

A Road Map to Deliver Smart Grid in the UK

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Summary

The concept of a 'smart grid' involves the combination of instrumentation, communications and analytics that allows power network infrastructure to be operated in a dynamic and efficient manner as opposed to the 'passive' operational approach which is currently the norm in the UK. There exists general consensus that the challenges of climate change and system security, in particular the ability to accommodate significant volumes of decentralised and renewable generation, requires that the network infrastructure must be upgraded to enable smart operation. Failure to do so will act as a major obstacle in the transition to a low carbon economy.

A second important aspect of network development involves the construction of a number of strategic interconnections across the North Sea to create a new off-shore grid. This opens up the opportunity to more fully exploit the vast untapped potential of off-shore wind energy. However, there are a series of obstacles which have hitherto hindered progress in upgrading the network. In particular, the current regulatory regime is not well designed to encourage network operators to embrace new technological opportunities and this is exacerbated by the extent of the risk and uncertainty involved.

The government has a key role to play in injecting the necessary momentum by providing strong direction to the regulator on the outcomes that must be delivered. In addition, the government needs to ensure the appropriate financing routes are in place that will enable Ofgem to set a regulatory framework that leads to a low cost of capital for investors whilst retaining the necessary management incentives on network operators to deliver the required outcomes. The creation of a Green Investment Bank provides a useful vehicle to help meet this objective since the government would be able to underwrite losses arising from changes to the policy framework and any resulting stranding of assets.

The government road map should be phased in three stages, designed to ensure that network developments do not obstruct or slow down the decarbonisation of the power system:

- *Prepare (2010 – 2015):* Early in this period the government must identify a series of key indicators and associated targets for the implementation of smart grid and ensure that the regulator is obliged to deliver these targets. The network operators need to develop their plans to meet the targets and this will need to be based on sufficient testing and trialling of the solutions to be adopted. Finally, the regulator will need to ensure that

the appropriate regulatory and commercial arrangements are in place to drive the subsequent deployment process.

- *Enable (2015 – 2025)*: During this decade the power network needs to become fully automated and interconnected and this process must be driven by obliging the regulator to ensure that staged targets are met against a series of key indicators. These indicators might include parameters which specify the system coverage of instrumentation, grid efficiency achieved, carbon reduced from a more efficient grid, proportion of despatchable demand, capacity of non-generation balancing services and progress with key strategic interconnectors.
- *Deliver (2025 onwards)*: The power system will have changed enormously by this time and the regulatory and commercial arrangements for the networks must support the ongoing progress towards a fully decarbonisation future.

It is a major undertaking to initiate the transition to a smart grid future and the government will need to develop an approach which tackles the complicated technical, regulatory and financial issues involved. Nevertheless, the urgency to undertake this transition means that it is vital that we do not hide behind this complexity and avoid taking the necessary steps. This note sets out an ambitious but practical set of actions that we believe are necessary to drive the transition that the UK power system requires.

Context

Traditionally, local power distribution networks have been built and operated on the basis of providing sufficient transport capacity (wires, transformers, etc.) to cope with the range of potential demands from local power users. The core activity of network businesses has involved investment in the infrastructure to create new capacity or maintain existing capacity, and operational interventions have largely resulted from the need to repair faults, typically arising from extreme weather events. This so-called 'passive' approach to system operation has proved adequate hitherto given that power flows on the network have been fairly predictable. However, this benign situation is unlikely to continue.

The transition towards a low carbon economy will trigger a series of changes in the way power is produced and consumed which will create a number of challenges and opportunities for distribution network operators. In particular:

- Much of the expected growth in large scale renewable generation will result in new generation capacity embedded within distribution networks. Moreover, the power produced by these generators will be intermittent and difficult to predict, being driven by factors such as local weather conditions.
- The drive toward reducing the carbon footprint of the built environment is likely to lead to many homes and businesses producing their own heat and power through small scale micro-generation units.
- Electricity demand could rise significantly as it increasingly becomes the energy source for heating and transport and the old approach of simply increasing system capacity could prove very expensive.

These changes cannot occur to the extent required unless changes are made to the way the distribution networks are managed. It is not feasible to accommodate significant embedded renewable and micro-generation on the network and maintain system security without moving towards a more dynamic approach to network operations. This, in turn, will enable the infrastructure assets to be used more efficiently, thereby reducing the amount that needs to be spent on reinforcing the network.

The concept of a 'smart grid' involves the combination of instrumentation, communications and analytics that allows a more dynamic and efficient operation of network infrastructure. There are a whole range of technologies and approaches that can fall within this definition, however, the ultimate goal would involve four key dimensions:

- Full monitoring in real time of power flows and network condition across the system,
- The real time communication of this data to network control centres,
- Expert computer systems capable of identifying optimal operational responses to changes in network condition, and
- The ability to remotely control levels of generation and demand along with other elements of network configuration.

It is now broadly accepted that a transition towards smart grid infrastructure is an essential element in the transition to a low carbon economy and most developed economies are therefore beginning to grapple with the best way to effect such a transition. Technology

already exists that would enable smart grid operation – the challenge is one of deployment and investment. This note sets out the obstacles to such a transition and proposes a way forward for government as it seeks to identify policies for the roll-out of smart grid.

The delivery challenge

Despite the fact that technologies already exist that would enable smart grid operation, it has not proved easy to initiate a process to upgrade the UK electricity networks. There are several significant obstacles:

1. *Regulatory regime:* Distribution network companies are a product of the regulatory regime that has driven their behaviour for nearly 20 years. They have been incentivised to deliver capital investment programmes rather than increasing spending on improving system operation and this, in turn, has reinforced the focus on refining tried and trusted methods and approaches. One of the key benefits of smart grid is that it has the potential to reduce the need to reinforce grid infrastructure. Moreover, the transition to smart grid will involve the adoption of a variety of new technologies and operating practises which will inevitably increase the risk associated with delivering outcomes. It is, therefore, not surprising that the network companies have failed to embrace the transition to smart grid as a core business imperative and changes in the regulatory regime are necessary to rebalance incentives between capital and operational expenditure and encourage network operators to take risks with new operational practises.
2. *Technology risk:* Information and communication technology is central to a smart grid and this is a field which has seen radical change over recent decades. It is likely that this level of change will continue and, therefore, a high probability that currently available technologies will become obsolete over relatively short timescales. This situation demands careful specification of technical standards such that the system can be adapted as new technological opportunities arise in addition to ensuring that robust ‘cyber-security’ systems are in place.
3. *Customer behaviour:* It is, as yet, unclear how changes in customer behaviour might emerge. Customers might remain largely passive purchasers of the product electricity in which case any behavioural change will need to be driven through regulation and the imposition of new centrally determined products and services. Alternatively, customers might be attracted to explore a range of new energy service retail products which in turn reveal new benefits to improve quality of life alongside reducing energy consumption and cost. In light of this uncertainty, the level of prescription and centralisation of customer facing aspects of a smart grid system -in particular, smart metering systems- is the subject of much debate.
4. *Future network need:* There are a number of credible future scenarios for how the electricity system may look in 20 years involving very different levels of demand, generation mix and the extent of interconnection to other power systems. It is impossible to design a network investment strategy that is robust to all possible future outcomes and progress demands that some strategic decisions are taken about the shape of the future system. This would be a significant intervention and there is no precedent in the current regulatory framework for such a centralised strategic view to be taken. However, in the

absence of a guiding hand it is extremely difficult to envisage how ‘bottom-up’ investment strategies will deliver the level of change required.

5. **Cost:** Any project to upgrade the entire UK electricity system to ‘smart status’ will not be cheap and will require huge levels of capital investment, perhaps around £20bn over and above the already vast sums needed to maintain and extend the network and install smart meters. The cost of capital will determine how efficiently these investments can be financed and this in turn will depend on the regulatory and commercial arrangements involved. Careful thought is therefore required to ensure that appropriate arrangements are in place to minimise financing costs whilst retaining appropriate incentives on management to deliver the required outcomes.

It is a major undertaking to initiate the transition to a smart grid future, and the government will need to develop an approach which tackles the complicated technical, regulatory and financial issues outlined above. Nevertheless, the urgent need to commence the transition, which is reflected in the consensus for action, makes it important that we do not hide behind this complexity and avoid taking the necessary steps. This note sets out a suggested action plan which we believe is practical and will create the necessary momentum for change.

Lessons from current policy initiatives

The development of smart grids is on the agenda of governments around the world. The USA has been in the vanguard of this initiative with equipment manufacturers investing substantial effort in the research and development of technology that can assist with system efficiency, reliability and demand management and with electricity providers planning a range of smart grid deployments. More recently, the federal government has stepped in with a significant funding infusion of around \$4bn through the American Recovery and Reinvestment Act. However, even in light of this progress, it is generally accepted that wide scale smart grid deployment will be a lengthy and fraught process progressed on a state-by-state, project-by-project basis with each initiative governed by state laws involving energy efficiency, conservation, demand management, metering, and other issues requiring regulatory approval for new rate structures and cost recovery. Although the regulatory process in the UK is very different from that in the USA, this experience does highlight the importance of ensuring that regulation and the associated commercial arrangements are aligned to facilitate, rather than obstruct, smart grid deployment.

Progress at the EU level is somewhat behind that in the USA with most of the work on smart grids focused at the technology and research level. This has led to a variety of efforts to raise the profile of smart grids and highlight the opportunities for power networks¹. Recently, the commission has published a communication on financing low carbon technologies in which it advocates spending €2bn on integrating research and 20 large scale demonstration projects with the objective of facilitating the roll-out of smart grid to 50% of the European Networks by 2020. It is important to note that much of the EU policy work on electricity networks to-date has focussed on developing an integrated European super-grid to promote the security of supply and efficiency of the single European electricity market. A key element for any plan to implement smart grid within Europe therefore must involve aligning smart grid developments

with the requirements of constructing major trans-national power interconnectors, creating the so-called 'super-smart grid'.

In the UK, network policy development has been largely lead by the regulator, Ofgem, through three major initiatives:

- The Energy Strategy Network Group (co-chaired with DECC) brings together key stakeholders in energy networks and work to-date has largely focussed on identifying transmission system needs to accommodate ~35% renewable generation by 2020. It is now turning its attention to smart grids with a view to producing recommendations for government on a deployment programme.
- RPI-X@20 is a major project looking at the possible need for fundamental change to the regulatory framework in light of new investment challenges for networks, including the need to develop smart grids. A number of working papers have so far been published as a result of this work.
- Ofgem has also developed a series of Long Term Energy Network Scenarios (LENS) to help inform the development of network policy.

In parallel with these longer term policy initiatives, Ofgem is conducting a periodic review of the price control arrangements for distribution networks with the outcome due to cover the period from 2010 to 2015. Previous attempts to incentivise innovation in network operation have proved ineffective, largely due to the relatively small financial sums involved. Therefore, in recognition of the urgency to move forward the implementation of smart grid technology over the period covered by the current price review, Ofgem has proposed a Low Carbon Fund of up to £500m that distribution companies can use to finance major smart grid pilot projects.

The next stage in the development of smart grid policy in the UK was flagged by DECC in the recent Low Carbon Transition White Paper. This stated that the government intended to publish a high level vision for a future smart grid later this year, followed by a delivery plan. Given that progress is being made at EU level and by Ofgem in the UK, it is important to understand the role government has to play in driving forward smart grid implementation.

The role of government

The future is highly uncertain and inherently unpredictable and any course of action -or inaction- represents a bet on future outcomes. It is interesting to note that the Ofgem LENS scenarios identified policy issues such as the role of government and the level of focus on the environment as key uncertainties in addition to other more fundamental issues such as technological change and customer behaviour. It is inevitable that a regulator that has historically been focused on cost efficiency will be cautious about sanctioning huge investment that may prove to be wasted under credible future scenarios.

Government therefore has two important roles in driving forward the transition to a smart grid future:

- Firstly, to inject momentum by clearly setting out the parameters within which it expects Ofgem to act to ensure that time and effort is not wasted in preparing for alternative futures, and

- Secondly, to recognise the extent of the ‘policy change risk’ and the impact this can have on the costs of investment and, therefore, to reduce investment costs by creating financing routes that insulate investors from the risk (cost) of future policy change and any associated stranding of assets.

A key challenge for government is to decide how it shapes the actions of Ofgem to ensure that momentum is appropriately injected. A smart grid will involve the application of a variety of technologies and analytics, and it is unlikely that the government will be able to define a specific technology and mandate a nationwide roll-out. On the other hand, an overarching framework that can incentivise the network operators to identify the number of ‘bottom-up’ projects that would be necessary to create a smart grid will be extremely difficult to define. We believe that the government needs to identify a series of key indicators for the implementation of smart grid, and give Ofgem the obligation to ensure that the regulatory and commercial arrangements are in place to deliver these outcomes. This would be analogous to the role of Ofgem in relation to the renewables targets where it is not for Ofgem to assess whether the targets are sensible, but rather to facilitate their delivery through appropriate reforms to the market arrangements. However, we believe that the critical role played by Ofgem in the activities of network businesses suggests a stronger and active mandate to ensure delivery. Key indicators for a smart grid might include, for example, the proportion of premises with smart meters and load that can be despatched, the proportion of the system which has been fitted with instrumentation which can send real-time information to automatic system control analytics, and the efficiency and carbon reduction achieved by such automation.

Network operators will need a clear business case to invest the time and money necessary to deliver a transition to smart grid and the returns will need to reflect the risks involved. Unless the government puts in place a financing route that insulates investors from significant policy in addition to performance risk, there is a real danger that investors might demand excessive costs of capital or simply be unwilling to provide the necessary funding. It seems that a government backed Green Investment Bank can fulfil a valuable role in meeting this objective.

Latest Ofgem thinking as part of the RPI-X@20 reviewⁱⁱ advocates an ‘adapted regulatory framework’ where a combination of industry and Ofgem define the investment path going forward taking into account government targets and policy. It is argued that this will ‘encourage innovation (including trials) and learning, and take account of the value of keeping options open’. However, there is a real risk that ‘keeping options open’ can translate into inaction unless the outcomes are tightly defined by government and aligned with a rapid transition to a smart grid future.

Finally, the government needs to arrive at a definitive view on the value of interconnectors in delivering both decarbonisation and improved security of supply. There is little dispute that a well interconnected Europe has the potential to deliver improved security of supply and at lower cost than a narrow nationalistic solution. However, this depends on an effective European market in which resources are shared equitably between member states. Perhaps of greater significance is the fact that strategic interconnectors can open up the option of moving towards an energy system that is virtually entirely supplied through renewable energy sources

by enabling the full potential of, for example, offshore wind energy in the North Sea or concentrated solar power from the Mediterranean to be shared across Europe. It is therefore important that government progresses investments in strategic interconnectors in parallel with the programme to deploy smart grid technologies. This initiative would almost certainly require that strategic interconnectors are provided with a regulatory return instead of taking merchant risk as is the case under the existing regulatory framework.

The smart grid road map

The government needs to establish a road map that includes clear and measurable indicators against which progress can be assessed. Moreover, Ofgem must be obliged to deliver these outcomes in the most efficient manner possible and it is important to establish whether this requires any amendment to existing statutory objectives. Hitherto, government energy policy has focussed primarily in two key areas:

- Increasing volumes of low carbon generation (renewables, nuclear, coal CCS)
- Changing customer behaviour (energy efficiency, distributed generation, smart metering)

However, the benefits from many of these developments will ultimately be limited unless corresponding changes occur in network infrastructure and operation. The timescales for the road map for smart grids must therefore be co-ordinated with other developments to ensure that networks do not constrain and, potentially, promote developments in low carbon generation and efficient consumption. There is likely to be a limited period of time during which the existing network and operational procedures will be able to cope with increasing levels of decentralised and renewable generation. However, at some point, network operators would need to restrict the use of such assets -or operate the system at higher risk levels- and this will significantly slow down the transition to a low carbon economy. We therefore recommend a road map that is split into three discrete phases: prepare, enable and deliver.

Prepare: 2010 – 2015

It is unlikely that the penetration of renewable energy will grow to the extent before 2015 that it cannot be accommodated within the existing network along with current upgrade proposals or that system balancing cannot be achieved using currently available sources of balancing services. This provides a valuable window of opportunity that must be fully utilised to prepare for the future beyond this point.

By 2015, the network operators must have developed complete investment plans for how they will deliver the transition to smart grid and they must have undertaken -or been sufficiently closely involved with- the necessary testing and trialling to ensure that these plans can be delivered. This requires that Ofgem approves the necessary investment costs that will enable this objective to be achieved. It is unlikely that Ofgem will be able to determine this through setting aside a 'financial pot' -such as the £500m Low Carbon Fund- but instead will need to take a view from a technological perspective against the future outcomes specified by government. The price control arrangements will have to be specified in a sufficiently flexible manner such that the necessary testing and trialling can be undertaken in a scope and scale that facilitates substantial learning. It is likely that a range of trials will be required, from small scale

testing of individual technical solutions, through to studies covering the 'smart' operation of whole towns or cities. In addition, the trials should include technologies which integrate the smart meter rollout with the smart grid to assure that the maximum benefit is achieved from the smart meter rollout as it occurs.

As part of the testing and trialling process, Ofgem will need to confirm the technical standards that will underpin the smart grid system. This is an important exercise which is necessary to ensure that future technological developments can be adopted without requiring a significant retrofit of existing instrumentation and equipment.

In addition to undertaking the necessary technological preparations, Ofgem will need to confirm and then implement the regulatory and commercial arrangements that will underpin the subsequent deployment of smart technologies. As mentioned previously, it is likely that changes will be required in order to shift the emphasis away from increasing network capacity towards investments that improve network utilisation, and network operators will need to be incentivised to take increased risk with new technologies and operating practises.

It is also important that this period is used to stimulate new providers of balancing services such as demand control and storage. It is recommended that regulations are introduced to force system operators to 'pump prime' these markets which will become very important in subsequent years. For example, system operators -potentially both at the transmission and distribution level- could be given a long term and increasing obligation to purchase a proportion of balancing services from non-generation sources. System operators would therefore need to enter into long term contractual arrangements during this period to ensure that these services are available in sufficient volumes in subsequent years.

During this time period, network operators should have incentives to commence early implementation of any technical solutions which demonstrate significant smart grid benefit and facilitate a full smart grid. This is critical to ensure that the UK does not delay in achieving carbon reductions from a smart grid, which may be necessary to overcome shortfalls in other areas.

Finally, the government and Ofgem will need to agree during this period which strategic interconnectors need to be built to improve system security and open up the opportunities for transmission from areas of large renewable power resource. It is likely that this will involve joint initiatives with other north western European Member States in specifying and agreeing a North Sea transmission infrastructure. It is likely that a new regulatory framework will be required to underpin these investments and that a tender process could be involved to ensure the assets are constructed at least cost.

Enable: 2015 - 2025

The decade from 2015 to 2025 is extremely important since it is during this period that the UK must change from an energy system similar to the one we have today to one that is very different. Network infrastructure must not hold up this transition.

During this decade, the networks must become fully enabled to deliver the smart grid future

and this will involve:

- A nationwide re-fit of the power network to create a fully network-connected system that identifies all aspects of the power grid and communicates its status and the impact of consumption decisions to automated decision-making systems on the network
- The construction of new strategic interconnectors and appropriate international co-ordination of system balancing
- The development of a range of commercial arrangements to support system balancing from new sources such as storage and the demand side

The delivery of this outcome will be underpinned by the government road map to smart grid, which needs to involve a number of key indicators and a target delivery profile against these indicators (typically moving from low levels in 2015 to ~100% levels in 2025 or sooner, since some smart grid technologies are likely to be required to facilitate the delivery of 2020 renewables targets). These indicators and targets will need to be specified as early as possible in the 'prepare' phase since this will allow the network operators and Ofgem to make the necessary preparations ahead of 2015. It is likely that the key indicators will include parameters which specify the system coverage of instrumentation, proportion of despatchable demand, efficiency of the system, capacity of non-generation balancing services and progress with key strategic interconnectors.

By 2025 at the latest, it is essential that we have a fully network-connected system that identifies all aspects of the power grid and communicates its status and the impact of consumption decisions to automated decision-making systems on the network, along with a North Sea power network capable of connecting significant additional volumes of off-shore wind power. This will provide the basis for accommodating large volumes of decentralised renewable generation, meeting the increase in demand associated with the electrification of heat and transport sectors and providing the springboard to move towards a fully decarbonised power system.

Deliver: 2025 onwards

It is impossible to say how the market will evolve in 20–30 years time. Key developments might include:

- High penetration of electric vehicles
- New products to control household energy demand
- Significant increase in local renewable generation

In addition, experience might identify that the regulatory and commercial framework requires further development.

However, it is important to be clear that these developments can only be realised in the context of a fully automated and interconnected grid system and it is vital that this state of readiness is achieved by 2025.

Costs and financing

The costs of developing a fully automated and interconnected grid system are significant. The recent analysis by Baringa for DECCⁱⁱⁱ estimated the costs of a nationwide roll-out of smart meters to be around £10bn. In the US, the Electric Power Research Institute (EPRI) estimates that national distribution of smart grid and smart metering would cost approximately \$197bn -covering 142 million customers of electricity in the US who purchase about \$343bn of electricity annually^{iv}- and it projects that such an investment will produce benefits over 20 years equal to 4 to 5 times the required investment.^v

Since a large portion of the cost is associated with adding sensing to the transformer network, the network design in the UK should result in a substantially lower cost due to a customer density per transformer of 125 in the UK compared to approximately 5 homes per transformer in the US. Therefore, costs in the UK are likely to be less than the US figures of £867 per customer or approximately £25bn in total.

The cost of new interconnectors will depend on the distance and terrain covered and the capacity involved, however, the Britned interconnector (260km and 1GW) cost around £0.5bn.

These costs (before taking into account any of the potentially substantial benefits) represent only a small part of the vast overall sums required for investment in the energy sector -Andris Piebalgs recently estimated €1tn across Europe- let alone that required for other infrastructure assets (transport, water, etc). With these enormous sums involved it is important that policy makers focus on reducing financing costs since small increases in the costs of capital can equate to very significant sums of money.

Income for the networks is currently determined by Ofgem through a variety of regulatory arrangements and a key aspect of the regulatory design involves the allocation of risk between the licence holder (and its investors) and customers. Traditionally, network businesses have involved relatively low levels of risk enabling Ofgem to insulate customers from the risk of non-delivery whilst attracting sufficient investment through setting (relatively) low costs of capital.

However, the move to new technologies and operating practises associated with smart grids involves a potentially sharp increase in the risks of delivering required outcomes, and Ofgem will have to decide how much of this risk rests with the companies and how much with customers. If too much risk is placed with investors then high capital costs will be required and it may even be difficult to attract the necessary investment. Alternatively, complete removal of risk from investors may undermine the management incentives to ensure effective delivery of the required outcomes. In the current proposals for the Low Carbon Fund, Ofgem has suggested that only 10% of the investment capital is placed at risk, even though there is the real prospect that the entire pilot could be self-financing. This highlights the appreciation that risk can act as a significant deterrent to action by network operators.

As part of the smart grid road map, the government must ensure that adequate and cost-competitive financing routes are available for network investment. The concept of a Green Investment Bank, where investments are underpinned by government guarantee, presents the opportunity for government to underwrite certain key risks, such as the stranding of assets arising from changes in the policy framework. This presents Ofgem with the opportunity to insulate customers from significant risk whilst ensuring that investors are only exposed to those risks necessary to incentivise delivery of the necessary outcomes. Therefore, even though the total investment sums associated with the implementation of a smart grid are relatively small within the overall context of the infrastructure investment required, a Green Investment Bank still has an important role to play in facilitating this vital element of the transition to a low carbon future.

Conclusions

The government must develop a road map for the implementation of smart grid infrastructure which ensures the necessary investments have been made which promote, rather than delay, the deployment of low carbon generation and efficient consumption solutions. This in turn requires that key indicators are identified and corresponding targets set such that a fully automated and interconnected grid system is in place by 2025 at the latest. There is a window of opportunity between now and 2015 in which the necessary preparations and trials can be made to ensure that appropriate deployment plans are developed along with the changes required to the regulatory and commercial framework. Ofgem has a key role to play in this transition and must be responsible for ensuring that these targets are met which may require changes to existing statutory objectives. In addition to setting a technical road map, the government also needs to ensure that appropriate and sufficient funding routes are available to meet the targets. A Green Investment Bank has an important role to play since it presents Ofgem with the opportunity to restrict the risks placed on investors to those necessary to incentivise delivery of the necessary outcomes without allocating all the remaining risk to customers.

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About Green Alliance

Green Alliance is an independent charity working to make environmental solutions a priority in British politics. We work with representatives from the three main political parties, government, business and the NGO sector to encourage new ideas, facilitate dialogue and develop constructive solutions to environmental challenges.

ⁱ see, for example, ‘Towards Smart Power Networks: Lessons learnt from European FP5 research projects, EUR 21970’

ⁱⁱ Regulating energy networks for the future: RPI-X@20 Working Paper 3, July 2009 , Delivering desired outcomes: who decides what energy networks of the future look like?,Ofgem

ⁱⁱⁱ Baringa Partners, April 2009, Smart Meter Roll-Out: Market Model and Evaluation Project

^{iv} U. S. DOE Energy Information Administration, January 2009, “Electric Power Annual, Table 7-1 Number of Ultimate Customers Served by Sector, by Provide” and “Table 7.3. Revenue from Retail Sales of Electricity to Ultimate Customers by Sector, by Provider, 1996 through 2007”,

^v EPRI, July 2004 , Power Delivery System of the Future: A Preliminary Estimate of Costs and Benefits, .