ICT Applications for the Smart Grid Opportunities and Policy Implications

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This report discusses "smart" applications of information and communication technologies (ICTs) for more sustainable energy production, management and consumption. The "smart grid" is a particular application area expected to help tackle a number of structural challenges global energy supply and demand are facing. The challenges include:

- The direct impact of energy supply industries on climate change and other environmental impact categories.
- Explosion of energy demand worldwide over the past decades.
- Wider uptake of renewable energy sources in national "energy mixes", which holds specific challenges.
- Accelerating diffusion of electric vehicles, which will impact volumes and patterns of electricity demand.
- Provision of reliable and secure national electricity infrastructures.
- Electricity provision to un served parts of the population in developing countries.

This report discusses these challenges in greater detail and links them to innovative applications of ICTs. These linkages provide the basis for what is termed the "smart grid", i.e. electricity networks with enhanced capacities for information and communication. In concluding, this report outlines policy implications for government ministries dealing with telecommunications regulation, ICT sector and innovation promotion, consumer and competition issues. But policy implications can reach further than that and the European Commission's recent Energy Strategy is just one example of how ICTs are expected to mitigate environmental challenges across the board. It points to the importance of ICTs "in improving the efficiency of major emitting sectors. [They] offer potential for a structural shift to less resource-intensive products and services, for energy savings in buildings and electricity networks as well as for more efficient and less energy consuming intelligent transport systems" .

Similarly, OECD ministers see ICTs and the Internet as a key enabling technology for Green Growth, a fact that resounds in the Green Growth Strategy report presented in May 2011 (OECD, 2011a). However, the magnitude and persistence of energy and electricity challenges require joint agendas of ICT firms and utilities, ICT and energy policy makers, as well as bridging dispersed academic and civil society communities around the smart grid.1 A major conclusion of this report is therefore that there is an for co-ordination between energy and ICT sectors, integrating also inputs from stakeholders in transportation, construction and related sectors.

Current and Future Stakes :

Global energy challenges are immense. Over the past three decades, global energy production and consumption have accelerated to unprecedented degrees. Between 1973 and 2008 (35 years) total energy production has basically doubled (OECD calculations based on

IEA World Energy Statistics). This is problematic because close to 70% of global energy demand is satisfied using energy generated from sources that emit relatively large amounts of greenhouse gases (carbon dioxide, CO2, is one of them). The energy supply sector, which is responsible for one quarter of global greenhouse gas (GHG) emissions, has therefore become a major target of climate change mitigation action

The link between energy and electricity

Electricity is a pivotal element in understanding global energy challenges. Electricity by itself (its existence) or its consumption does not emit greenhouse gas emissions. It is an energy carrier, a sort of intermediary, between the supply of primary energy sources (e.g. coal) and the demand for energy-using services (e.g. transport, heating, lighting) (see Figure 1). It is, in fact, the main energy carrier used around the world for residential, commercial and industrial processes next to fuels .

The climate challenge related to electricity stems from the fact that over two-thirds of global electricity production is generated from the combustion of fossil fuels (IEA, 2010a). The electricity producing sector is a major user of fossil fuels, responsible for one-third of global fossil fuel use (IEA, 2010b). As a result, electricity plants have outpaced other contributors in terms of greenhouse gas emissions (GHGs) since the 1970s, making mitigation action in the electricity sector a necessary condition for sustainable economic growth worldwide.

Further to the past increases in contribution to climate change, the electricity sector globally is facing structural challenges that will amplify the detrimental effects of business-as-usual practices on the environment. The emerging shift from internal combustion engines to electricity-powered engines is only one of them. Further challenges involve the provision of electricity in developing countries, industrial demand for electricity as well as a reliable electricity supply. The latter factor expands the "smart grids"discussion beyond environmental considerations to include the economic development dimensions of electricity. Reliable electricity supplies are necessary to power manufacturing and services provision, to empower poor populations, etc. The required investments to satisfy energy demand will be large if no changes are made to the volumes of energy consumption and their patterns.

A list of key electricity sector challenges

To understand the potential of ICT applications in the electricity sector, it is important to get a solid understanding of the key challenges in the sector. On a global scale, the main energy sector challenge is the dependence on fossil fuels such as oil, gas and coal. This dependence has environmental and economic implications. From an environmental perspective, it is evident today that the combustion of fossil fuels is a major contributor to anthropogenic causes of climate change. Moreover, the combustion of fossil fuels has other polluting characteristics, notably acidification of land and water resources through emissions of sulphur and nitrogen oxides (e.g. "acid rain"). From an economic standpoint, dependence on scarce resources that, in the case of most OECD countries, need to be imported creates ulnerabilities to changes in prices and availability. Political and social unrest in oil-exporting countries have contributed to price shocks in the 1970s and 1980s leading to "car-free" days in some countries. In 2008 and 2011, these issues have re-emerged with unrest in a number of major oil-exporting countries.

Growing levels of living standards and industrialisation in emerging economies expands the demand for energy originating in non-OECD countries. About half of global electricity production took place in the OECD area in 2008; this was down from over two-thirds in the 1970s (IEA, 2010a). Energy demand in the OECD is expected to remain flat over the next two decades while the global total is projected to more than double (increase by 151%), driven by growth in emerging economies (IEA, 2010c). As a result, a growing number of countries compete for scarce energy resources. More and more energy-exporting economies will need to satisfy domestic energy demand as economic development advances, creating further pressures on global availability of oil resources. New reserves for fossil fuels might be discovered and exploited, e.g. through deep water drilling, Arctic exploration, shale gas.

A look at the traditional energy sector value chain translates global energy sector challenges to tangible areas for action where ICT technologies already provide solutions or might be able to do so in the future.

- **Electricity generation** is the process of converting primary energy sources to electricity as the energy carrier. This includes conventional power plants (nuclear, oil, gas), incinerators (waste to electricity), on-site generators, etc. but also wind turbine parks, solar panel installations, etc.
- **Electricity transmission** is the first step in the transportation of energy, encompassing high voltage transmission lines (overhead, underground, seabed) that typically use alternating current (AC). Transmission systems under high voltage and using direct current (HVDC) are an important element in energy systems where generation is far from the sites of consumption (e.g. off-shore wind parks or hydro power). The largest transmission line today covers a distance of 2 000 km between a large hydropower plant under development in the Chinese provinces of Sichuan and Yunnan and the city of Shanghai. Use of direct current is typically associated with lower physical losses of electricity than alternating current, but requires additional equipment investments when compared with AC.
- **Electricity distribution** refers to power delivery to the point of consumption, i.e. medium and low voltage power lines that use almost exclusively alternating current (AC). These distribution lines can span several kilometres starting at substations that transform high voltage electricity to medium and low voltage electricity, ending at electricity meters at the customer site.

Role of the "Smart Grid"

Definition

Various definitions of the smart grid exist. Before proceeding towards a working definition for the purpose of this report, it is important to highlight that the smart grid is not a product. It must be seen as a continuous process of modernising existing electricity grids and of designing future grids. The smart grid is meant to address a number of key challenges – environmental and economic – that the electricity sector is facing. The use of ICTs and Internet applications are at the centre of this modernisation.

Smart grids can essentially be defined by their functions and their components. Environmental and economic challenges in the electricity sector transcend individual steps in the value chain. The smart grid is therefore expected to address the key challenges stakeholders in the sector are facing: mitigation of climate change, disruptions in supply of conventional energy sources, exploding global demand for electricity, wider diffusion of renewable energy sources, accelerating use of electric vehicles and louder consumer demands for greater transparency.

Turning to the components, smart grids are typically described as electricity systems complemented by communications networks, monitoring and control systems, "smart" devices and end-user interfaces

"A smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability."

Policy Implications

Overarching challenges for policy makers

A key message underlying this report is that innovation drives the development of the smart grid. The smart grid is expected to help achieve levels of electricity production that are sustainable in the long run,that reduce environmental burdens, but that also permit individuals to maintain or improve standards of living. Policy makers have some options at hand to facilitate "green innovation" and transformational change through the use of ICTs in the electricity sector (OECD, 2011b). Diversification towards sustainable energy sector products, services and infrastructures can be achieved through i) market mechanisms, e.g. for transparency and access to information for all value chain participants, ii) financial incentives, e.g. contribution to investment costs or tax breaks for infrastructure investments, iii) targeted regulation, e.g. the recent EU Directives mandating a roll-out of smarter electricity meters that inter alia provide improved information to final customers (2006/32/EC and 2009/72/EC). Governments can also facilitate innovation "spill-overs" from the ICT to the energy sector and related industries such as transport and construction. Ways to do so include promoting R&D and commercialisation overall, reducing barriers to entry for smaller enterprises, supporting cross-sector technology development and diffusion and coordinating national policy agendas for energy, IT and communications (see OECD Council Recommendation on ICTs and the Environment, 2010b).

. Information and communication:

Information asymmetries across the electricity sector value chain remain an important issue to tackle, and with them the need for effective and reliable communications channels. The electricity sector's "line of command" in cases where electricity demand risks peaking (e.g. extremely hot or cold days) remains to a large degree patchy and mediated. Final electricity consumers, in particular residential consumers, have little effective means of obtaining information about the current state of electricity production, its availability, cost and environmental impacts. Press releases issued by utilities about upcoming peaks may or may not be picked up by the local media and customers may or may not pay attention to aggregate information about the electricity system and its state. Direct messages over digital communications channels, especially when linked with customer-specific information and advice, represent "low-hanging fruit" as far as communication channels are available.

Information asymmetries also affect upstream processes. Utilities have relatively little information about disaggregated electricity consumption patterns below the distribution system level and losses of electricity along transmission and distribution lines are not always accounted for systematically.

- **Economic and financial hurdles:** High investments in research, development and deployment (or RD&D) are necessary to modernise national electricity systems. National grid assets in OECD countries are often several decades old and function close to maximum capacity. In many emerging economies electricity infrastructures are "greenfield" investments – this means more advanced technological levels from the start but it requires higher investments too. Overall, the IEA estimates that maintenance and expansion of transmission and distribution networks globally will require investments of over USD 8 trillion between 2010 and 2050 (this excludes investments in power generation). Making these grid investments "smart" would add at least USD 3 trillion to the bill (IEA, 2010b). Looking at closer horizons, needed investments are estimated at around USD 600 billion in Europe by 2020 and close to USD 500 billion in the United States by 2030.26 Although proponents of the smart grid point out substantial returns on investment, concerns also exist that some purposes of the smart grid (e.g. energy efficiency and conservation) might not be consistent with business models that are traditionally based on volume sales. Large-scale investments are also at risk from low and falling levels of private and public-sector spending on energy R&D over the past decades. Despite ambitious political agendas in this area, expenditures are unlikely to rise substantially, reflecting the impact of the economic crisis and tightening public budgets.
- **Consumer acceptance, engagement and protection:** Improved information on energy use and better access to it can bring substantial social, economic and environmental benefits. Mediated or automatic control of electric devices can help manage electricity demand and lower electricity bills. Benefits of the latter sort can be of particular importance to low-income groups spending relatively large parts of their household income on energy. However, trial outcomes on electricity demand and costs are ambiguous. Various survey results show that consumers are concerned about privacy issues and costs related to smart meters. These concerns need to be addressed when designing products and services from the start, otherwise public opinion risks turning against smart grid initiatives. The smart meter, for example, provides valuable information, but it also adds a level of complexity to an area of consumption that so far used relatively simple tariff structure (c.f. Consumer Focus, 2010). Dynamic pricing of electricity will change that, making electricity prices dependent on levels of electricity supply, demand and their environmental impacts. These changes are necessary, but they will require well-designed interfaces between the user and the technology. And it requires behavioural changes that can come about through guidance and education. Consumer concerns around the smart grid focus also on electricity provision to poorer and vulnerable parts of the population. Consumer rights groups highlight that smart meters potentially lower the operational barriers for utilities wishing to remotely turn off electricity supply or switch customers to more expensive pre-paid tariffs (c.f. Consumer Focus, 2010). It therefore seems necessary to meet these new technical possibilities with improved legal and other safeguards for concerned customers. Otherwise, the smart meter risks facilitating wider diffusion of controversial business practices.

ICT-specific policy implications

Policy implications that are of specific relevance to ICT policy makers and telecommunications regulators include:

Regulatory and networks issues

Converging energy and telecommunications services. The report shows that energy and telecommunications services are increasingly intersecting. The smart meter is a prime example of smart grid technology that blends electricity provision and consumption with advanced communication requirements. There is a potential need for open access provisions allowing smart meter service providers and utilities access to data capacity over telecommunications networks.

Connectivity.

Communication channels need to be available across the economy to all electricity users to maximise the potential benefits of smart grids. Ensuring communication channels are available universally across the economy will remain a key goal of policy makers and there are significant potential synergies that could be exploited between communication and electrical distribution companies (e.g. utility pole or duct sharing). Increased reliance on communication networks in the electricity sector will put to test existing infrastructures regarding speed, quality of service and equal treatment of competitors' information. Although the need for real-time communications links along the electricity sector value chain is likely to be an exception, fast response times are nevertheless necessary to simultaneously send control signals to virtual power plants that can comprise hundreds, or even thousands of individual entities. The number of connected devices could grow by orders of magnitude if projections for annual sales of electric vehicles (7 million worldwide in 2020) and mandated smart meter installations are realised (around 180 million in Europe in 2018).29 Utilities, grid operators and 3rd party intermediaries will depend on efficient network infrastructures to control the charging (grid-to-vehicle) and discharging (vehicle-to-grid, vehicle-to-home) of electric vehicles. Bandwidth requirements are difficult to estimate. On the one hand, data traffic will predominantly cover status information and control signals, which can be designed for reduced size. On the other hand, the sheer amount of connected entities and devices that will have to communicate simultaneously in smarter grids could require significant bandwidth. Finally, there are possible needs for more spectrum for wireless data exchange.

Converging IT and operational technologies (OT). The use of IT is not new to the electricity sector. However, a change is taking place in the quality of engagement between utilities and ICT firms. IT firms that want to provide value-added services in the smart grid need a more detailed understanding of operational processes. This refers to services targeting utilities (e.g. distribution grid management), consumers (e.g. energy consumption optimisation), or both (e.g. operating virtual power plants). The trend can be described as converging IT and operational technologies (OT).30 The ever-tighter integration of IT into operational processes in the electricity, transport and buildings sectors requires the alignment of research and policy agendas. Co-ordinated approaches are important to drive innovation (see above), but also to make ICT applications relevant to the challenges of making electricity supply efficient, reliable and sustainable.

Emerging skills requirements.

Immediate skills needs are accelerating at the same time as some OECD countries are noticing declining attraction of students to so-called STEM subjects (science, technology, engineering, mathematics). This could trigger shortages when smart grid developments accelerate. Moreover, the growing need for an operational understanding of electricity, transport and buildings management might require adapting curricula for engineering courses and other IT-oriented education programmes.

Implementation of smart grids projects will require field-specific knowledge of legal frameworks, environmental impacts, etc.

Security, resilience, privacy and exploitation of personal data

. Risks of converging IT and OT. Closer integration of large-scale operational systems with IP based networks such as the Internet increases the openness of critical infrastructures. The

Stux Net worm and its impact on targeted industrial systems is only one example of the potential threats. Operational systems that exchange data with IP-based networks need to be designed for security and resilience. Critical infrastructures converging with information infrastructures require scenario-building that includes consideration of highly unlikely types of events.

. Upholding availability, integrity, confidentiality and authenticity. The smart meter is likely to become a key node for managing information about the electricity system (e.g. grid loads) and about final customers (e.g. preference "profiles" for charging of electric vehicles). Questions must be addressed about unauthorised access to electricity data, the prevention of "malware" in the smart meter and connected devices and other potential security threats. Trends towards greater automation and remote control need to be accompanied by policies that can guarantee integrity and authenticity of information. The smart meter will send and receive control signals that directly impact the functioning of associated devices, e.g. electric vehicles, domestic appliances and small-scale energy generators. In many cases, wireless communications channels will be used for short-distance communications and connected devices.

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