interest.

Use of system charging can still be used to cover the cost of ANM installations; however any compensation to be paid to generators for reducing output will come from the curtailment market fund. This will be funded by charging a market participation fee. The market participation fee may take a form similar to Balancing Services Use of System (BSUoS) charges applied at to participants in the wholesale market at transmission level in GB (National Grid, 2012a).

It is unknown if the level of compensation received by the wind farms will be more, less or equal to that previously received through incentive schemes such as ROCs and FITs. This will depend on market competition, choice of compensation payment and will change over time.

This model assumes that the ANM operator deals with individual NFG directly however, it is possible that an Aggregator may act as a ‘middle man’ between ANM Operator and NFG. This would allow small wind farms who are perhaps not experienced enough, or capable of dealing directly with a market system to benefit from the market ANM scheme.

## 5. Conclusions and policy implications

This paper has outlined a number of Principles of Access for the curtailment of non-firm generation in Active Network Management schemes and how the costs of Active Network Management might be recovered as ‘business as usual’ by power network operators.

Firstly an extensive literature review has allowed the reader to understand the current issues faced by renewable generation wishing to connect to power systems. The drive in the last decade as a result of EU Carbon targets and UK Government incentives has resulted in an increase in the volume of wind generators wishing to connect to both transmission and distribution networks. This increase in connection applications has not always been met by increased investment in deeper network reinforcement and

therefore network operators have been forced to consider alternative connection approaches in order to allow renewable generation connection. One method of doing so is installing an ANM scheme which can manage power flows on the network by curtailing wind generation at times where there are constraints e.g., voltage limits or thermal line limits.

The literature review then goes on to discuss the small number of ANM trials at distribution level and examples of curtailment from transmission level in the UK and worldwide are used to develop a number of PoA at distribution level. These include LIFO, a PoA which has successfully been implemented in the Orkney ANM scheme, and Pro-Rata which was selected by UK Power Networks for use in their FPP project in Cambridgeshire.

The case studies presented in Section 2.2 give an overview of ANM schemes operating in the UK, and one proposed in Belgium. Lessons learned from the Orkney ANM scheme are being applied to the NINES ANM scheme in Shetland. The cost of all UK ANM schemes discussed in the paper is significantly lower than the traditional network reinforcements as demonstrated in Table 2.

In Section 3, a quantitative analysis of different PoA arrangements is presented. This allows comparison between three non-market PoA and the impact they each have on NFG connected to an example network. Constraint analysis techniques are used, and the CFs compared in order to highlight the impact PoA can have on the revenue of NFG.

As Ofgem encourages DNOs to move towards BAU for ANM schemes, there is a need to determine how network owners and operators will recover costs associated with ANM schemes. There are a number of different ways in which network operators could recover costs and a qualitative analysis of the options led to the development of the business models presented in Figs. 5 and 6. The development of new BAU cases will depend on a number of factors, including regulation changes, distribution code changes, market configurations, etc. The more changes required by any proposed business model, then the more difficult it may be to implement these within a reasonable time frame.

In the long run, markets can result in the best scenario for all parties however there are still a large number of issues to consider with regards to curtailment markets and wider ANM roll out. The inclusion of such technical difficulties, mean that the initial benefits of market PoA are not always apparent.

For centralised ANM equipment i.e. the central controller, there are uncertainties as to how the cost of such large, shared equipment will be recovered. One option is to charge the initial group of NFG connecting to the scheme; however this could discourage small developers from connecting. A second option, and the one which is proposed in Figs. 5 and 6, is to recover the cost of shared ANM equipment through DNUoS charging. This would result in some of the cost being passed on to demand customers and the DNO would have to justify this additional cost to the regulator.

Curtailment of wind generation will result in a reduced profit for the wind farm owners from ROCs or FITs – however this could be compensated through use of a Market curtailment scheme. Depending on the size of market participants, and number of

**Table 2**  
Summary of ANM vs. reinforcement costs.

	Additional wind (MW)	ANM cost	Traditional reinforcement costs
Orkney	25	£500 k	£30 million
Shetland NINES	10–15 <sup>a</sup>	£33.54 million	£300 million
FPP	24.2	£6.7 million	£15.3 million

<sup>a</sup> The NINES scheme also includes a 6 MWh battery, a district heating system and domestic demand side management scheme.

competitors, the level of compensation will vary. It is unknown if this will be higher or lower than ROC/FIT levels. Future work by the author is to explore market behaviour of wind generators in curtailment schemes in order to determine likely outcomes from a Curtailment Market.

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