HOW2GUIDE for

Smart Grids in Distribution Networks

Roadmap Development and Implementation

International Energy Agency

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INTERNATIONAL LOW-CARBON ENERGY TECHNOLOGY PLATFORM

INTERNATIONAL ENERGY AGENCY

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Foreword

This *How2Guide for Smart Grids in Distribution Networks* (*Distribution SG H2G*) seeks to provide decision makers with tools and steps for developing and implementing a strategic plan for smart grids at the national, regional or municipal level. It is the second in the International Energy Agency (IEA) series of *How2Guides* (H2Gs), concise manuals that seek to guide the reader through the key steps to developing and implementing a roadmap for a given technology, sector or system. This series has been initiated under the framework of the IEA International Low-Carbon Energy Technology Platform, a key tool for IEA engagement with partner countries on low-carbon energy technologies.

As the global energy demand continues to rise, and with it human-induced carbon dioxide (CO_2) emissions, the need grows stronger for low-carbon technologies to play a prominent role in limiting a temperature rise to 2 degrees Celsius (2°C) by 2050. Improvements in energy efficiency and increased use of renewable energy sources will be instrumental to the decarbonisation of electricity generation necessary to achieve the IEA *Energy Technology Perspectives* (*ETP*) 2°C Scenario (2DS). With the capabilities to modernise grid systems, smart grid technologies are considered critical infrastructural components for the energy sector in an era of climate change.

If successfully planned and implemented, smart grids can offer a host of benefits for widely developed and less-extended electricity grids alike. These benefits enable informed customer choices about consumption, accommodate electricity generation and storage options, and optimise asset utilisation and operating efficiency in response to issues of the variability of renewable energy and resilience to disturbances, attacks and natural disasters. For grid systems in emerging and developing countries, smart grids can offer these benefits as microgrid configurations that have the option of then later being connected to regional or national grids.

Smart grids are made up of a suite of advanced technologies, yet they provide a more "human" element to customer interaction with energy use that is missing from most electricity infrastructure. Smarter grids enable consumers to use energy more prudently in a variety of ways, such as through controls and communication technologies that enhance the efficiency of home appliances, and with electricity pricing that can incentivise more sustainable patterns of energy consumption, from the scale of neighbourhoods, to regions and countries. Ultimately, with greater information flows on how, when and where power is consumed, future energy systems can be designed and operated to more closely match customer's needs.

The possibilities for an energy sector transition through smart grids have only begun to be realised. Project applications can be driven by a simple need to replace an outdated technology aimed to accomplish energy savings. Or, as exemplified by the case studies from South Korea and China in this report, smart grid projects can provide the foundation for fully transformed ecological urban development. In short, smart grids can play a fundamental role in global efforts to pave the path towards a more secure, sustainable and innovative energy future, and this *H2G* is one small part of the IEA efforts to support that transition.

This publication is produced under my authority as Executive Director of the IEA.

Maria van der Hoeven
Executive Director
International Energy Agency

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Introduction

About technology roadmaps

The ultimate goal of a technology roadmap is to optimise the deployment of a specific technology or group of technologies. A roadmap is simply a strategy, a plan that describes the steps to be taken to achieve the stated and agreed goals on a defined schedule. It helps to identify the technical, policy, legal, financial, market and organisational barriers that lie before these goals, and the range of known solutions to overcome them. Roadmaps can be developed for varying levels of deployment, such as global, national and regional, and can be sector- or technology-specific.

The process of developing a roadmap is as important as the final document itself: it represents consensus among the full range of stakeholders consulted in its development, who have considered potential barriers to deployment, sought early solutions and, in some cases, avoided anticipated issues altogether. The success of a roadmap is based on early planning and foresight, establishing a commonly "owned" vision, a full understanding of the national challenges and opportunities, the importance of "champions", commitment to outcomes by both public and private stakeholders, and ongoing evaluation and reports on the progress. Ideally, a roadmap is a dynamic document that incorporates metrics to facilitate the monitoring of progress towards its stated goals, with the flexibility to be updated as the market evolves.

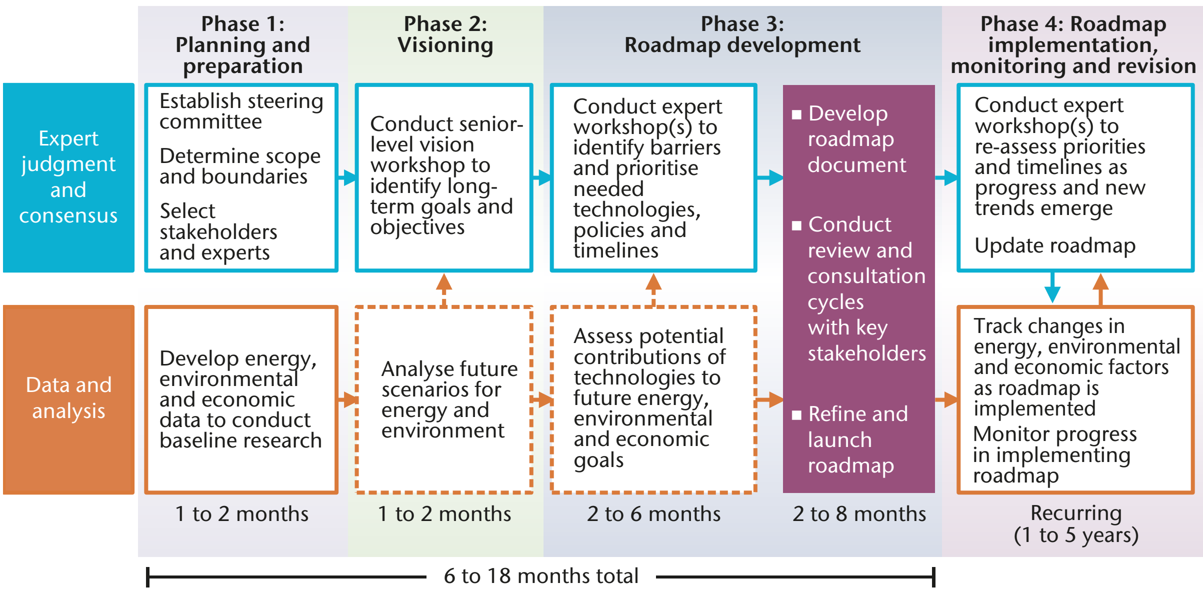
About the *How2Guide for Smart Grids in Distribution Networks*

This *How2Guide for Smart Grids in Distribution Networks* (*Distribution SG H2G*) is designed to provide interested stakeholders from both government and industry with the necessary tools to plan and implement a roadmap for smart grid deployment in distribution networks, at the national, regional or municipal level. This guide draws on the IEA generic roadmap methodology manual, *Energy Technology Roadmaps: A Guide to Development and Implementation* (hereinafter the IEA *Roadmap Guide*),[1] which was released in 2010 and updated in 2014 (IEA, 2014a). Figure 1 shows the general process of developing a roadmap as set out in the *Roadmap Guide*. In addition, the IEA global smart grid roadmap, *Technology Roadmap: Smart Grids*, was released in 2011.[2]

1. The *Distribution SG H2G* is based on the methodological approach to road mapping in the updated version of the IEA *Roadmap Guide* (IEA, 2014a). It envisages four phases of roadmap development, as does this *H2G*. It is arguable that a "Phase 0" of developing a roadmap is to secure a high-level commitment to the overall process. Guaranteeing support for a roadmap, politically, financially and logistically, can be addressed in a "foresight" stage to ensure that the process will carry forward with momentum. This could be strategised through initial representations in a steering group and will likely merge with establishing the stakeholders in Phase 1.

2. It is anticipated that an update of the *Technology Roadmap: Smart Grids* (IEA, 2011) will be released in 2016.

Figure 1: Roadmap development process



Note: dotted lines indicate optional steps, based on available analytical capabilities and resources.
Source: adapted from IEA (2014a), *Energy Technology Roadmaps: A Guide to Development and Implementation*, OECD/IEA, Paris.

The attention on distribution networks has been chosen (as opposed to both transmission and distribution [T&D] networks) because smart grid technologies are underutilised in this part of electricity systems, and because there is a significant opportunity for an accelerated deployment to support the overall development and transformation of the electricity system. However, the application of smart grid technologies to whole systems means there are unavoidable overlaps of some points regarding distribution and transmission networks in this *H2G*. Some of the examples and figures provided consider the entire electricity system (including transmission, distribution, generation and end use), but still serve to illustrate practical aspects that can be applied specifically to distribution networks.

Recognising that it would be impractical to attempt to cover every aspect of smart grid technology in divergent national cases, examples of common drivers and barriers are discussed in detail throughout. Selected case studies are included to illuminate for the reader the wide array of technology applications, along with specific examples of practical issues and solutions.

About smart grids

What are smart grids and why are they important?

The term "smart grid" is used in many contexts. Although there are numerous definitions, the IEA has developed a comprehensive description that has supported the development of this guide and of the IEA smart grid analysis more broadly (Box 1).

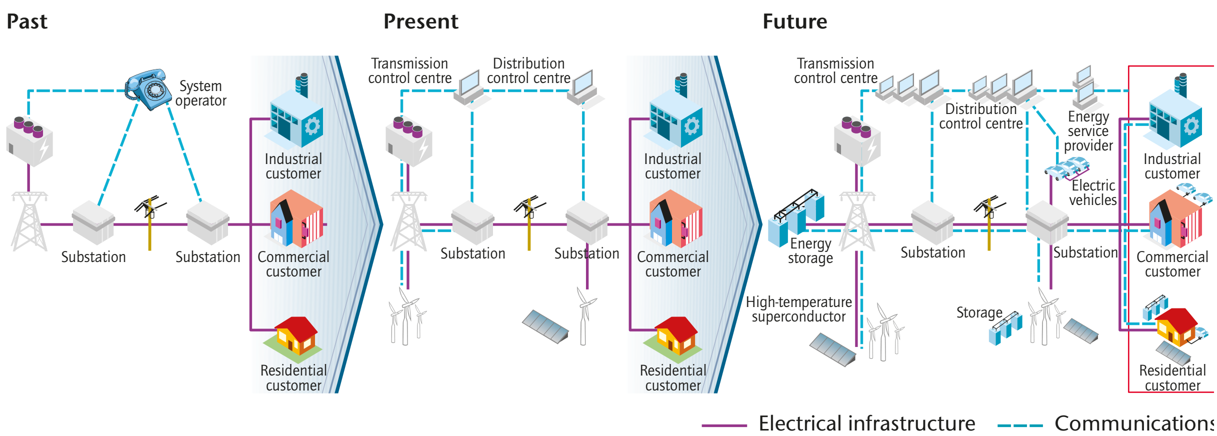
A grid does not become "smart" in a single step. This happens over time through an evolutionary process. Incremental changes and improvements in the system will take place gradually, typically over decades. Figure 2 highlights the need for smart grids to be approached as a system rather than in

Box 1: IEA smart grid definition

A smart grid is an electricity network system that uses digital technology to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users. Such grids are able to co-ordinate the needs and capabilities of all generators, grid operators, end users and electricity market stakeholders in such a way that they can optimise asset utilisation and operation and, in the process, minimise both costs and environmental impacts while maintaining system reliability, resilience and stability.

Source: adapted from IEA (2011), *Technology Roadmap: Smart Grids*, OECD/IEA, Paris.

Figure 2: Electricity system evolution



Source: IEA (2011), *Technology Roadmap: Smart Grids*, OECD/IEA, Paris.

an isolated fashion, demonstrating ways to identify near-term needs in a way that does not negatively impact long-term requirements. Such an approach emphasises the importance of long-term planning and thus complements the road mapping process outlined in this guide. Additionally, when utilised and considered as a system as opposed to singular technologies, smart grids can help shift grid systems to more holistically integrated functioning systems.

Broadly, smart grids can offer the following benefits (adapted from US DOE, 2009):

- enable informed choices about consumption by customers
- accommodate all generation and storage options
- stimulate new products, services and markets
- optimise asset utilisation and operating efficiency
- provide the power quality required for a range of identified needs
- provide resiliency to disturbances, attacks and natural disasters
- catalyse sustainable energy infrastructures for cities, regions and countries.

Figure 3 is an illustration of the common challenges energy systems face and the possible benefits that smart grids may bring in response. This figure illustrates what a country can expect from the integration of smart grids into its electricity system; for instance, how smart grids can address non-technical losses (including electricity theft) by providing a tool for tracking distribution demand and forecasting possible losses, or how smart grids can address peak loads and the variability of renewable energy sources by ensuring flexibility of the electricity system.

Smart grid technologies can be equally effective infrastructural tools in developed and developing countries alike, or more generally, in highly connected grid systems or less-extended grids. For emerging grids in developed and developing countries, smart microgrid configurations often operate in an "islanded" mode, with the option of then later being connected to regional or national grids. This opens possibilities for distributed generation (DG) and to utilise high-quality renewable energy resources in locations far from the main grid, while also providing an efficient approach to grid management that offers both near- and long-term benefits. In areas isolated from national or regional electricity grids, such as in rural settings or in developing countries that have wide gaps in connectivity to a larger grid, smart

Figure 3: Energy system challenges and the role of smart grids in response

Source: Siemens (2013), "The smart grid – Constant energy in a world of constant change: Energy meets intelligence", presentation by Martin Sanne, IEA workshop, Johannesburg, South Africa, 26-28 February 2013.

technologies that can utilise variable renewables and support microgrid infrastructures may also spur economic and social benefits because of the introduction of reliable electricity.

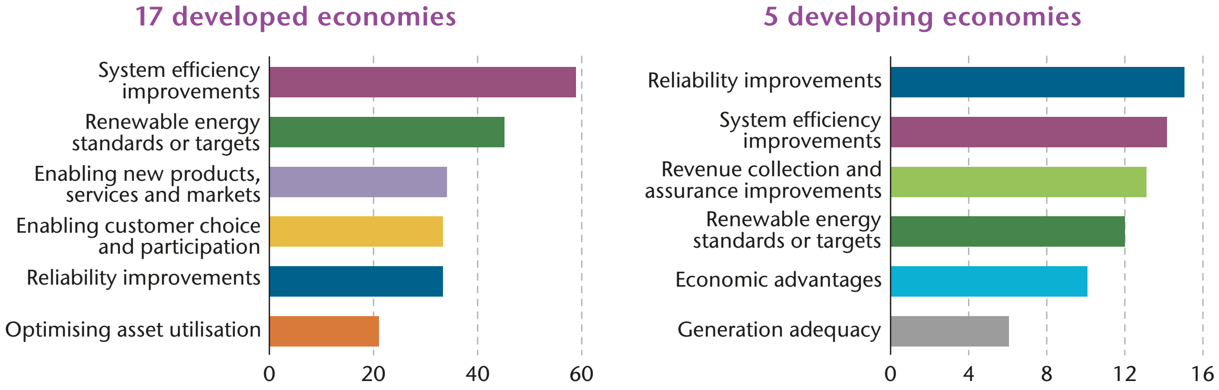
The diversity of applications and drivers for smart grid deployment is further illustrated in a survey analysis performed by the International Smart Grid Action Network (ISGAN) in 2014 (Figure 4). This figure shows the top six drivers for smart grid deployment as ranked by 17 developed economies and five developing economies, respectively.

The difference in terms of prioritisation of drivers is telling. Indeed, many Organisation for Economic Co-operation and Development (OECD) countries stated during the expert workshops for this guide that integrating renewables into the grid was a key driver for the deployment of smart grid technology. In such instances, distribution automation and control centre systems will be of the greatest relevance. In another setting, developing and emerging economy countries involved in IEA expert workshops appeared to be more driven by the need to improve the quality and reliability of available electricity and to reduce non-technical losses, such as electricity theft.

It is important to note that not all the characteristics of the deployment of smart grid technologies that can be accomplished will necessarily be needed immediately or at all in a given electricity system. Technologies can be added incrementally as needed or as able, which means that some investments can be made in the near term and some can be considered for future deployment. Emphasis is best placed on determining technologies that meet a need or address an objective in a way that provides value to the system and its stakeholders. In addition to solutions for an immediate, pressing need, given the long life time of grid infrastructure, flexibility should be maintained to address possible longer-term requirements that may arise in the future. Drawing on analysis of Figure 4, the integration of distributed renewable energy resources may quickly move up the priority agenda for emerging and developing countries as costs for such technologies (e.g. solar photovoltaics [PV]) continue to decrease.

Smart grids can tie together multiple stakeholders' objectives, whether they are societal, regulatory, policy, financial or technology objectives. The ability to link these considerations provides the potential for both opportunities and concerns for deployment. If deployed properly, smart grids can provide a broad range of benefits to the concerned stakeholders. By contrast, deployment of a smart grid system lacking sound planning may result in unexpected barriers and, ultimately, fail to deliver expected benefits.

Figure 4: Top drivers: ISGAN survey analysis of 22 countries



Source: adapted from ISGAN (2014), "Smart grid drivers and technologies by country, economies, and continent," ISGAN website, www.iea-isgan.org/index.php?r=home&c=5/378 (accessed 29 September 2014).

Why focus on smart grids in distribution networks?

The deployment of smart grids throughout an entire electricity system is a very large undertaking that can take many years to carry out. In recent decades, the introduction of smart technologies in the transmission system has progressed at a much faster pace than that in distribution networks. To accelerate the deployment of smart grid technologies in distribution networks is one intention of this *H2G* for reasons that are outlined below.

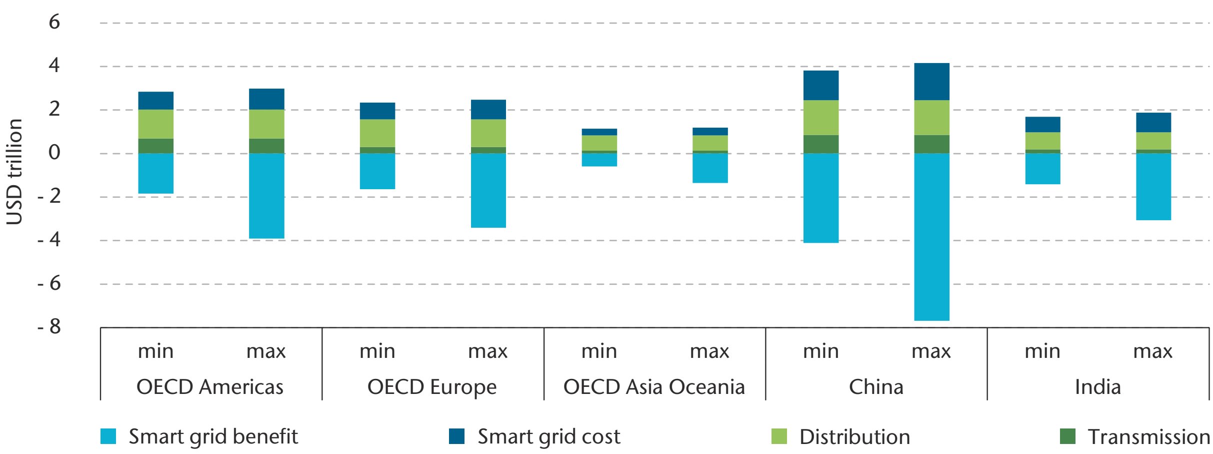
Distribution networks are crucial: they make up over 90% of the total electricity system network length (ABS, 2010) and a very large percentage of all electrical demand and renewable generation is connected to the distribution networks, trends that are expected to continue in the future. The resulting size and complexity of most distribution networks means that under the IEA 2DS[3] distribution network investments will have to make up between 65% and more than 80% of all the network investments to 2050, depending on the locations analysed.

These metrics reinforce the challenge and need for a targeted consideration of distribution networks. Although the cost recovery for distribution grids under a business-as-usual scenario is fairly straightforward, the challenge comes into play with increased DG and demand-side integration going hand-in-hand with coupling to other energy sectors (e.g. heat or transport). Delivering "smartness" for improved asset utilisation, operational efficiency and flexibility are where particular benefits are seen with regard to distribution grids. The investment needed to establish and maintain a distribution network will be significant, but the resulting management of the demand on the system can greatly optimise the planning and operation of electricity systems. Figure 5 provides an overview of the total investments needed for a significant deployment of smart grids globally and demonstrates the benefits that can be gained from investing in smart grid technologies (light blue) as compared with the initial cost (dark blue).

This does not mean that the transmission grid – either itself or the related stakeholders – should be ignored. The interface between transmission system and distribution system operation is a significant challenge. This should be addressed by co-ordinating efforts on all levels in terms of planning, road mapping for smart grids and for other energy or infrastructure technologies, and operation. Transmission system stakeholders should be consulted during the road mapping process for smart grids in distribution networks to consider and co-ordinate appropriately the impacts from investments into and modification of distribution networks. A targeted examination of the distribution network will moderate the size of the roadmap effort and provide the necessary focus to enable practical decisions that can be made to yield benefits in this much needed area.

3. The IEA *ETP* 2DS sets the target of cutting energy-related CO_2 emissions by more than half in 2050 (2009 baseline), and ensuring that these continue to fall thereafter.

Figure 5: Investments needed to upgrade electricity grid infrastructures



Source: IEA (2012), *Energy Technology Perspectives 2012*, OECD/IEA, Paris.

Overview of types of smart grid projects in distribution networks

As previously explained, the number of individual smart grid technologies is vast, and each technology cannot be fully considered in an isolated manner. Individual technologies are often packaged with hardware, communications infrastructure, software and training into various types of smart grid projects, adding intelligence or smartness to the grid in a targeted fashion. Throughout this guide, the term "project types" is thus used to refer to the grouping of technologies into a single type of project for the deployment of smart technologies into the grid.

Of course, each project will have detailed variations depending on the particular objectives or barriers – political, technical or otherwise – that smart grid deployment in a country is aimed to address. Similarly, project types may be cross-cutting and interrelated. Advanced metering infrastructure (AMI), for example, will typically include some items that form part of a project concerning control centre systems. Smart grids that use combined heat and power (CHP) have the potential to provide additional benefits of more efficient heat use. Based on a review of existing projects and feedback received during the four workshops held for this report, the project types summarised in Table 1 are divided into ten categories and outline the vast suite of technologies and options for project applications. (Technology descriptions can be found in Annex 3.)

Table 1: Types of smart grid projects and their function

Project type	*Hardware*	*Systems and software*	*Function*
AMI	Smart meter, in-home displays, servers, relays, communication equipment	Meter data management system, communication software, workforce management systems (WMS)	Revenue collection, reduction of electricity theft, outage notification, service and maintenance scheduling
Customer-side systems	Smart appliances, routers, in-home display, building automation systems, thermal accumulators, smart thermostat, electric vehicle (EV) charging infrastructure, batteries, inverters	Energy dashboards, energy management systems, energy applications for smart phones and tablets, energy billing, EV billing and charging for smart grid-to-vehicle (G2V) charging and discharging vehicle-to-grid (V2G) methodologies	Broad range, but can include energy use awareness, support for demand response (DR), control of individual appliances, provision of smart G2V and V2G, management of heating and cooling devices
Distributed energy resources (DERs): DG	Power-conditioning equipment for bulk power and grid support, communication and control hardware for generation and enabling renewable and non-renewable generation technology that may or may not be connected to the main grid, such as CHP, wind, solar and others		Control, management and monitoring of variable and dispatchable DG assets, system-impacts (e.g. line voltage) management
DERs: Demand response (DR)	AMI systems, targeted customer appliance control devices or systems	Energy management system (EMS), distribution management system (DMS), geographic information system (GIS)	Shift the load to decrease peak demand, increase customer awareness and choices, improve system flexibility, counteract system events, avail cheaper time-of-use (TOU) tariff options and take advance of TOU pricing
DERs: Storage	Power-conditioning equipment for bulk power and grid support, communication and control hardware for generation and enabling storage technology, as well as conversion into other energy carriers (e.g. power to gas)		Control, management and monitoring of storage assets

Project type	Hardware	Systems and software	Function
Substation automation	Automated re-closers, switches and capacitors, remote-controlled DG and storage, transformer sensors, wire and cable sensors installed within the substation	GIS, DMS, outage management system (OMS) and WMS	Optimise substation and support upstream and downstream use of assets
Distribution automation	Automated re-closers, switches and capacitors, remote-controlled DG and storage, transformer sensors, wire and cable sensors		Operation and management of the grid during normal, outage or maintenance conditions, minimising impacts on customers
Control centre systems	Information and communication technology (ICT) equipment such as data storage, monitors, communications security and back-up systems and supporting systems to GIS, DMS, OMS, WMS		Provide visual representation of system status and ability to manage operation and maintenance
Cross-cutting: ICT integration	Communication equipment (power line carrier, worldwide interoperability microwave access, long-term evolution, radio frequency mesh network, cellular), routers, relays, switches, gateway, computers (servers)	Enterprise resource planning software, customer information system	Collect, transmit and analyse electricity system data for specific purposes
Asset management	Sensor technology on some or all assets, communications	Models and methodologies to assess healthy and safe loading for devices and circuits	Manage and optimise asset utilisation and maintenance

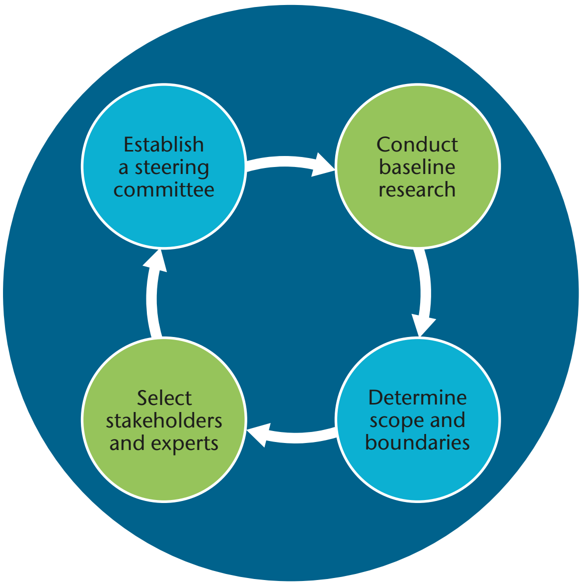
Source: adapted from IEA (2011), *Technology Roadmap: Smart Grids*, OECD/IEA, Paris.

The roadmap development process

Phase 1: Planning and preparation

The first phase of the roadmap process looks at essential planning and preparation that should be considered when starting a roadmap exercise. This section of the *Distribution SG H2G* focuses on two specific aspects of roadmap development tailored to smart grids: identifying stakeholders and conducting baseline research.

Figure 6: Steps in the roadmap planning and preparation phase (Phase 1)



Note: In this figure and in Figures 9, 11 and 12, each circle represents a step in one of the four phases of the roadmap process set out in the *IEA Roadmap Guide*. Green shading in Figures 6, 11 and 12 indicates sub-steps that are discussed in this *Distribution SG H2G*. For more information on the steps in blue, see the *IEA Roadmap Guide* (IEA, 2014a).

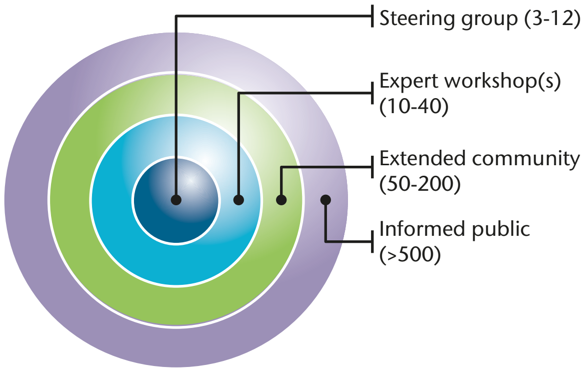
Identifying stakeholders for smart grids in distribution systems

The stakeholders needed to develop a roadmap for smart grids in distribution systems will be defined by the scale and scope of individual projects. National programmes will include residential consumers, industrial companies, manufacturers and vendors of smart grid products of all types, other commercial organisations and the electricity utility industry in all its forms. Beyond this traditional list of institutional stakeholders are governments (which are likely to have national goals that smart grids can help to achieve), regulators who draft and oversee the rules governing how the electricity utility industry operates and environmental and customer-focused non-government organisations (NGOs). Due to the interactions across the electricity system, it is also important to include some transmission system stakeholders. For projects that specifically address regional or local distribution grid issues, additional stakeholders may include municipalities or regional authorities, spatial and strategic planners, property developers, individual distribution system companies, and geographically defined user groups and load centres, such as new housing developments, commercial districts or new industrial load and economic development partnerships.

Not only is it important to identify these stakeholders prior to developing a roadmap, but it is also important to consider how different stakeholders should be involved in the road mapping process. As explained in greater detail in Table 2, plotting identified stakeholders on a "RACI chart"[4] may assist not only in the comprehensive identification of relevant stakeholders, but also in the coherent assignment of functions. Figure 7 illustrates the four categories of stakeholders in the RACI chart: Responsible, Authorised, Consulted and Informed. To assist with the identification of necessary stakeholders in developing a national smart grid roadmap, Table 2 describes typical smart grid stakeholders and lists their possible categorisation according to the RACI chart.

4. The "Responsible, Authorised, Consulted and Informed" (RACI) chart is a management tool used to define responsibilities among a group. It is a responsibility assignment matrix. More information is given in Annex 2.

Figure 7: Categories of stakeholders in the RACI chart



Source: IEA (2014a), *Energy Technology Roadmaps: A Guide to Development and Implementation*, OECD/IEA, Paris.

Table 2: Stakeholder mapping for smart grids

Stakeholder type	Description	Role
Distribution system operator (DSO)	DSOs are typically the owners of the distribution network and are responsible for building, operation, maintenance and development. Often this same entity is the retailer of electricity to the customers, but these roles can be held by other entities depending on the structure of the electricity industry in the respective country or region.	Responsible and/or authorised
Government	This category of stakeholder is often a national, regional or municipal department in charge of energy or electricity. This can sometimes include natural resource ministries and other interested ministries.	Responsible and/or authorised
Regulator or regulating body	Typically charged by a governmental body, this entity is responsible for establishing the rules for the operation of the electricity system and respective actors, as well as setting tariffs based on the established legal framework. For the electricity system stakeholders that own and operate the system to make investments and changes to the physical system or how it is operated, they must seek approval from the regulator or regulating body. In many markets, a regulator's role is to protect the interest of ratepayers (i.e. consumer protection), which links to the fact that many grid investments ideally need to show some level of consumer benefit (direct or indirect), which can be a key barrier absent sound methodologies to assess those benefits.	Responsible and/or authorised
Billing and customer service	The organisation that provides the interface to the customer and collects the revenue from the customer – it may be part of an energy retailer or of a DSO, or an outside third party.	Authorised and/or consulted
Conventional energy generator	This category corresponds to the generation sources that provide the majority of the energy in the electricity system, traditionally coal, gas, nuclear, large hydro or oil. Many markets around the world have both regulated generation and independent power producers using conventional generation. These sources are often connected to the transmission network.	Authorised and/or consulted
Distributed and renewable energy generator	This category refers to the growing segment of distributed and renewable generation owners and operation such as solar, wind, CHP and other sources. These are often smaller in size compared to conventional generation and are connected to the distribution network rather than to the transmission network, and therefore may drive the need for changes and are affected by changes to the distribution network.	Authorised and/or consulted
Energy retailer	The provider of electricity services to the customers in a competitive retail market. Typically, they have customers in multiple distribution network territories and compete for customers with other energy retailers.	Authorised and/or consulted
Independent system operator (ISO), regional transmission system organisation, transmission system operator (TSO)	These entities operate the high-voltage network or transmission system and, depending on the model in a location, they may actually own the transmission assets. If the operator and the owner of the transmission grid are the same entity, the transmission owner and this row should be merged together. It is important to bear in mind that, in addition to differences in asset management, ISOs may differ in regard to market operation, i.e. in some instances an ISO operates the physical wholesale market, while in others this is done by an independent power exchange.	Authorised and/or consulted

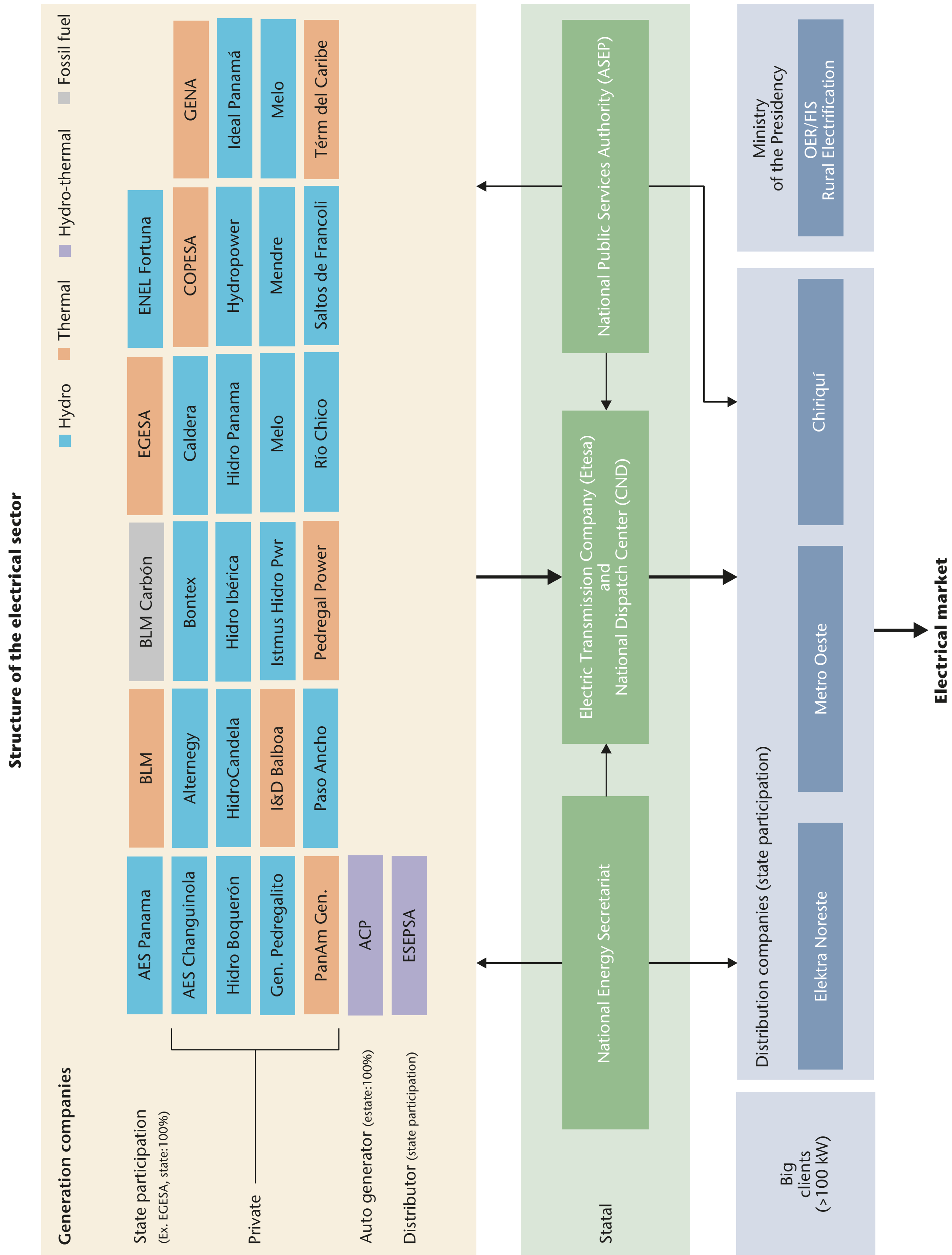
Stakeholder type	Description	Role
Storage or energy-conversion providers	This category refers to the growing need for flexibility as well as the efficient use of DG (including prosumers)* in the distribution grid through electricity storage or energy conversion. As this role is not institutionalised in most countries or regions, guaranteeing representation should be a key consideration.	Authorised and/or consulted
Trade organisation	This stakeholder is the owner of the higher voltage network used to move electricity between cities and major power plants. In addition to the difference in voltage to that of distribution networks, in many cases there is an owner of transmission and a separate operator of transmission.	Authorised (occasionally) or consulted
Transmission owner	This stakeholder is the owner of the higher voltage network used to move electricity between cities and major power plants. In addition to the difference in voltage to that of distribution networks, in many cases there is an owner of transmission and a separate operator of transmission.	Authorised and/or consulted
Emergency services	Police, fire departments and other first responders who deal with emergencies and interoperability of communications equipment (particularly during an emergency) are crucial stakeholders to enable the functionality of technologies for anti-islanding/reverse power-flow concerns, fire codes, etc.	Consulted
Equipment manufacturer	A manufacturer that builds equipment used in building part of the electrical infrastructure, including any part of the electrical infrastructure used in distribution, transmission, generation or customer domains. This stakeholder can provide valuable input as to the technologies that can be deployed, but inputs need to be vetted to ensure that specific interests are not favoured over others.	Consulted
Third-party service providers	Independent firms offering a service that expands on or replaces the services of another entity listed above. Often new providers face significant barriers because existing systems do not consider them when regulation is passed. Questions of data ownership, the role of DSOs and the link between electricity suppliers and smart grid aggregators are likely to be key focus areas in this stakeholder category.	Consulted
Certification bodies	Certification bodies often participate in the safety analysis of many new technologies, notably the public adoption of electricity and the drafting of safety standards for electrical devices and components. These types of organisations can be instrumental to identifying barriers, gaps and key needs in a roadmap.	Consulted and/or informed
Commercial customer	This category includes all non-industrial and non-residential consumption points on the grid (e.g. stores and office buildings, and schools, hospitals and other services-related buildings). The smart grid will enable new or increased opportunities for these stakeholders with DERs. Like residential customers, because of the diffuse and non-expert nature of this stakeholder group, often its constituents are represented by a consumer advocacy groups or by the regulator.	Consulted and/or informed
Environmental NGOs	Such groups may represent a wide range of public stakeholders and parts of civil society that support policy measures and technology deployments that contribute to decarbonising the energy system.	Consulted and/or informed

Stakeholder type	Description	Role
Industrial customer	This category is inclusive of all the manufacturers in the world. They are companies that mine, build, smelt and otherwise transform raw materials into technologies applicable to smart grids. Industrial customers often consume large amounts of electricity and are, in some cases, connected to the transmission system.	Consulted and/or informed
Industry association or union	The interest of various actors in the electricity system can be represented by unions. Unions can be particularly important stakeholders as they can gather significant support or opposition from their members for the roadmap to impact the implementation of its recommendations and milestones.	Consulted and/or informed
Installer	A person or company responsible for building or modernising the electrical infrastructure by adding additional equipment. This could be anything from meters at residences to new substations.	Consulted and/or informed
Residential customer	This category includes all forms of residential housing for people, notably the families and individuals that live in homes and apartments. The smart grid enables new or increased opportunities to be a producer and a consumer at the same time through DG options. Owing to the diffuse and non-expert nature of this stakeholder group, often its constituents are represented by a consumer advocacy group or by the regulator.	Consulted and/or informed
Spatial planner and/or regional economic development body	The body responsible for forward planning economic development, such as commercial and housing projects, in an area. These bodies will enable smart grid projects to take account of future load projections in specific geographies and enable the future proofing of local smart grid projects. These bodies may be quasi-state organisations, independent or in partnership with municipalities or government, and may have access to enabling infrastructure funds.	Consulted and/or informed
Standards development and co-ordination bodies	To facilitate stronger interoperability of technologies and networks, standards and co-ordination bodies should be involved for sharing information and fostering a streamlined functionality of products and services. These bodies can be instrumental in identifying barriers, gaps and key needs in a roadmap.	Consulted and/or informed
System integrator	A company specialised in software development, e.g. by combining commercial off-the-shelf products from different vendors and making them communicate and work together, as well as customising commercial products to better meet the requirements of the project. System integrators are essential stakeholders because interoperability among systems and technologies is critical in the deployment and market adoption of smart grid technologies.	Consulted and/or informed
Third-party communications network	A cellular, fibre, radio, telephone or other communications network that is owned and operated by someone other than the utility that owns the electrical infrastructure.	Consulted and/or informed

Note: Table 2 is organised by the hierarchy of roles. Stakeholders within each of the four RACI categories are listed alphabetically.
* A "prosumer" is a producer of energy and consumer of that self-produced energy.

Turning to a practical example, Figure 8 shows a wide range of stakeholders that would likely have an interest in smart grid deployment in Panama in the initial discussions and feasibility analysis and in the later road mapping process.

Figure 8: Network of stakeholders in Panama



Source: Secretariat of Energy of Panama (2012), "Loss reduction and rural electrification", presentation by Fernando Diaz, IEA workshop, Mexico City, 26-28 March 2012.

Conducting baseline research for smart grid potential

To determine the remits of a national roadmap that focuses on smart grids in distribution networks, it is valuable to carry out an inventory of the country's current situation with regard to smart grid technologies and how they fit into the electricity system as a whole, considering such factors as existing technologies, human capacity and grid interconnectivity. This so-called "baseline research" is also vital to clarifying what a roadmap can be expected to achieve and subsequent timelines.

Conducting baseline research will help to map the key factors and priority areas that affect the decision to develop a roadmap, as well as the contours of the roadmap itself. The baseline research should aim to provide a detailed update on the status of the technologies, markets and policies relevant to smart grid deployment, as set out in Table 3.

The baseline research aims to set a foundation from which the discussion and analysis can begin and should help to determine how and where in the distribution network smart grids can make a significant contribution to addressing problems consistent with the overall energy goals of the country. Not all countries will have the baseline data readily available or be able to perform the long-term modelling that could support the development of a roadmap. If such information is lacking domestically, it can be useful for governments or utilities to work with other organisations for support in compiling this information. Some countries will have larger gaps in data availability, and in these cases may find it useful to seek out-of-country assistance to make it possible to assess the data of comparable energy systems in light of domestic situations and priorities. An increasing number of networks and organisations are emerging that provide assistance to utilities and governments with data and grid analysis to support long-term modelling for the road mapping process. ISGAN, the European Technology Platform on Smart Grids, the 21st Century Power Partnership and the Software Engineering Institute of Carnegie Mellon University are examples of institutions from which support for this process can be sought.

Table 3: Key questions for baseline research on smart grids

Category of question	*Description*
Resources and technology	• Does the country have strong supporting technology strengths (i.e. a strong ICT sector to support smartening the grid)? • What is the present ability of the T&D grids to accommodate variable power generation? • Does the country/region have specific plans or targets for modernising its grids, integrating renewables to the grid, deploying EVs, etc.? • Does the country/region have a technology roadmap for its electricity grids (e.g. for generation, transmission, distribution)? • What is the total number of customers (residential, service, industrial, agricultural)? • What is known about customer-specific load profiles? • What is the amount of electricity consumed (timeframe/unit) and the load curve? • When is the peak demand for power? • What is the overall capacity of the system? • What are the key network metrics (such as length of overhead and underground lines, number of low voltage (LV) and medium voltage lines, size of network area, rural and urban area components, age of network)? • Is the current ability of distribution grids to accommodate variable resources in line with current and long-term deployment levels? • How much experience does the country/region have in developing smart grid projects? • What are the strengths of the existing workforce in the country/region?

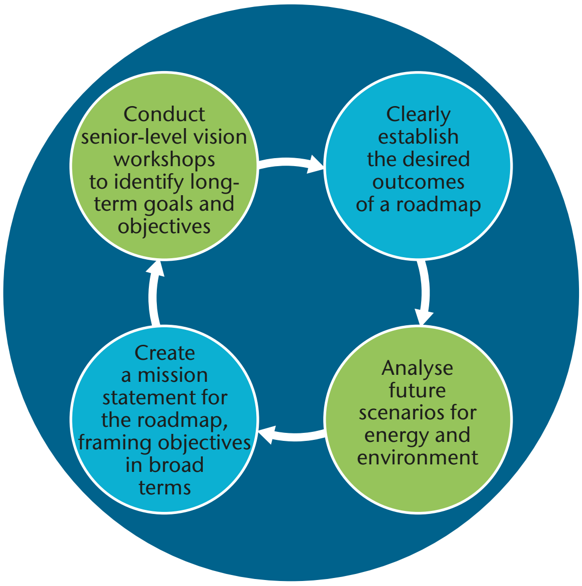
Category of question	Description
Market and energy portfolio	● What are the current market and regulatory frameworks? ● How is the system operated and how are the roles for the TSO versus DSO distinguished? ● How many companies operate within the distribution system(s)? ● What trends are having or are likely to have an impact on the electricity market in the roadmap timeframe (e.g. demand growth, supply deficit, ageing infrastructure, public sector investment, electricity sector restructuring)? ● What near- and long-term investments are planned? ● What is the annual net turnover of the system(s)? ● What is the current and projected future generation mix? ● What are the dominant local energy resources?
Public policy	● What are the key socio-economic priorities that might be supported by the deployment of smart grids? ● Do national/regional policy makers have a coherent energy strategy? Are all the relevant government ministries or agencies involved and co-operating? Have adequate personnel resources proportionate to the scale of the national/regional ambition been allocated within the key bodies to implement change? ● What is the level of national or regional integrative planning (e.g. water-energy-food nexus)? ● Do national/regional policy makers have targets for low-carbon emissions? ● Do national/regional policy makers aim at higher shares of renewable energy in the electricity mix? Does a dedicated policy framework and target for such an increase exist? ● Do national/regional policy makers aim at energy efficiency gains? Does a dedicated policy framework or sectoral target (e.g. for the residential sector) exist? ● Do the national/regional policy makers have industrial policy goals for given technologies? ● Has energy sector reform been considered to allow for large-scale variable generation into national or regional grids?

Phase 2: Visioning

A sound roadmap will contain a clear statement of the desired outcome, followed by a specific pathway for reaching it. Thus, the second phase of roadmap development is to outline a vision for smart grid deployment, within a given timeframe, in the distribution networks of the country or region. This will serve as the mission statement for the roadmap, framing what the roadmap will aim to do in broad terms. This visioning phase builds on the knowledge gained through the involvement of stakeholders in Phase 1 and on the baseline determinations of the current capabilities of the infrastructure to support smart grid deployment. As shown in Figures 1 and 9, Phase 2 may involve senior-level workshops to identify long-term smart grid goals and objectives that align with national energy strategies, including an analysis of future scenarios for energy, as well as environmental and other considerations. A range of tools already exist to assist with developing such scenarios.[5] For further guidance on conducting such workshops, see the IEA *Roadmap Guide* (2014a).

5. See, for example, the European Foresight Platform (EFP), a global network that engages forecasting and other methods of future planning and studies (EFP, 2015). Providing this kind of information for the smart grid context is also a focus of the "Annex 7" activity of ISGAN.

Figure 9: Steps in the roadmap visioning phase (Phase 2)



Source: adapted from IEA (2014a), *Energy Technology Roadmaps: A Guide to Development and Implementation*, OECD/IEA, Paris.

A roadmap will ordinarily also include a set of more specific objectives for the desired outcomes associated with smart grid deployment. These objectives should incorporate the overall vision of the future for smart grids in the target area within the short-, medium- and long-term, including environmental, technology and policy goals. The visioning process should largely focus on the high-level impacts that an improved or optimised distribution system could have on the country or region. Provided below are three concrete examples:[6]

- At the IEA workshop in Johannesburg held in 2012 while developing this guide, the South African Smart Grid Initiative led by the South African National Energy Development Institute (SANEDI) described their vision of using smart grids to revolutionise the South African electricity system by 2030 by integrating 21st century technologies to achieve a seamless generation, efficient delivery and end use, and an overall flexible, scalable and adaptable grid that provides benefits to South Africa as a whole.
- The Irish national roadmap on smart grids released in 2011 considers smart grids in terms of how they can contribute to increasing the amount of variable renewable energy incorporated into the electricity system, improving domestic energy supply security and playing an important role in achieving Ireland's long-term targets for the reduction of greenhouse gas emissions.
- In the Korean Smart Grid Roadmap released in 2010 by the Korea Smart Grid Institute, the vision for smart grid implementation was articulated simply as laying the foundation for a low-carbon, green growth system by 2030.

6. Although these examples are applied to objectives across the entire electricity system, such objectives could also be specific to distribution networks.

Box 2: Active engagement of municipalities in smart grid projects as a development strategy

Researchers from the University of Leeds investigated the multiple benefits of smart grid deployment, particularly for economic development in cities and the civic ownership of smart grids. Capturing these multifaceted benefits could help accelerate smart grid investments. This research identified three specific economic values that are currently uncaptured by traditional ways of paying for smart grids.

First, by regulating spatial planning and managing distributed resources actively with smart grids (thus increasing the hosting capacity), municipalities are in the perfect position to gather and co-ordinate new renewable generators. By connecting renewable energy generators in tranches, non-firm (interruptible) connection agreements can be offered. This approach can avoid the need for conventional reinforcement, which not only makes connections cheaper, but also enables new smart solutions to be offered. Municipalities can retain the tax uplift from new generators in their area and recycle it into further smart grid projects in a virtuous circle.

Box 2: Active engagement of municipalities in smart grid projects as a development strategy (continued)

Second, to attract business and industry into cities, municipalities often subsidise transport and communications infrastructures with economic development funds. This research found that economic development funds have much relevant knowledge that can be applied to smart grids to release the capacity on existing networks (Hall and Foxon, 2014). Municipalities benefit from this mechanism as it enables further economic growth on specific sites for business and industry, leveraging local public/private funding.

Third, a surge of interest on the municipal-scale Energy Service Companies (ESCos) offers new opportunities for DR. New tariff structures can offer load management and reduction on specific parts of regional networks. Innovative business models and regulatory arrangements are being investigated to identify how this approach could offer new services to grid operators for network balancing from aggregated commercial and residential consumers.

Smart grid infrastructures can deliver benefits to a wide range of stakeholders beyond the energy sector. Some of these benefits can enable citywide economic development and deliver real benefits to municipalities. By paying attention to municipal resources, such as business tax retention, economic development funding and new supplier structures, research showed that smart grid projects could bring new stakeholders and new resources to bear on smart grid investment. In future, entrepreneurial cities may be key partners in delivering smart solutions, and should be considered by smart grid project planners.

Source: Hall, S. and T.J. Foxon (2014) "Values in the smart grid: The co-evolving political economy of smart distribution", *Energy Policy*, Vol. 74, pp. 600-609.

Developing a strong vision for smart grids that encompasses how they can improve multiple aspects of a distribution network is essential to utilising the full potential of the technologies, and thus helping countries identify areas in which smart grids could address issues in ways not previously considered. Smart grids stand out because they can often solve more than one problem at once or enhance an energy system in unexpected ways, as demonstrated in Box 2.

The remainder of this section describes a collection of the central drivers behind the deployment of smart grids in national or regional distribution networks, and closes with three case studies that illustrate how certain drivers can be addressed through smart grid technology response actions.

Drivers for the deployment of smart grids in distribution networks

The main drivers for smart grid deployment can differ greatly from one country or region to another. The benefits that can be derived from these technologies are often a concrete response to one or more national or local needs, whether related to technical improvement of the grids or economic, social and environmental advantages. The identification and prioritisation of the drivers for smart grid deployment go hand-in-hand with determining the goals of a roadmap and identifying appropriate smart grid technologies to address these goals. Prioritisation of drivers should help develop a roadmap vision for smart grid deployment that is both comprehensive and realistic.

Typically, drivers for smart grids can be categorised as follows and as detailed further in Table 4:

- reliability (e.g. power quality improvement for electricity grids and risk for loss of load)
- grid efficiency (e.g. management of technical and non-technical electricity losses for smart grids)
- economic (e.g. reducing operation and distribution/transmission costs and opening revenue streams for new producers/consumers, including energy affordability)
- environmental (e.g. reduction of CO_2 emissions through efficiency gains, shifting peak loads and integrating low-carbon technologies)

- security (e.g. technology to mitigate and isolate power outages)
- renewable energy integration (e.g. enabling grid integration of the generation from variable renewables)
- safety (e.g. reduction of accidents to utility workforce)
- cross-cutting (e.g. rural electrification, EV integration opportunities and increased consumer involvement).

The list in Table 4, originally developed with inputs from over 20 developed and emerging economies by ISGAN, an IEA Implementing Agreement and initiative of the Clean Energy Ministerial, is not intended to be all-encompassing. Additionally, some of the metrics will spread across other parts of the electricity system, including generation and transmission. This is due to the interrelated nature of the electricity system as a whole. Great care is therefore required to target metrics that are tailored to measuring progress against the roadmap's specific vision and objectives. However, it is useful to address persistent methodological issues with metrics. For instance, system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI) and momentary average interruption frequency index (MAIFI) are not measured in the same way across markets, and making comparisons among them can be challenging. Stakeholders who develop smart grid roadmaps may want to consider standardising the methodologies used for the metrics (to the extent possible under law/regulation).

Table 4: Categorisation of typical drivers for smart grid deployment

Drivers	*Potential metric/indicator*
Reliability	
Reliability improvements	Change SAIFI, SAIDI and MAIFI
Power quality improvements	Change in customer complaints on power quality
Power restoration improvements	Annual outage data
Network adequacy	Usage hours of/with grid congestion, amount of required re-dispatch, load curtailment following grid restraints
Generation adequacy	Amount of required generation, number of hours during which demand approaches the available generation capacity
Efficiency	
System efficiency improvements (reduction in peak load, losses, etc.)	Percentage of losses, hours of reduced peak load
Optimising asset utilisation	Percentage of substations with advanced measurement technology, percentage of circuits operated with dynamic line rating
Energy efficiency improvements	Reduction in technical losses, reduction in average household use of electricity
Enabling new products, services and markets	Number of different tariffs offered by retailers, number of new companies entering the market, number of companies existing in the market
Customer switching rate	Percentage of customers served by optional suppliers

Drivers	Potential metric/indicator
Economic	
Economic advantages	Total system costs, target electricity price
New revenues	New revenue from DG utilisation
Revenue collection and assurance improvements	Reduction of non-technical losses
Reducing operating and maintenance costs	USD/kWh for maintenance, automated maintenance programme in place
Environmental	
Renewable energy standards or targets	Percentage generation of RE, installed capacity
Reduce carbon footprint	CO_2 emissions
Regulatory compliance	Progress towards targets
Security	
National security concerns	Diversity of generation sources
Enhanced power system resiliency to natural and human threats	Decreased system restoration times due to failures (tested or actual occurrences)
Safety	
Safety improvements	Reduction of accidents to utility workforce
Cross-cutting	
Ageing infrastructure concerns	Accurate asset management data
Increased flexibility	Capacity of distribution network to adapt to changes, whether climatic, infrastructural or by accommodating new generation
Rural electrification	Decreased losses, better voltage control in rural applications, percentage of electrification
Shifting ownership structures	Number of new options for the civic control of local energy systems, percentage of assets owned by local entities
Integration of DG (dispatchable or variable)	Percentage of capacity from the distributed sources
Consumer involvement	Choices for energy usage and percentage of consumers utilising smart grid technologies
Job creation	Number of new jobs

Sources: adapted from ISGAN (2012), "Metrics and Indicators Report", Clean Energy Ministerial, Korea; JRC (2013), "Smart grid projects in Europe: Lessons learned and current developments" (2012 update), Scientific and Policy Report by the JRC of the European Commission, Institute for Energy and Transport, Petten, the Netherlands.

Table 5: Selection of smart grid project types linked to drivers

Legend:

- Can address driver as a primary outcome of the project (Primary)
- Can address driver as a secondary outcome of the project (Secondary)
- Can address driver to a small degree as a project outcome (Small)
- Driver and project type not typically linked (blank)

Driver	Project type: Advanced metering infrastructure	Distribution automation	Control centre systems	Customer-side systems	DER – storage	DER – distributed generation	DER – demand response	Substation automation	Asset management
Reliability									
Reliability improvements	Primary	Primary	Primary	Secondary	Primary		Secondary	Primary	Small
Power quality improvements	Primary	Primary	Primary	Small	Secondary	Small	Secondary	Primary	Small
Power restoration improvements	Primary	Primary	Primary			Secondary	Secondary	Primary	Small
Network adequacy	Secondary	Primary	Primary	Secondary	Primary	Secondary	Primary	Primary	
Generation adequacy	Secondary	Secondary		Secondary		Primary	Primary		
Efficiency									
System efficiency improvements (peak load reduction, T&D losses, etc.)	Primary	Secondary	Primary	Primary	Primary	Primary	Primary	Primary	Secondary
Optimising asset utilisation	Primary	Primary	Primary	Secondary	Primary		Secondary	Primary	Primary
Energy efficiency improvements	Primary			Primary	Secondary		Primary		Small
Enabling new products, services and markets	Primary			Primary	Primary		Primary		Small
Enabling customer choice and participation	Primary		Primary	Primary			Primary		
Economic									
Economic advantages	Secondary			Secondary	Secondary	Secondary	Primary	Secondary	Primary
New revenues				Secondary		Secondary	Secondary		
Revenue collection and assurance improvements	Primary			Primary					
Reducing operating and maintenance costs	Primary	Primary	Primary					Primary	Primary
Environmental									
Renewable energy standards or targets	Secondary		Primary		Primary	Primary	Primary		
Reduce carbon footprint			Primary		Small	Primary	Primary		Secondary
Regulatory compliance				Small	Small	Primary	Small		
Renewables	Primary	Primary	Primary		Small	Primary	Secondary	Small	
Security									
National security concerns		Secondary	Small			Small			Small
Enhanced power system resiliency to natural and human threats		Primary	Primary		Secondary	Secondary	Secondary	Primary	Secondary
Safety									
Safety improvements		Primary	Primary				Small	Secondary	Secondary
Cross-cutting									
Ageing infrastructure concerns	Primary	Primary	Secondary			Secondary	Secondary	Primary	Primary
Rural electrification		Secondary				Secondary	Secondary	Secondary	Secondary
Job creation	Secondary		Secondary	Secondary	Small	Secondary			Small
Increased flexibility	Primary	Primary	Primary	Secondary	Small	Small	Primary	Secondary	Small
Shifting ownership structures			Primary	Secondary		Secondary			Primary
Consumer involvement	Primary			Primary			Primary		

Finally, Table 5 shows the primary, secondary and tertiary links between drivers and various kinds of smart grid projects. This can serve as a starting point for identifying the kinds of smart grid technologies or projects that could address the key drivers within a country or region. As this table shows, some project types will address more than one driver, and, notably, many drivers will result in cross-cutting applications.[7]

This is an important message because, although some drivers may not be of immediate relevance, it is worth considering the incremental cost of adding functionality to a project at the outset to address a potential driver that may be more relevant in the future. The Infrastructure UK and Leeds University's iBuild project termed this type of option-enhancing planning as "passive provisioning" and can be defined as the facilitation of real options within an investment opportunity action (Foxon and Hall, 2014).[8] An example of passive provisioning is to design smart grid projects with the flexibility to upgrade technologies or system management strategies in the future to deal with more or less severe impacts of climate change. Such long-term planning is particularly relevant in the context of roadmap development and energy system investment because of the dynamic nature of local needs.

Project types

This subsection describes network issues that are frequently faced by countries or utilities and that often serve as drivers for the deployment of smart grid projects. The drivers and potential response actions that can be provided by a suite of smart grid technologies are further illustrated by way of three case studies (see Boxes 3 to 5).

Customer-oriented projects

Examples of smart grid projects that are primarily customer-oriented include AMI, DER projects and customer-side systems (see Tables 1 and 5). Figure 10 provides an illustration of the outlook for the AMI technology roll-out in Europe in the second quarter of 2014, which shows the relatively high level of European engagement with the implementation of customer-oriented projects, such as AMI technologies. For such projects, it is important to engage with a broad set of customer-focused stakeholder groups and to pay particular attention to barriers that may impact these stakeholders. Such stakeholders likely include customer groupings[9] and/or customer advocacy organisations, billing and customer service entities, energy retailers and a regulator or regulating body.

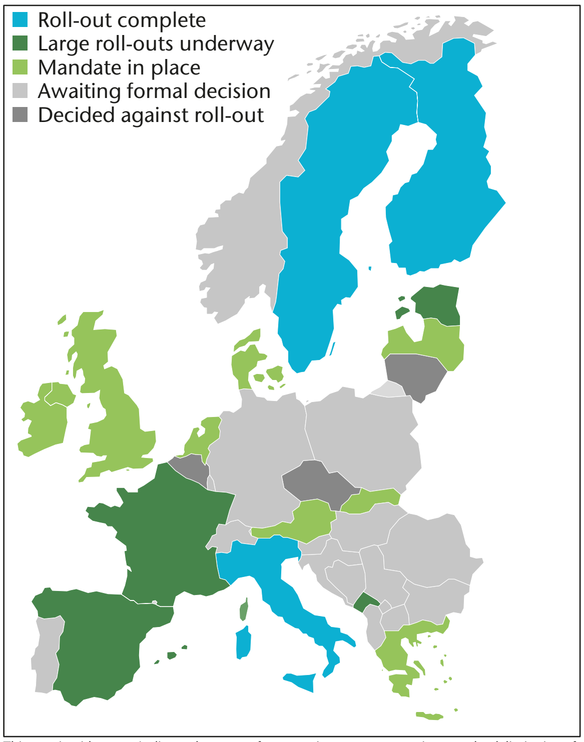
In customer-oriented projects, the key barriers are likely to concern security and privacy, legal and regulatory (especially tariff setting and reliability or service considerations), and project planning and delivery issues. Pilot projects in which existing customers can use and experience the technologies or implement a project on a temporary basis provide valuable input for the full-scale project design. Positive experiences from existing customers may also provide comfort to new customers. In this area, pilot projects can be important for furthering the knowledge of

7. For example, AMI addresses drivers in three broad areas – namely, reliability, efficiency and economic considerations.

8. A real option is an alternative or choice that becomes available through an investment opportunity or action. Chapters 4 and 5 of the *iBuild/Leeds report* (Foxon and Hall, 2014) analyse passive provisioning with a focus on economic evaluation in sustainable energy provisioning, specifically heat network investments.

9. Customer groupings include general population groupings (such as residential, commercial, industrial) and also more sophisticated, nuanced categories based on customer needs. Utilities and other grid decision makers should, ideally, take into account more specific customer needs rather than simply amorphous categorisations, such as residential, commercial and industrial.

Figure 10: European AMI outlook 2014 (Q2)



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries, and to the name of any territory, city or area.

Source: BNEF (2014), "Europe smart meter policy," personal communication, C. McKerracher, 11 December 2014.

customer behaviour and technology practicalities. To facilitate learning applicable to the broader propulsion of smart grid technologies, customers should be deliberately prepared beforehand and surveyed after participating in any pilot study.

Another key solution is communication and education to help stakeholders understand the changes and benefits. Dedicated events and workshops can be useful in this instance. Although customers may not always be in favour of such changes, adequate time for end users to prepare may help to prevent negative responses. Moreover, if a strong rationale is clearly communicated why the changes must occur or why smart grid technology deployment is sought, there may be a higher likelihood of acceptance.

System infrastructure-focused projects

System infrastructure-focused projects have a greater impact on system operators and their respective staff and employees. Projects that typically fall into this category include those for distribution system automation, substation automation, control-centre system improvements and asset management (Tables 1 and 5). Changing the organisational and methodological management in energy infrastructure is often a key challenge and yet is very important as these projects significantly affect how electricity systems are operated and maintained, as well as ongoing planning and expansion. The regulator still plays an important role in determining how this will affect electricity system customers, but the involvement of senior-level management within the DSO is essential. The overall acceptance and participation of all actors in the DSO can determine whether the goals of certain project types are realised.

The solutions to barriers in these types of projects frequently focus on developing an adequate business case for project deployment and on determining ways to finance this through savings in the operation of the system and/or increases in the base rate. Often long-term discussions with regulators, combined with significant analysis as to the needs, benefits and risks of the project, are essential. In such instances, regulators still play an essential role in consumer protection, particularly when rate recovery is used to cover the costs of grid investments, because benefits need to be able to be delivered (directly or indirectly) to the consumers.

Cross-cutting projects

Some technologies can have cross-cutting applications and impacts. The introduction of ICT and a communication infrastructure, for example, can enable multiple other project types, as well as enhanced security, privacy and system planning (Tables 1 and 5). Key barriers to these types of projects often relate to perceived costs and benefits, as well as to privacy issues. Costs for such projects may exceed the benefits if they are not leveraged across various projects carried out over a multi-year plan. Sometimes, the projects themselves may not offer significant benefits but build the foundation for future projects. Stakeholder groups essential to the successful implementation of cross-cutting projects include the regulator as well as senior decision makers and government officials who can influence and approve expenditures that have both short- and long-term impacts, but that can also be the investment of least regret.

Addressing the barriers in cross-cutting projects often require somewhat "out of the box" solutions. For example, addressing communication technology deployment issues from cost, security and privacy perspectives requires collaboration with non-energy system stakeholders, such as telecommunication companies. This may not be a common approach with energy companies that prefer to maintain operation and control of their system in house; however, such partnerships may offer costs savings and expertise not found internally.

Addressing drivers through three case studies

The following three case studies illustrate distribution network restraints that can be addressed through the response actions of smart grid technology, in particular:

- addressing technical and commercial distribution losses and electricity theft (case study 1 in Box 3)
- harnessing the cross-cutting benefits of smart grid infrastructures to catalyse sustainable urban electricity systems (case study 2 in Box 4)
- using a suite of smart grid technologies to improve efficiency and security of supply for both customers and distributors (case study 3 in Box 5).

While the *H2G* has thus far addressed the phases of planning and preparation (Phase 1) and visioning (Phase 2). Phase 3 considers preparation of the roadmap document with a focus on identifying barriers and subsequent response actions, defining timelines and selecting key milestones of technology deployment.

Box 3: Case study 1: Loss reduction programme (Mexico)

Description: In the past, the Mexican electrical utility Comisión Federal de Electricidad (CFE) regularly experienced substantial distribution system losses. In 2011, over 11% of the electricity generated was lost, with approximately 79% resulting from technical losses and 21% resulting from commercial losses or electricity theft. These losses represented USD 2 446 million in decreased revenue. The strategy to reduce losses, introduced in 2011 with actions to 2026, combines smart grid technology with a systematic evaluation mechanism to make improvements in both infrastructure and operational procedures.

Objectives: Reduce technical and commercial losses in the distribution network, while improving the overall infrastructure and optimal functionality.

Main actions:

- systematic field assessments looking for irregular connections, tampered or damaged meters and unmetered consumers (both customers and irregular users)
- use of boxes to seal customers' connections
- construction of distribution networks less vulnerable to tampering and irregular connections
- replacement of obsolete meters
- monitoring public lighting systems
- AMI project reconfiguration of distribution networks
- analysis of distribution feeders with the highest losses
- reactive compensation
- demand management in distribution transformers
- development of a master plan and efficient planning of electrical system
- construction of substations.

Outcome: The long-term strategy to 2026 to reduce commercial and technical losses estimates that targeted investments and planned actions can reduce losses by over 50%.

Source: CFE (Comision Federal de Electricidad) (2012), "Mexican Experience in Reduction of Energy Losses" Presentation by Moises Rodriguez, IEA workshop, Mexico City, 26-28 March 2012.

Box 4: Case study 2: Smart grids for smart cities (China and Korea)

Incorporating smart grids into sustainable city planning has the potential to take advantage of the majority of the cross-cutting benefits that smart grids are capable of providing, from integrating renewable energy into microgrids to enabling V2G technologies. Smart grid technologies can be used as a sustainable energy infrastructure that facilitates the transformation of the energy sector. The Tianjin eco-city project in China and the Jeju demonstration project in South Korea are evolving models of cutting-edge technologies that support advanced, sustainable city planning.

Sino-Singapore Tianjin eco-city project (China)

Description: The Sino-Singapore Tianjin smart grid demonstration project is being constructed in Tianjin (southeast of Beijing) co operatively by the Chinese and Singapore governments, and covers 34.2 square kilometres.

Objectives: The objective is to build an ecological city in which 350 000 inhabitants will live in a friendly environment and harmonious society, frugally using resources while being a model of a developed economy. The role of the smart grid is to provide a sustainable and advanced infrastructure system to support a high-functioning society.

Box 4: Case study 2: Smart grids for smart cities (China and Korea) (continued)

Main actions:

The completed projects as of 2014 include:

- a 4.5 megawatt (MW) wind farm and two distributed PV systems with 5.66 MW and 4.089 MW connected to the power grid
- a microgrid composed of a 6 kW wind turbine, a 30 kW PV system, an energy storage system (15 kW for 4 h) and 15 kW loads
- a 110 kV smart substation
- two double-loop network structures, including 82 switching stations and 22 distribution automatic lines
- a total of 10 000 electricity users in 19 communities installed smart meters, which realised remote meter reading
- a large EV-charging station, which can realise the charging requirements of eight electric buses at the same time
- an optical fibre communication network was built, and the optical fibre was connected to each meter of end-user
- building of an intelligent community, which can achieve remote control for users' appliances and electricity consumption analysis.

Outcome: The project includes 12 completed subprojects aimed to promote energy efficiency and strengthen data application. The eco-city project will be complete in 10 to 15 years, while the smart grid demonstration project was completed in 2011 and has been stably operated since that time.

Jeju Smart Grid Demonstration project (Korea)

Description: The Jeju Smart Grid Demonstration was established in Gujwa-eup, the northeastern region of Jeju Island, Korea, in December 2009. The project was completed in May 2013 as a precursor to nationwide smart grid implementation. It was designed to promote the commercialisation and export of smart grid technologies.

Objectives: The all-encompassing objective is to build the world's best nationwide smart electricity grid and realise a low-carbon, green growth society.

Main actions:

- Smart power grid: real-time power grid monitoring and usage of digital technology to optimise operation of distribution system.
- Smart place: power management of intelligent homes and increased choice of supply options and tariffs for consumers.
- Smart transportation: build and test EV-charging facilities and operate vehicles as a pilot project.
- Smart renewable: operate and expand the use of microgrids to connect DG, power storage devices and EV.
- Smart electricity service: facilitate greater consumer choice of electricity rates and opportunities to produce and sell renewable energy.

Outcome: The Jeju project is part of a 20 year vision to develop a nationwide smart electricity system, which is characterised by self-recovery of grids in the event of failures, zero energy homes and buildings, increased sophistication of the system, increased consumer choice and involvement, and market operation towards optimisation.

A total of USD 250 million was invested between 2009 and 2013 and the test bed was completed in 2013, with the input of the ten consortiums who participated in testing and developing business models. Even with significant investment recently injected into the Tianjin project, the eco-city still only maintains an occupancy of around 8%, which draws attention to the need to involve users and communities in the design and operation of smart grid projects at the distribution grid level. The usability of these technologies is a key measure of the project success and highlights the need to include all stakeholders, such as those consumers who will be using the technologies, in the phases of roadmap development and preparation.

Sources: State Grid Corporation of China (2014), "Smart grid demonstration project in Sino-Singapore Tianjin eco-city", personal communication, 25 December 2014; Korea Smart Grid Institute (2010), Korea's Smart Grid Roadmap, Seoul.

Box 5: Case study 3: Electricity Supply Board smart green circuits (Ireland)

Description: "Smart green circuits" were developed and demonstrated in Ireland, and enabled operational efficiency, monitoring of line conditions, loss reduction and protection. These efficiencies were the main drivers of the demonstration project in Ireland, as the size and scale of the country's electricity distribution system presents unique challenges in terms of maintaining continuity of a high standard of supply to customers and ensuring that network losses are minimised. The Electricity Supply Board (ESB) conducted tests on four distribution circuits, three in rural applications and one in an urban setting.

Objectives: Improve the operational efficiency and monitor the capabilities and integration of DG with technologies that reduce the carbon footprint of the distribution network.

Main actions: A number of systems and applications were evaluated to help create efficient, cost effective and "self-healing" circuits, including:

- A smart fault passage indicator system was added that locates and analyses faults and communicates information to network operators via a general packet radio service that facilitates a quick response. Fault notification is sent to the mobile devices of network technicians.
- An arc suppression coil protection system was installed on ESB's 20 kV circuits. This protection system is designed to: carry earth faults safely while continuing to supply customers; explore and test multiple resources and technologies for reducing losses; explore how DG can be utilised to reduce the carbon footprint of a green circuit; and develop and test new algorithms for estimating the load flows, losses and voltage drops on rural feeders while examining the impact and benefits of voltage control in the efforts to reduce the carbon footprint.

Outcome: The self-healing circuit has operated successfully in over 12 separate incidents of faults. On all occasions, a faulted section of the network was isolated and supply was recovered for the remaining customers within seconds. The success of the trial led to plans to change the weakest performing network sections in the country into self-healing circuits. Sixty such schemes that entail the installation of 300 devices were planned and rolled out in 2012.

The performance of the arc suppression coil protection system, complemented by a range of earth-fault management facilities in operation on ESB's 20 kV network, has proved successful. ESB achieved cost reductions; fault-finding time was reduced by 84%; and the measured continuity of performance improved by 100%. The change in circuit voltage resulted in significant reductions in energy demand. The conversion of networks from 10 kV to 20 kV resulted in a 75% reduction in network losses, an improvement in voltage dropped by a factor of four, and network capacity increased by more than 100%.

The potential to reduce distribution system losses and to improve the efficiency and security of supply to customers has been explored through pilot trials of a range of systems and technologies within three rural distribution networks that are representative of Irish circuits. The implementation of self-healing loops and distribution automation, coupled with a higher resolution, highly accurate down-line measurement and enhanced communications, are enabling an improved security and control (EPRI, 2011) for consumers and operators alike. Moreover, "self-healing" circuits create more efficiency for the management of key infrastructural components of the distribution system, improving organisational management practices with added technologies, as well as improving service reliability for customers.

Sources: EPRI (Electric Power Research Institute) (2011), "Project abstract: Electricity supply board smart grid host site progress report", Palo Alto, California, www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001023253 (accessed 16 February 2015); EPRI (2012), "Smart grid demonstration initiative four-year update", Palo Alto, California.

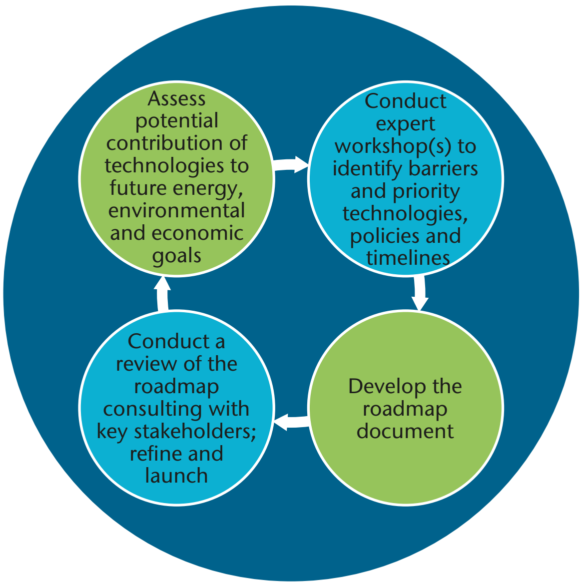
Phase 3: Preparing the roadmap document

The third phase of roadmap development concerns the preparation and review of the roadmap document itself. As shown in Figure 11 the content of the roadmap is usually shaped and discussed during a number of expert workshops aimed at identifying existing barriers to smart grid deployment within the country or region and possible response actions that a country could undertake to overcome these obstacles.[10]

The draft roadmap document usually also contains a timeline for the implementation of the roadmap, as well as key milestones and responsible actors for implementing the identified actions. As roadmap implementation usually involves a wide range of stakeholders from the public and private sectors (previously identified in Phase 2 in Table 2), it is crucial to involve these actors when drafting the roadmap document to secure buy-in and support for their identified actions. For suggestions on the structure of a roadmap document, see Annex 1.

10. See the IEA *Roadmap Guide* (2014a) for guidance on holding a successful roadmap workshop.

Figure 11: Steps in the roadmap document preparation phase (Phase 3)



Source: adapted from IEA (2014a), *Energy Technology Roadmaps: A Guide to Development and Implementation*, OECD/IEA, Paris.

To facilitate this phase of the roadmap process, this section of the *Distribution SG H2G*:

- presents common barriers to smart grid deployment and provides an overview of possible response actions to overcome these barriers
- provides recommendations on how to set a realistic timeline and milestones for the deployment of chosen smart grid projects to effectively meet the objectives set out in the roadmap
- provides a case study from Italy to illustrate how early milestones can be used to leverage the future expansion of an initial technology deployment.

Common barriers to smart grid deployment and possible response actions

Many of the main barriers to smart grid deployment in distribution networks are common across regions. Nonetheless, the local evaluation of a project's feasibility will still involve a determination as to the severity of such barriers and the degree to which they may have an impact on a particular type of smart grid project. Ideally, a cost-benefit analysis that takes into account the phases of smart grid deployment and the potential economic benefits for wider-ranging facets of the electricity system should be conducted (and should be ongoing as technologies are actually deployed). Such an analysis can provide a holistic picture of the impacts of smart grid technologies as an essential part of identifying barriers and illuminating response actions.

Barriers can be broadly categorised into five areas:

- legal and regulatory
- project delivery and workforce capability
- economics and financing
- electricity market and systems aspects
- social and cyber security considerations.

Table 6 provides a list of common barriers under each of the above categories and gives examples of the types of issues that each barrier might involve. The list can provide a starting point for the identification of potential barriers to the particular smart grid projects already shortlisted for consideration in a given country. The table is followed by a more detailed description of each of the five categories of barriers alongside the possible response actions.

Table 6: Categorisation of barriers to smart grid deployment

Barrier category	Subcategory	Description	Examples
Legal and regulatory	Legal and regulatory	The costs and benefits of smart grid technology may not be accommodated easily by existing legal and regulatory structures. These issues must be addressed before project deployments can proceed. In developing a timeline, regulatory processes may take years or longer, which needs to be considered and factored into time allocation.	• Meter pre-pay regulation • Data ownership • Opt-out versus opt-in determination • Communication-spectrum availability • Unclear responsibilities among stakeholders • Lack of legal clarity on necessary roles (e.g. storage or energy-conversion provider) • Creation of market value (e.g. for storage and flexibility services)
Project delivery and workforce capability	Project planning and delivery	This includes concerns for the project development and technology deployment, which needs to be paired with consumer education and awareness programmes to help stakeholders feel comfortable with changes and foster optimal usage of and engagement with demand-side technologies.	• Integration with existing systems • Short timeframe resulting in unsatisfactory consumer notification • Long-term goals that are currently intangible • Inflexible procurement process • City planning and integration • Insufficient infrastructure to support smart grid technologies • Ownership of equipment
Project delivery and workforce capability	Knowledge and/or experience gaps	To support the long-term transition of the electricity system from the present state to meet future plans and objectives (see Figure 2), R&D needs must be identified and steps for implementing them should be taken up in research agendas.	• Identifying open questions, challenges and research needs • Development of a strategic research agenda • Roadmap monitoring
Project delivery and workforce capability	Human resources development	The deployment and use of new equipment will often be unfamiliar to existing staff. The development of staff skills will take time and may require interim solutions to address adequately the new requirements.	• Skills availability (internal/external) • Change in needed organisational skills • Lack of training material • Competition with other industries for skills

Barrier category	Subcategory	Description	Examples
Project delivery and workforce capability	Technical and/or product solutions	Limited experiences exist with smart grid technology and product solutions at the local level. This creates concerns and the need for a detailed analysis and clear communication of the expectations of opportunities and risks.	• Interoperability between systems • Lack of tried and tested solutions
Economics and financing	Financing and/or cost	This includes addressing the costs of deploying smart grid equipment. It will include both capital and operating costs. Funding sources can include rate recovery, private finance, government incentives or lending mechanisms.	• High capital costs, particularly in comparison with conventional distribution infrastructure costs • Uncertain return on investment/business case • Obtaining and repayment of capital • Lack of incentives • No full cost-accounting practices
Electricity market and systems	System operation aspects	The increased operational capability enabled by smart grids will require changes in internal operating processes and potentially a revision of relationships with customers.	• Billing procedures • Determination of tariff structure • Managing new operational metrics
Electricity market and systems	Operations and maintenance	New equipment may require different operating and maintenance efforts. Smart grids will also impact how existing maintenance is carried out, enabling more targeted opportunities with better component information and data.	• Determining maintenance responsibility • Future supply-chain management • Addressing the shorter life expectancy of some ICT components
Social and cyber security	Security and/or privacy	The increased use of ICT to operate the system and the collection of consumer data will provide opportunities to optimise the system, but also open new ways to nefariously impact the system. Ownership and the use of customer data will need to be addressed.	• Physical and remote access security • Balancing privacy and data-based revenue opportunities • Data ownership • Lack of regulation • Data and cyber security
Social and cyber security	Social	This broad category covers societal and high-level leadership concerns that can integrate a range of governance, financial and technical barriers. This can also act as a place to capture important barriers that are difficult to otherwise categorise.	• Standards (or lack thereof) • Insufficient government/societal leadership • Customer backlash due to costs, health, etc. • Consideration of social acceptance and customer usage of technologies

Legal and regulatory

Although regulation may act as an enabler, it can also sometimes present a challenge to the installation and uptake of smart grid equipment. Early in the process it will be necessary to identify existing gaps or regulations that act as barriers to smart grid project deployment. Selecting the right regulations and supporting market design at the outset can facilitate the development of appropriate tariffs and incentives, as well as ensure that adequate revenues are collected by system operators or owners to build and maintain the system in a sustainable manner, along with savings being passed on to customers.

With respect to the actual smart grid equipment, selecting the right standards[11] and the right options within standards allows the equipment and software that meet current requirements to be installed more easily, prevents vendor lock-in and provides an interoperable grid. This, in turn, can facilitate equipment from different systems working together, which brings major advantages, notably in regards to the integration of work, time and expenses by system integrators.

In almost any situation, regulations and standards make the implementation process more orderly and the installed solutions less costly. The challenge, however, is to foresee both the intended and the unintended consequences of these regulations. For example, California experienced an electricity crisis in the early 2000s when regulations were set in place to open the market, which put into question the design of power market liberalisation as a wider topic and caused specific tribulations for smart grid deployment. The process had a number of unintended consequences, including billions of dollars in cost overruns and the decision of the state government to rescind the opening of the market. While there were various factors that affected the restructuring process, one key issue concerned a lack of integration among operators. The Power Exchange and the California Independent System Operator were developed under the California Public Utilities Commission to control new wholesale markets, but they were run as two separate organisations rather than as an integrated system, which arguably created market inefficiencies and opportunities for market manipulation (Sweeney, 2002). This example illuminates the importance of integrative planning among stakeholders, particularly operators, and the need for streamlined standards. Anticipating both intended and unintended consequences at the outset can be handled largely by inclusion of the relevant stakeholders (e.g. the stakeholders mentioned in Table 2) in the planning and deployment phases.

Project delivery and workforce capability

A second enabling issue is to ensure an appropriate workforce that can plan, design, engineer, install, operate and maintain a smart grid. In the United States and Europe, increasingly training programmes are being developed to support the new generation of grid equipment. As the grid becomes more complex and needs more constant monitoring to ensure smooth operation, the workforce needs to be not only better trained but also more specialised to meet new requirements. Another factor in workforce development is to ensure that an organisation can embrace new technologies and ways of managing the grid. This area is frequently referred to as organisational change management and is the focus of many discussions among private sector and academic experts. Willingness to accept and adopt new technologies, systems and methods is a major determinant in the success of a smart grid technology programme.

With constantly evolving technologies, it can be a challenge for utilities to keep pace with adopting new technologies while also ensuring workforce capability. The Software Engineering Institute of Carnegie Mellon University manages the Smart Grid Maturity Model (SGMM),[12] which is a tool developed by utilities that assist other utilities to plan their smart grid transformation and to track progress. The model is designed to characterise the status of a utility's smart grid implementation and was developed to help organisations chart a technical, organisational and operational path through their grid-modernisation efforts. Assistance from the SGMM and this initial assessment and planning exercise is useful to determine the current status of infrastructure and subsequently select the most appropriate technologies that provide solutions for local considerations.

Economics and financing

Smart grid technologies may involve considerable direct and indirect costs – such as for the upgrading of the existing power system infrastructure, the relatively high price of new technologies and the *potentially* higher maintenance costs or more complex management requirements, at least in the

11. International efforts are ongoing to develop global standards to increase competition and interoperability and to provide a broader range of product solutions for electricity-system stakeholders.

12. SGMM materials are available for download at: www.sei.cmu.edu/smartgrid/start/downloads.

short term (e-harbour, 2013). In some instances, the additional cost of deploying smart grids as opposed to a more conventional distribution system may be viewed as too high given the uncertainty of the return on investment associated with new technologies, and therefore serve as an economic obstacle to smart grid deployment.

However, the upfront investment in a smart grid project may bring high returns and benefits over the longer term. As such, a cost-benefit analysis that considers the potential financial barriers as well as the wide scope of potential benefits that may be derived by outfitting electricity infrastructure with smart grid technologies should be undertaken. Ideally, an assessment should accurately account for and consider all the benefits (or costs) that may appear in different parts of the system to form a wide-spectrum picture of the impacts of smart grids. Indeed, the benefits shown in Figure 4 (in blue) include both operational and capital savings. Operational cost savings can include reduced fuel use for electricity generation through efficiency savings, direct CO_2 emission reductions (where there is a price on carbon) and lower system operational and maintenance costs. Grants or other kinds of financing schemes may help to alleviate the burden of high upfront investments. De-risking the financial investment in smart grids can also be accomplished, in part by involving more stakeholders, which spreads and diversifies the risk.

A response action – and a communication tool – is to develop a cost-benefit analysis that takes account of long-term savings. The European Commission Joint Research Centre[13] (JRC) developed guidelines for conducting a cost-benefit analysis for smart grid projects that assists utilities or governments to identify and monetise costs, assess externalities and social impacts, perform sensitivity analyses of critical variables and tailor projects to local conditions (Giordano et al., 2012). Examples of financially advantageous factors to include in a cost-benefit analysis are: the cost of new technologies; available subsidies; infrastructure updates that must be in place before smart grid technologies can be deployed; utilisation of DG; savings from prevention of power outages; potential reduction of peak load; and line losses and electricity theft.

Although rate recovery, one of the most common funding sources, can be an effective means of enabling the roll-out of smart grid technologies, it is also important to recognise that consumers often bear the brunt of the costs for system improvements through such a method. This can serve as a primary barrier if not accompanied by sound methodologies to identify and realise the benefits of the grid investment. It is important to build in mechanisms whereby customers can directly or indirectly reap benefits from the grid investment through, for example, improved reliability, resiliency, lower costs or other means. Regulators play a role in protecting consumers during any such phase of rate recovery.

Electricity markets and systems

It is vital that regulatory and market models – such as those addressing system investment, prices and customer participation – evolve as technologies offer new options. Some markets allow vertically integrated utilities, which own and operate infrastructure assets, notably in the distribution sector. It is important to distinguish between the network investments made in natural monopolies and the delivery of services that use such infrastructures. The latter can be organised in a competitive way. In this regard the integration of distribution-asset ownership and electricity-service provision is the main issue. It can be difficult for competitors to enter such markets and compete with incumbent players, which could hinder innovation and increase prices for consumers. However, the climate for competitiveness depends largely on whether the market is governed by appropriate regulatory structures.

There may often be a need to clarify the roles of certain stakeholders and providers within electricity markets. For instance, in many countries and regions, storage and energy-conversion providers have not been institutionalised, even though their representation is important to be able to utilise and absorb emerging opportunities within electricity markets. Without institutionalising these roles, discrepancies may result in hindrances for the deployment of appropriate technologies and integrative management, including the failure of an electricity market to benefit from available technologies.[14]

13. JRC's assessment framework is structured into a set of guidelines that can be separated into three main steps: (1) definition of boundary conditions (e.g. demand growth forecast, discount rate, local grid characteristics) and of implementation choice (e.g. roll-out time, chosen functionalities), (2) identification of costs and benefits and (3) sensitivity analysis of the outcome of the cost-benefit analysis to variations in key variables and parameters. JRC's guidelines build on an earlier cost-benefit methodology that was published by the EPRI and developed by the US DOE and Navigant for assessing the costs and benefits of the projects under the American Recovery and Reinvestment Act of 2009, a United States stimulus programme for job creation. See the US DOE website for more information: www.smartgrid.gov/recovery_act/program_impacts/computational_tool.

14. This challenge is being considered through ISGAN initiatives.

"Unbundling" of the electricity system, which is intended to allow increased competition, has required entities that operated across the entire system to divide into market-based and regulated units, either functionally by creating separated operating teams within companies or by selling companies or creating new ones to separate activities. Market-based activities typically include the retail sector. The introduction of market-based activities through unbundling can bring many benefits to the electricity sector, primarily a continued downward pressure on prices, but such objectives can also be met in vertically integrated markets. Smart grid investments could be deployed more rapidly in vertically integrated utilities where the business case – including assessment of benefits and costs – can be taken across the entire electricity system (or value chain), although this is not always the case. In the many areas where this is not possible, more strategic co-operation between DSOs and TSOs is needed.

Social acceptance and cyber security

Standards play a key role in the interoperability among systems, as well as in smart grid cyber security. Securing the smart grid requires a combination of common and advanced cyber security technologies. To maintain the stability of the whole system, most smart grid subsystems need to maintain functionality under all circumstances – even if one or more assets are breached or under attack. Standard cyber security technologies and best practices are necessary to protect the smart grid, such as data encryption, antivirus provision, firewalls, intrusion prevention systems, network security design, defence in depth and system hardening. In addition to these common protection mechanisms, advanced cyber security is required to protect against more sophisticated attacks, including security information and event management systems, application whitelisting and security features embedded at the processor level, among others (Intel Corporation, McAFee, and Alstom, 2013). However, with the addition of more sensitive equipment comes growing concerns about the physical security of critical infrastructures. Further mechanisms to protect physical and technical infrastructures should be considered as more equipment is installed.

Greater participation from customers through demand response programmes can also support efficiency, adequacy and security of power infrastructure. The cost-effectiveness of dynamic pricing already has been demonstrated for large-scale industrial and commercial customers, even with their greater metering cost, as well as effectiveness of shifting or reducing peak load. Meanwhile, pilot projects demonstrate that experimental populations of residential customers reduce consumption when electricity prices are high (MIT, 2011). Demand response programmes may reduce the total cost of maintaining system balance by inducing changes in consumption, particularly through increasing the utilisation of the system, thus contributing to and reducing the cost of system adequacy and security (MIT, 2011).

Microgrid configurations using smart grid technologies can also provide increasingly valuable security benefits. Microgrids can either be connected to the larger grid or operate fully in isolation (in "island" mode). If connected to the larger grid, a key feature of a microgrid is the ability to operate autonomously and support the larger grid. By connecting and disconnecting at will from the grid, microgrids can provide grid recovery services during disturbances, support power quality and host distributed generation more efficiently. The deployment of smart grid technologies can face significant barriers from end users regarding issues associated with data sharing and ownership. Customers may be worried that smart technologies can affect the privacy of their data. This is an area that has been significantly improved over the past several years, with the emergence of successful privacy policies that protect consumers against unwanted third-party sharing of their energy usage and data.

Beyond cyber and climatic security issues, the deployment of smart grid technologies can also face strong opposition from end users regarding issues associated with data sharing and ownership. Customers may be worried that smart technologies can hinder the privacy of their data. This is an area that has been significantly improved over the past several years, with the emergence of successful privacy policies that protect consumers against unwanted third-party sharing of their energy usage and data.

Customers' data and privacy must be secure in order for a smart grid to be considered a success. Drawing in part on lessons from other industries that handle and store sensitive information, regulators and other interested parties have developed privacy principles that fit the needs and particularities of the electric utility industry. Key principles include notice and awareness, choice and consent, access and participation, integrity and security, and enforcement and redress.

Table 7: Possible actions to overcome barriers to smart grid deployment

	Possible response actions																							
	Legal and regulatory				Project delivery and workforce capability									Economics and financing				Electricity market and systems					Social acceptance and cyber security	
Common barriers	*Laws and regulatory strategic planning*	*Tariff restructuring*	*Revise ownership structure*	*Standard product requirement*	*Targeted installation*	*Management oversight*	*Local telecomm partnering*	*Design to recycle*	*Develop local workforce*	*Reskill technicians*	*Establish new training facilities*	*Attract qualified workforce from abroad*	*Adapt higher education curricula*	*Long-term financing*	*Private financing*	*Fiscal incentive schemes*	*Grants*	*Progressive installation pace*	*Support local industry development*	*Partner with global manufacturer for local production*	*Develop "open source" products*	*International partnering*	*ICT security solutions*	*Communication campaign*
Financing/cost	✓	✓	✓	✓			✓							✓	✓	✓	✓							
Project planning and delivery			✓	✓	✓									✓	✓	✓	✓	✓	✓			✓		
Technical/product solutions				✓				✓												✓	✓			
System operation aspects				✓	✓				✓	✓	✓	✓									✓			✓
Operations and maintenance				✓	✓				✓	✓	✓	✓	✓						✓		✓	✓		
Security/privacy	✓			✓			✓			✓	✓	✓	✓										✓	✓
Legal and regulatory	✓	✓	✓	✓		✓	✓	✓															✓	
Human resources development					✓	✓	✓		✓	✓	✓	✓	✓	✓			✓	✓	✓	✓		✓		
Cross-cutting	✓		✓			✓									✓	✓					✓		✓	✓

An example of good practice in this area is the data privacy and protection measures adopted by San Diego Gas & Electric, built into the initial design, and continuously a top priority in ongoing evaluation and re-design (Jones and Zoppo, 2014). Third parties can only access the strictly necessary data to perform work promised for the utility under contractual obligations, and information is only shared with customer consent. A stipulation under the privacy policy of San Diego Gas & Electric is that customer data cannot be shared for commercial benefit. Utilities need to use the data they collect to provide electric service to their customers and to ensure that such service is reliable and cost effective. Aside from any valid business uses necessary to the reliable service they provide, utilities should give their customers the option to share or withhold third-party access to their data (Jones and Zoppo, 2014). This simple step can drastically boost social acceptance, especially when paired with customer outreach and education programmes.

Technology solutions can help to address social concerns over the issues of data privacy and cyber-attacks through a heightened ICT security coupled with more effective communications and marketing about what smart grids are and the benefits they can bring. Stronger communication between utilities and customers regarding the benefits of smart grids can also help customers accept the costs of smart grids while increasing their trust and subsequently their usage of customer-side technologies. Importantly, such communication will not simply be one way; ideally, customers will be engaged by the utility (or other implementing organisation) through town hall meetings, hotlines, working with other trusted organisations or other means of realising customer involvement.

Table 7 maps the possible barriers to smart grid deployment against potential response actions. Roadmap drafters should identify the barriers likely to be most applicable in their own situation (as well as others not mentioned here) and prioritise the order in which they are to be addressed according to their own objectives and schedule. In identifying appropriate actions, a number of criteria may be helpful:

- potential effectiveness to respond to the identified barrier
- cost effectiveness
- technical feasibility, given the country's existing energy infrastructure and resources
- likelihood to be implemented within the roadmap timeframe
- degree of stakeholder support for the solution.

When finalising the set of action options for each barrier, the team responsible for road mapping should pay close attention to stakeholder input to encourage buy-in and thus a strong foundation for successful implementation of the roadmap. Transparency about choices made and clear reasons for discounting alternative actions are likely to be important.

Timeline and milestones for smart grid deployment

A smart grid roadmap is expected to define a series of milestones, in a predetermined timeframe, for the sustainable deployment of chosen smart grid project types. Smart grid milestones represent the building blocks of the smart grid, and completion of each requires the deployment and integration of various technologies and applications. When defining timelines and milestones, relevant stakeholders will have to determine what is technically and politically feasible while keeping in mind that a roadmap is intended as a long-term effort.

The timeframe of a roadmap can vary substantially from the short term (up to five years) to the long term (until 2050, for instance). Appropriate milestones vary according to regional contexts, project applications and the complexity of long-term goals. For a roadmap that results from a supporting law or ministerial directive, the first milestones may be implementation at the project level. By contrast, for a roadmap effort that has been conceived as a response to a policy gap, to seek formal high-level governmental or regulatory support could be one of the first significant milestones.

Some of the key elements for determining a timeline and milestones will be:

- whether or not – as well as what kind of – regulatory approval is required to implement the identified projects
- "first mover" situation versus second, third and subsequent followers on technology deployment
- desired scale of technology deployment
- choice of "step-by-step" progress versus "big-step" initiatives
- current status of the electricity system and available resources for the proposed investments (human and financial)
- interrelation with other plans (national energy plans, utility specific plans, regulatory change cycles)
- availability of relevant data.

Box 6: Case study 4: Automated meter management project (Italy)

Description: In 1999, Enel, the Italian utility, began developing the Telegestore Project (Italian Automated Meter Management System), a system for LV concentrators and remote meter management. By 2008 more than 32 million smart meters had been installed. These smart meters allow Enel to periodically collect data on voltage quality and interruptions, daily consumption, active and reactive energy measurements, and to manage contractual activities remotely. Meters are able to transmit data regarding consumption, receive updates of the contractual parameters and remotely manage the supply connectivity.

Project functionalities:

- improved fault identification and optimal grid reconfiguration after faults
- enhanced monitoring and control of power flows and voltages
- identification of technical and non-technical losses through power-flow analysis
- additional information on supply quality and consumption to support network investment planning
- sufficient frequency of meter readings, measurement granularity for consumption/ injection metering data (e.g. interval metering, active and reactive power, etc.)
- remote meter management.

Future efforts to leverage the system: There is a proposal to exploit potential synergies between electricity metering and other utility metering systems, which could include gas and water. This will provide opportunities to leverage knowledge gained from the initial data collected on consumption to utilise in planning long-term future benefits to consumers and the grid infrastructure at large. The increased information on system operation provided by the Telegestore deployments has enabled new considerations for future operation that have assisted in further development of long-term milestones. Currently, renewable integration options are being tested and regulation of bi-direction flow in the distribution network is being developed as part of Enel's Isernia project. This is an example of how the usefulness of data collected through initial deployments (short-term milestones) can leverage the medium-term and long-term evolution of smart grid options, and the longer-term milestones.

Source: ISGAN (2013a), "AMI case book version 1.0: Spotlight in advancing smart metering infrastructure", Clean Energy Ministerial, Korea.

Expert consultation early on can help to provide realistic estimates of the technology deployment process, and to identify the initial steps that need to be taken for deployment in line with the intended goals throughout the full project timeline. Key stakeholders for a consultation process may include the DSO, manufacturers, other deployment stakeholders and regulators who can comment in detail on the approval processes. Where possible, it is also worthwhile to seek inputs internationally, especially by looking at experiences from those who have already deployed smart grids. Experts are able to identify unanticipated challenges and highlight suboptimal choices that affect other smart grid systems and that could be avoided with the appropriate steps, which is why consultation is best suited at the beginning of a project. Expert consultation plays a large role in shaping and meeting short-term milestones. Short-term milestones can include successfully gaining political support and relieving policy barriers to deployment. Support from a broad spectrum of stakeholders on financial, technical and policy issues is required to propel an initial project into an environment or market that is ready for larger-scale deployment.

As many of the necessary steps to implement smart grid projects are complex, milestones stretch from basic accomplishments in the short term to more sustainable and widespread capabilities in the long

Table 8: Categories of milestones for smart grid deployment

Category	Details
Building consensus for smart grid deployment	Before key legislative actions can be taken, a broad level of support will be needed.
Utility policy and regulation	Key supportive regulations and policies are needed before deployment can occur, including clarifying roles and responsibilities among stakeholders.
Customer policy and regulation	This category includes communication and engagement with customers as to why changes are being enacted and what impact these could have on the individual customers. It can clarify important steps before a significant financial investment is made in hardware or software. It can also articulate when key barriers should be addressed in the process of project planning and deployment.
Technology development, demonstration and deployment	This will include detailed deployment metrics, such as the number of meters installed, but also metrics as a result of the technology deployment (reduction of losses, increased reliability).
International collaboration	Provides an opportunity to promote nationally developed skills and gain from international best practices and lessons learned. It also refers to international interoperability, which is needed to overcome the barrier of technology manufacturing standards.

term. Baseline research into macro-level projections, such as renewable deployment targets and future electricity demand, provides insight into developing the electricity system in a way that can support long-term milestones. Such milestones will often be highly dependent on larger-scale national goals such as economic or industrial development, but could also be influenced by international project developments, such as successful projects in other regions, the significant reduction or increase of global technology or commodity prices or a successful change in supportive policy.

Medium-term milestones should bridge technologies proposed in the short term to system-wide adoption in the longer term. Medium-term milestones should take into account the successful implementation of initial technology deployment, while also including mitigation strategies if the intended short-term objectives are not met. Enel's Telegestore Automated Meter Management Project is an example of how such projects can be planned and how medium-term milestones can leverage long-term milestones (Box 6).

Milestones can be organised in a variety of ways and can be of a qualitative or quantitative nature, as shown in Table 8. This is by no means a complete list of milestone types but provides an example of breaking down areas of project deployment that deserve consideration when developing project targets and timelines.

Phase 4: Implementation, monitoring and revision

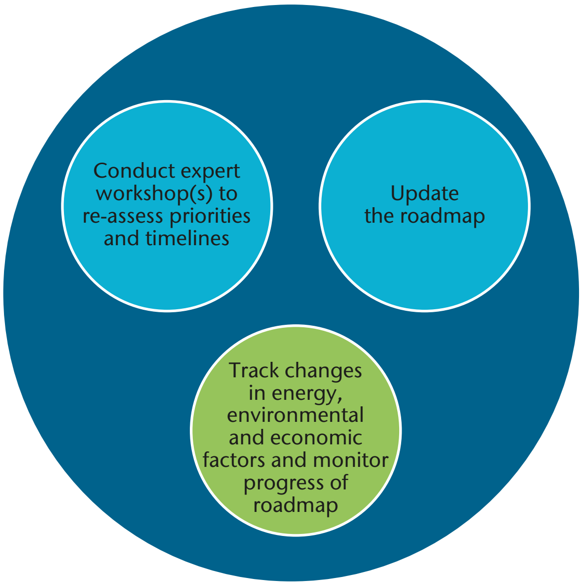
A crucial fourth phase in the life of a technology roadmap is the actual implementation, monitoring and revision of the roadmap document itself. This is a continuous process, as shown in Figure 12. This section of the *Distribution SG H2G* provides suggested indicators to track and monitor progress in implementing a smart grid roadmap.

Tracking and monitoring progress in implementing a smart grid roadmap can be challenging. US DOE has 21 metrics for its biennial Smart Grid System Report[15], many of them qualitative (such as cyber security and regulatory recovery of smart grid investments), whereas the JRC has identified over 50 key performance indicators (KPIs)[16] for a smart grid (such as power quality indicators and energy losses in T&D). Depending on the level of baseline data at the beginning of the roadmap project, progress may be difficult to assess and must be considered when evaluating and selecting project types to ensure that progress can be measured and managed.

15. See the US DOE 21 metrics for its Smart Grid System Report: energy.gov/sites/prod/files/2010%20Smart%20Grid%20System%20Report.pdf.

16. See JRC's KPIs: ses.jrc.ec.europa.eu/sites/ses/files/documents/smart_grid_projects_in_europe_lessons_learned_and_current_developments.pdf.

Figure 12: Steps in the roadmap implementation, monitoring and revision phase (Phase 4)



Source: adapted from IEA (2014a), *Energy Technology Roadmaps: A Guide to Development and Implementation*, OECD/IEA, Paris.

When considering metrics, there is, on the one hand, a danger of pursuing too many complicated metrics, while, on the other, a danger of applying too few or too narrow a set of metrics such that the system effects of smart grids cannot be captured. For instance, counting smart meters can be useful, yet insufficient to truly understand the deployment of smart grids. The area of data and metrics is one that requires further, deep attention and one that is arguably ripe for more international engagement and development of best practices. Notably, this is a principal effort facing ISGAN and many other national and regional collaborative grid efforts.

As metrics and methodologies for measuring progress remain a challenge, the lack of a commonly used framework for assessing incorporated penetration of "smartness" into a grid with specified indicators necessitates use of limited indicative data and smart grid drivers rather than smart grid deployment indicators that are measurable across regions. This is a key challenge in determining market penetration of smart grid technologies and, thus, progress. International efforts are being made to create simplified indicators and metrics to more easily track progress within a unified framework. ISGAN is playing a lead role in these efforts; emphasis is correctly being placed on creating a number of tools that will provide a quantitative foundation that can be used to establish easily understandable indicators of the "smartness" of the grid.

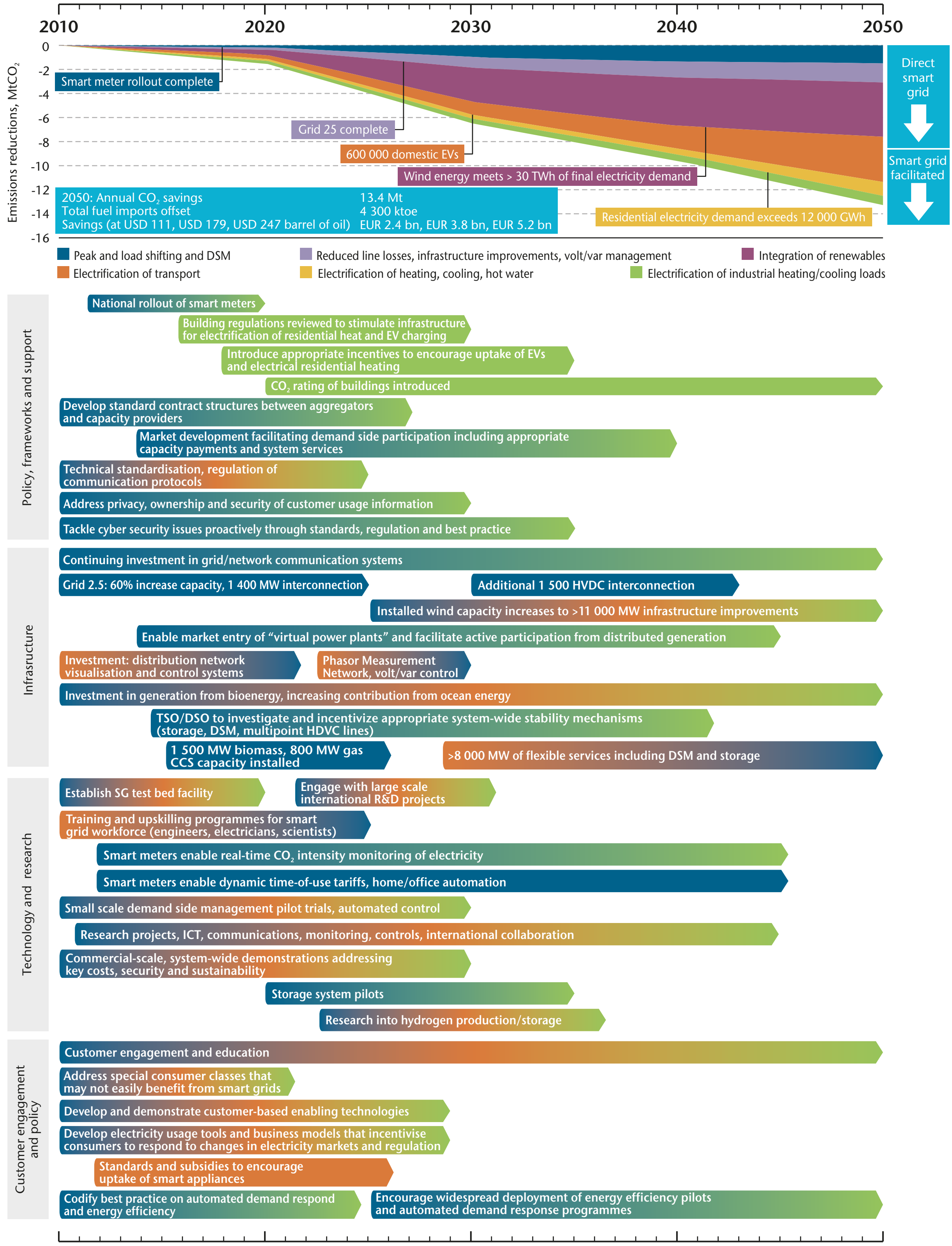
Figure 13 provides an illustration of what the roll-out of national roadmap milestones can look like. This example is taken from the national roadmap on smart grids developed by the Sustainable Energy Authority of Ireland. This example is particularly interesting in that it sets the order of prioritisation of actions for an island country. It defines priority actions under four streams: policy framework and supports; infrastructure; technology and research; and customer engagement and policies. For each stream, the document defines a set of actions, their related timeframes and responsible actors.

Drawing on discussions during the IEA's workshops[17] for this *Distribution SG H2G*, Table 9 provides an overview of possible qualitative and quantitative indicators that can be applied to track progress in implementing a smart grid roadmap. The indicators listed in the table represent a combination of outputs (e.g. number of stakeholder workshops), outcomes (e.g. policies defined and adopted) and impacts (e.g. CO_2 reductions) derived from the roadmap process, where a balanced analysis of progress would ordinarily seek to address all three. While the use of these indicators comes into play in the fourth phase of the roadmap development and implementation process, in fact, it is recommended that the indicators, as well as the teams responsible for monitoring them and the related verification mechanisms, are identified earlier on in the road mapping cycle.

For each indicator, robust data and transparent analysis will be important. This may be challenging where new metrics are created and data series are short. Specific resources may need to be allocated to bolster data collection and verification. The collection of such data must, of course, take account of commercial sensitivities. Data can be anonymous, although increased transparency for publicly subsidised projects may yield both greater accountability and faster learning curves for the entire industry.

17. See "Workshop presentations and background material" at the end of this report for cited presentations from IEA workshops.

Figure 13: Irish smart grid roadmap: Key milestones



Notes: The following acronyms stand for: Mt = million tonnes; ktoe = thousand tonnes of oil equivalents; bn = billion; TWh = terawatt hours; GWh = gigawatt hours. The illustration includes both distribution and transmission aspects in the shown milestones, but the explanation is relevant to the consideration of distribution systems only.
Source: SEAI (Sustainable Energy Authority of Ireland) (2011), *Smart Grid Roadmap*, Dublin.

Table 9: Qualitative and quantitative indicators for monitoring progress of implementing a smart grid roadmap

Indicator type	Description	Metrics
Smart grid technology deployment	• Number of (pilot) projects implemented • Generation capacity connected to the smart grid • Reduction of losses • Consumer adoption of technologies	• Unit • MW/GW • Comparison with pre-smart grid metrics • Number of consumers connected to the smart grid
Financial	• Grants and incentives available • Market expansion for smart grid technologies • Project financing with lending by financial institutions	• Total value of secured funds • Monetary growth over timeframe • USD
Processes	• Number of stakeholder workshops organised • Number of new institutions created • Effectiveness of awareness raising/ campaigns organised	• Unit • Unit • Number of customers impacted by marketing or engagement strategies; qualitative assessment of customer acceptance
Policy	• Policies defined and adopted • Increase in political support • Milestones specific to sectoral strategies	• Unit; qualitative assessment of goals of policies and whether the right tools are being deployed • Qualitative assessment of policy makers' actions • Number of milestones being met
Socio-economic and environmental impact	• Social: jobs created; customer education/training • Environmental: CO_2 reductions; increased system efficiency	• Number of jobs and customers reached • Comparison with pre-smart grid metrics

Conclusion

A technology roadmap should not be a document left "on the shelf". It should be viewed as a dynamic blueprint that can be updated regularly and that can serve as a reference for stakeholders in their own sectors or activities. Of course, one solution does not fit all and this guide does not provide all the answers as to how a given country should deploy smart grids. Instead, this *H2G* aims to provide countries with a portfolio of options and a methodology to select the project types and actions that will be most effective for their own unique contexts.

A concerted effort is needed to accelerate the deployment of low-carbon technologies globally, and smart grids present an important element in meeting this challenge. Actions on both the national and the municipal levels have a crucial role to play to deployment efforts, and technology roadmaps help to provide pathways to the deployment of specific technologies identified as having great potential for a given country. The success of a roadmap is based on early planning and foresight, establishing a commonly "owned" vision, a full understanding of the national challenges and opportunities, the importance of "champions", commitment to outcomes by both public and private stakeholders, and ongoing evaluation and reporting on progress.

This *H2G* provides the tools necessary to develop a roadmap that could become the national or municipal programmatic document for the deployment of smart electricity grids, particularly in distribution networks. Focusing on the four phases of planning and preparation (1), visioning (2), preparing the roadmap (3) and implementation and monitoring (4), the guide highlights the following actions: identifying smart grid stakeholders; conducting baseline research; determining drivers for smart grids and appropriate projects to meet such needs; identifying barriers and response actions for successful deployment; and setting timelines and milestones for deployment so as to monitor implementation of the roadmap.

IEA analysis has shown that the return benefits for upfront investment in smart grid technologies can arrive quickly in terms of, for instance, the economic savings to consumers thanks to better tracking of energy use. There are also energy security benefits from smart grid technologies in that they can help with rapid disaster responses and recovery through the facilitation of demand-side response technologies. The increased and improved efficiency of renewable energy integration can also be seen as energy security benefits because it diversifies energy portfolios and utilises domestic capacity. Bringing improved efficiency, the ability to integrate renewable energy and EVs, and enabling customer involvement in shifting electricity consumption, smart grids are vital to transforming electricity networks into systems that can support the transition to the 2DS as well as tackling some of the associated risks in an era of climate change. Taken together, smart grids can play the role of a catalyser for a more reliable and sustainable energy sector while enabling multiple cross-sector benefits.

As a measure of progress of technology deployment, the IEA *Tracking Clean Energy Progress* report found that global penetration of smart meters reached 20% in 2013, and is projected to achieve 55% by 2020 (IEA, 2014c). Overall, the smart grid market is growing, but the current rate of deployment does not appear sufficient to adequately support the 2DS goals. Both the unfortunate truth of the current insufficient deployment of smart grids and their strong role in a low-carbon energy future dually provided fuel for the inspiration of this publication, for governments to improve their grid capabilities and for the continuation of efforts to use smart grid technologies to shape more efficient, innovative energy systems.

Annex 1: Possible structure of a smart grid roadmap

Executive summary/key findings and actions
- Key findings of the smart grid roadmap

Introduction
- Roadmap concept and rationale for the deployment of smart grids in the country/region
- Objectives, process and structure of the roadmap

Context: national/regional/municipal energy profile
- Essentially a summary of the baseline research

Vision for national/regional/municipal deployment of smart grids
- Scenario or set of scenarios for smart grid deployment in the country by an identified time frame
- Barriers to achieving that vision
- Possible response actions and selected actions, with rationale for those choices

Implementing the vision for smart grid deployment: actions and time frames
- Identified actions with corresponding milestone dates to achieve them, identifying responsible parties and the cost and benefits of those actions
- This section may have subheadings, such as technology development, system needs, policy, finance, public acceptance and/or international collaboration

Monitoring and adjusting this roadmap
- Agreed approaches to monitoring progress, with specific metrics where possible
- Identified parties tasked with monitoring implementation

Annex 2: Stakeholder categories and mandate: The RACI chart

Stakeholder type	Definition	Mandate can include
Responsible	This is the group that has the authority to approve the final product. The composition of this group should reflect the bodies that will be involved in the implementation of the roadmap recommendations. Membership should be limited to senior individuals (typically Director level) from government, industry and research. It may often be the case that the broader the membership, the greater the likelihood that the roadmap will secure buy-in. Throughout this guide, this group is referred to as the "steering committee" or "steering group".	• Approve the roadmap goal, scope and boundaries • Assign various road mapping responsibilities to members of the roadmap project team (referred to as "Authorised" [see below]) • Direct the analytical effort (including and based on the baseline research) • Approve the RACI chart • Approve communications to the wider stakeholder community in the "Informed" category • Track progress of the project
Authorised	This is the core team that actually undertakes the vast majority of the work to develop the roadmap. Also referred to as the "project team", this group should mirror the composition of the "Responsible" category, but at a working level. A project leader should be identified to lead and co-ordinate the activities of the project team and should lead all communication activities with the stakeholders.	• Manage the project (project leader) • Communicate with the stakeholders (project leader) • Organise consultation cycles • Develop drafts • Plan the necessary workshops • Document the gathered information • Perform the analysis
Consulted	This group typically includes expert representatives from organisations that have a key role for the deployment and commercialisation of the technology, from utilities to manufacturers and bodies or NGOs that represent individual consumers, who will need to be involved in the implementation of the roadmap recommendations and milestones.	• Attend workshops • Provide inputs • Review roadmap drafts • Be actively involved in the process as appropriate
Informed	These stakeholders are those that have an interest in the technology and who can bring added value to the road mapping analysis. They will not be directly involved in the implementation of the roadmap recommendations and milestones, but will, however, be affected by the roadmap.	• Informed about roadmap findings • Not typically actively involved in the workshops or other activities

Source: IEA (2014a), *Energy Technology Roadmaps: A Guide to Development and Implementation*, OECD/IEA, Paris.

Annex 3: Brief descriptions of smart grid technologies

Advanced metering infrastructure (AMI)

The AMI project type consists of a number of components, and can vary in its intended function. The components may include smart meters, a field communication system that allows the meter to communicate with the central control site (connecting data from the field back to the utility office), ICT systems that run the field communication system, ICT systems that provide operational data, and yet more ICT systems that allow billing and other administrative actions to happen. How many of these components are part of an initial installation varies from location to location. Many AMI systems today have only the meters, field communication and field ICT. With more extensive AMI systems, the organisation can gain benefits not only from billing, but from operational savings and improvement of the service, and other improvements that include, but are not limited to, detect outages, identify theft of electricity, detect issues with vegetation on the lines and provide other operational information.

Distributed energy resources (DERs)

DERs can be categorised into three areas: distributed generation (DG), demand response (DR) and storage. Efficiently incorporating DERs into the grid can be seen as a driver for smart grid projects, and specific technical components, such as power electronics in distributed generators, can be used as smart grid technologies.

Distributed generation

Traditional grid design assumed that power was made at a central station, flowed through transmission to distribution to customers and the customer used the power. DG technologies now enable customers to produce power with both renewable and fossil-based generation such as wind, solar, natural gas or diesel. These are small electric generation sources that can be installed in many places in the grid. In most cases the DG is installed at the customer location. DG can be broken down by a number of distinct categories, as shown in Table 10:

Table 10: Examples of distributed generation

	Renewable	*Non-renewable*
Dispatchable	• Biomass • Small hydroelectric dams (including reservoir hydro)	• Fossil fuel generation (e.g. diesels, gas and coal)
Variable	• Photovoltaic • Run-of-the-river hydro • Wind mills	• Industrial process co-generation (i.e. waste gas or power generation from waste heat, but in both cases without storage) • Waste gases from refineries

It is important to understand that today's electricity system primarily operates using dispatchable generation. As more and more variable generation is installed, either the other dispatchable generation or the load has to adjust to maintain the needed match between load and generation in the absence of large-scale electricity storage. The small percentage of variable generation installed in most of the grids today means there is little noticeable impact on the grid operation. As the amount increases, new management schemes will be required. These new schemes are a major reason that smart grids have been proposed.

Smart grid technologies can alter the capability of the grid to accept high levels of DG (both variable and dispatchable), which makes the grid more flexible in terms of the resources that it can efficiently utilise. Supporting increasingly higher levels of DG is often seen as a primary objective of smart grids in the near and long term.

Demand response

DR describes a system in which the customer's load is typically reduced, but in some cases increased, for a period of time without necessarily impacting the level or quality of service provided, or the overall energy delivered; whereas demand-side management focuses on the reduction of demand, often through energy efficiency measures. The increased capability of smart grids is opening up new and expanded opportunities. Some examples include:

- Direct load control (DLC) provides the utility the ability to turn on or off one or more of the devices remotely with the permission of the customer at the customer's site. The most successful DLC programmes historically turn off items that the customer would not notice, like the hot water heater on a hot day, instead of the item they are using at the time, like air conditioners. Increasing capabilities and decreases in the costs of smart grid technologies are broadening the type of appliances that can be controlled.
- Demand limiting provides a threshold of demand that the customer has to stay below. This means that the customers have to maintain their overall energy use below the demand limiter that is typically built into the meter. Enel in Italy built demand limiters into the smart meters they installed at 27 million households.
- Price response (PR) provides the customers with a given price for electricity for an upcoming period of time and they decide whether to pay more or reduce the amount of electricity they use. PR includes TOU pricing, real-time pricing (RTP), critical peak pricing, and other pricing programs.
- Equipment like smart meters, in-home displays, home area network and other technology is making DR more reasonable to contemplate for a larger number of customers with smaller loads.

Storage

Storage technologies can have multiple applications and therefore multiple benefits in any one configuration. Storage can be broken down into two major categories: returnable (i.e. electricity in, electricity out) and non-returnable (i.e. electricity in, thermal energy out). Batteries and pumped storage are both returnable storage in that the electricity that went in will eventually be returned to the grid as electricity – with some losses. The vast majority (97%) of installed plants at present are pumped hydro storage facilities, which operate at the transmission level. Smaller, distributed electricity storage technologies, such as batteries and flywheels, are less mature and still face business case concerns, typically because of the capital costs and non-supportive market conditions. Non-returnable storage is storage where the electricity is converted and used later, but does not return to the grid, such as domestic hot water production. Water can be heated at almost any time and stored in an insulated tank until needed. Other thermal storage technologies, such as ice storage for cooling applications, are often cost effective solutions within distribution systems when offered to customers under the right market conditions. Energy storage systems can act as both a sink and a source, which in many cases makes them difficult to classify and equally difficult to regulate.

As indicated above, smart grids increase the system capabilities to integrate storage technologies, particularly at the distribution level. This could mean that variable renewables, like wind and solar, can be used in greater amounts, because the storage can buffer the changes in output from the variable resource. Storage can also mean not having to upgrade an urban underground circuit to support a few hours a year of peak, but rather the energy can be delivered at an off-peak time and then used when needed to avoid issues with the constrained circuit. Smart grids will offer the ability to control such systems and optimise usage to the benefit of various stakeholders.

Customer-side systems

Home energy management systems (HEMS) / building energy management systems (BEMS)

While the smart meter is the interface between the distribution system and the customer's home, it is the HEMS or BEMS in home or business that can deliver the information and support the ability of the customer to adjust the use of electricity. In addition to pricing, other information may be provided, such as: demand limit information, demand limit commands, DLC commands to specific devices in the home or business and forecasting information to help customers plan (e.g. "Tomorrow will be a hot day and electricity prices will be high.").

Smart appliances and smart entertainment systems are devices that can understand and respond to information provided by the utility or a third-party demand-side management (DSM) provider. These appliances are starting to be available in the market, and increasingly being incorporated in mainstream appliances. Communication protocols are being developed by various organisations to ensure global manufacturing can support these functionalities. In the future, smart appliances will need information on the DSM programmes and timing, which can be delivered using the same communications options noted above or through AMI systems.

Electric transportation

Electric transportation includes methods of transportation that most major cities have or have planned for, such as trains and subways. This kind of electric transportation is already incorporated into grid design and operations. EVs include passenger cars, taxicabs and buses. EVs hold both challenges and promises for the future grid. The charging infrastructure needs to be designed to support additional loads, as well as the ability to accurately price the electricity for EV owners.

Smart grid technologies are capable of balancing the demand from the charging systems of EVs with the capacity of the distribution system, while maintaining the voltage within required limits. One potential benefit for the grid lies within the storage potential of EV batteries, which can help address the peak demand at a local area and thus extend the time period over which the infrastructure can support the demand without having to be upgraded. There are benefits from both discharging and charging the batteries (e.g. demand-responsive smart charging schemes), and both have potential to balance some of the variability issues associated with the utilisation of intermittent renewable energy resources.

Control-centre systems

With the advent of smart meters, the number of available sensors has grown from a few thousand at most, to millions. As additional sensors are deployed in substations and distribution automation, the number of sensors that will be available will be approximately 1.5 sensors per customer connected to the grid, far more sensors than existing EMS can handle and, more importantly, more sensors than the operators can ever pay attention to. A new generation of software was started based on the existing EMS, called Distribution Management Systems. Now a new generation of DMS are just starting to appear that are based on mapping technology and underlying analytics. These systems provide a more reasonable view of the grid and the customers connected. They hide much of the detail of the system until the analytics notice that something is starting to go wrong and then they display the information in a way that allows the operator to quickly review the situation and drill into the detail as needed to make the correct operations decisions.

The next generation beyond this generation of DMS will offer the ability to suggest and even make many automatic decisions for the operator, within limits, and send orders to equipment on the grid. As the number of DER locations increases, this may be the only way to operate the grid in the future. These systems can also offer operational support for dispatching system maintenance crews and needed materials.

The next generation of dispatch systems will grow in parallel to the integration of OMS that take input from customers, meters, crew observations and other sensors to determine where the root cause of an outage is. When coupled to the new generation of dispatch systems, automated routing and dispatch can be done to reduce the time it takes to start recovery after a storm or other natural disaster.

Managing this massive amount of data means data warehouses, fast networks, large database servers and clusters of processors with evolving options, including the use of outside data centres or the creation of data centres owned by private utilities. One major issue facing the industry is that today most individual vendors do not have all of their software on a single server/operating system integration platform. Therefore, a typical utility with multiple vendors has a real problem to make all their software applications work together. It is necessary, again, to stress the importance of interoperability and industry standards, particularly when integrating software systems. Software, systems and integration solutions will be the fastest evolving part of smart grids. Today, much of what is needed exists in one form or another, but as large-scale smart grid implementations happen, the lessons learned from these deployments are going to drive continuing changes in the full range of operations software applications.

Distribution automation

Over the past 20 years, automation has started to make its appearance. The first items to make a wide appearance were lightning arrestors and circuit breakers, which replaced fuses in standard outages. These autonomous devices allowed many customers to be very quickly restored without human intervention. The next step in most utilities has been to automate capacitor banks. This initially meant using timers that turned the capacitor banks on and off at predetermined times. More modern systems include remote actuators and local sensors that allow the capacitor banks to be turned on as needed, either based on local readings or on remote commands.

Some of the newer equipment now being deployed to add to the capabilities of the grid is as follows:

- Re-closers (or auto-re-closers): devices that are installed on the distribution feeder to detect and interrupt faults.
- Feeder switches: devices that are installed on the distribution feeder for local or remote-controlled open and close of the circuit.
- Sectionalisers: devices that are installed downstream from the re-closer (see above) and are able to detect fault currents. Other devices also improve reliability switching capability, load balancing or other characteristics of the grid.

Some companies are offering and installing peer-to-peer communications and networks that connect a number of local devices together so that they co-ordinate as they operate. In other cases, companies are building and installing sensors and controls that are read and operated from a central control centre. These systems can operate in co-operation with or independently from information that is gathered by revenue meters attached to customer locations. Examples of the latest technologies for distribution systems include: the dynamic rating of equipment, using smart meters to monitor distribution transformers directly and using aggregated smart meter data to detect distribution circuit over-loads and other issues.

Substation automation

The original, manual substations installed required a human being to enter the substation and move levers to make any changes in the substation or provide information to a central operator. Substation automation starts by adding sensors to the substation that are tied to a communications network to automatically feed information back to a control centre. For larger substations, protection equipment will often be able to communicate with protection equipment in other large substations. In new Chinese substations, although there are still onsite staff, the sensors communicate automatically with operations via a communications network.

Additional advances include:

- remote actuators to the controls in the substation so that the operator can remotely control the levers without the necessity to have a human being on site
- intelligence that monitors the sensors locally and makes local decisions that result in the actuators making changes based on the local intelligence and reporting these changes to the operator and networking substations that are close to each other.

These enable joint decisions to be made on what changes to make to optimise the grid. Future advances in this area are expected.

Asset management

Across the globe, almost every distribution organisation in operation today functions in a similar manner. When it comes to the majority of their assets (e.g. power lines), a distribution organisation installs them and visually inspects them from time to time, and the lines are used until they fail. Underground lines are often sometimes abandoned because it is too hard to find and replace them. Instead, if a new line is needed, it is installed and the old one rots in the ground. This is the result of the optimisation of cost in the distribution utility. In a transmission utility, on the other hand, the assets are monitored and maintained; failure of a transmission asset while under load is considered to be a failure of the asset management programme.

Asset rotation for overloaded assets will extend the life of the assets and allow larger replacements to be put in place before the customer experiences a failure. The removed asset can be rotated to a location with a lower load and that will extend the life of the asset for years to decades. Additionally, asset management can be used to rate components dynamically in the grid, and so allow them to run safely at peak times with loads higher than the manufacturer's recommendation. This allows short-term increases in the power flow to keep the lights on and the air conditioning running, rather than having to resort to rolling blackouts or other demand-reduction schemes on a non-voluntary basis.

The key to the future of asset management is based on three items: large numbers of new sensors placed in the grid; communications networks that will allow the sensor data to securely move to the control centre; and ICT systems with asset models that can accept the data and determine the health and safe loading level for assets and circuits.

Cross-cutting technologies

There are a number of cross-cutting technology areas that require due consideration when developing a pathway for smart grid projects, or can be an additional opportunity to leverage smart grid technology deployments or utilise the resultant data. These are not specific to smart grid projects, but are necessary to support and facilitate certain types of smart grid projects.

Information and communications technology (ICT)

All smart grid projects will involve an increased ICT foundation. This technology will support the collection, analysis and use of an increased amount of data from the various parts of the distribution systems, end users or generation sources. Usage of this information will depend on the type of smart grid project proposed, but could include control of the end-user equipment in the context of a DR project or the control of automated feeder switches in the distribution system. As various project types interact, it will be important to leverage investments in a way that integrates them to operate together. A number of projects have chosen some large multinational supplies of ICT equipment to help manage different technical needs.

Security and privacy

As the smart grid becomes more connected and more equipment (including DERs) is installed with modern standards, security needs to increase. There are now dedicated teams of professionals employed by national governments whose purpose is to prepare for all-out cyber warfare, and the electrical infrastructure is a prime target. Society depends on electricity to function; therefore, a power system taken out via cyber warfare would have a detrimental impact on the lives of everyone in the area impacted by the attack.

Privacy is also a growing issue as the smart grid systems inherently capture data, such as where and how electricity is consumed. That the policies maintain privacy is crucial to gaining customer acceptance and getting customers to use the technologies actively.

Regardless of any smart grid programme, security improvements will have to happen on systems connected to and controlling the grid and generation stations. Taking advantage of the need for these upgrades to look at a more comprehensive programme of smart grid communications may, in the long run, be the most secure and cost effective approach.

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Glossary

Baseline research: Analysis of the current situation to identify the starting points for roadmap development.

Critical peak pricing (CPP): A tariff structure in which TOU prices are in effect, except for on certain peak days when prices may reflect the costs of generating and/or purchasing electricity at the wholesale level.

Cyber security: Effective strategies to protect the privacy of smart grid related data and to secure the computing and communication networks that will be central to the performance and availability of the envisioned electric power infrastructure.

Distribution: The transfer of electricity from the transmission system to the end-use customer.

Flexibility: The capability of a power system to maintain reliable supply by modifying production or consumption in the face of rapid and large imbalances, such as unpredictable fluctuations in demand or in variable generation. It is measured in terms of MW available for ramping up and down over time.

TOU pricing: A tariff structure in which electricity prices are set for a specific time period on an advance or forward basis, typically not changing more often than twice a year. Prices paid for energy consumed during these periods are pre-established and known to consumers in advance, which allows them to vary their usage in response to such prices and manage their energy costs by shifting their usage to a lower cost period or reducing their consumption overall.

Transmission: The transfer of bulk energy products from where they are produced or generated to distribution lines that carry the energy products to consumers.

Variable renewables: Technologies, such as wind, solar photovoltaic, run-of-river hydroelectricity and tidal, in which the production of electricity is based on climatic conditions and therefore cannot be dispatched based on a need for additional power alone.

Acronyms, abbreviations and units of measure

Acronyms and abbreviations

2DS	2°C scenario
AMI	advanced metering infrastructure
bn	billion
BEMS	building energy management systems
BNEF	Bloomberg New Energy Finance
CHP	combined heat and power
CO_2	carbon dioxide
CPP	critical peak pricing
DER	distributed energy resource
DG	distributed generation
DLC	direct load control
DMS	distribution management system
DR	demand response
DSM	demand-side management
DSO	distribution system operator
EMS	energy management system
ETP	*Energy Technology Perspectives*
ERP	energy resource planning
ESB	Electricity Supply Board (Ireland)
EV	electric vehicle
FiT	feed-in tariff
G2V	smart grid-to-vehicle
GIS	geographic information system
H2G	*How2Guide*
HEMS	home energy management systems
ICT	information and communication technology
ISGAN	International Smart Grid Action Network
ISO	independent system operator
IEA	International Energy Agency
JRC	Joint Research Centre
KPI	key performance indicator
MAIFI	momentary average interruption frequency index
NGO	non-governmental organisation
OECD	Organisation for Economic Co-operation and Development
OMS	outage management system
PR	price response
RACI	responsible, authorised, consulted and informed
RTO	regional transmission operator
RTP	real-time price
SAIDI	system average interruption duration index
SAIFI	system average interruption frequency index
SANEDI	South African National Energy Development Institute
SES	smart electricity service
SG	smart grid
SGMM	Smart Grid Maturity Model
T&D	transmission and distribution

TOU	time-of-use
TSO	transmission system operator
USD	United States dollar
US DOE	United States Department of Energy
V2G	vehicle-to-grid
WMS	workforce management system

Units of measure

EJ	exajoule
Gt	gigatonne
GW	gigawatt
ktoe	thousand tonnes of oil-equivalent
kWh	kilowatt hour
LV	low voltage
Mt	million tonnes
Mtoe	million tonnes of oil-equivalent
MW	megawatt
MWh	megawatt hour

About the IEA International Low-Carbon Energy Technology Platform

Created at the request of the then G8 and IEA ministers, the International Low-Carbon Energy Technology Platform (Technology Platform) is a tool for engagement on fostering the deployment of low-carbon technologies between IEA member countries and emerging and developing economies as well as between international organisations and other stakeholders. The Technology Platform serves as a means to adapt analyses and disseminate policy recommendations, which are often technical and/or global in nature, from the IEA or other expert organisations for the deployment of low-carbon technologies at the national and regional levels. It also serves to share international best policy practice.

About the *How2Guides*

Under the Technology Platform, the IEA launched an initiative to produce a series of manuals to guide policy makers and industry stakeholders in developing and implementing technology-specific roadmaps at the national level. Building on the Agency's global, high-level energy technology roadmap series, this project responds to the growing number of requests for IEA assistance with the development of such roadmaps that are tailored to national frameworks, resources and capacities. It also represents a new stage in the IEA roadmap work itself – a move towards implementing and adapting the IEA global level roadmap recommendations to the national level.

Building on the IEA roadmap methodology presented in the generic manual, *Energy Technology Roadmaps: A Guide to Development and Implementation* (IEA, update 2014), each *H2G* provides technology-specific guidance on considerations of importance when developing a roadmap. These include specific questions one could investigate to assess the country baseline, the identification of stakeholders to involve in a national road mapping exercise, the identification of key barriers and response actions for the deployment of a given technology, and indicators for tracking the implementation of the roadmap.

A second phase of the *H2G* initiative is the dissemination of its guidance through training seminars. This provides an excellent means of helping build the capacities of national and local governments, as well as private sector planners and programme managers, in the area of energy technology planning. The IEA welcomes collaboration with its member and partner countries, the private sector and other organisations for both phases of this initiative.

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HOW2GUIDE *for* Smart Grids in Distribution Networks *Roadmap Development and Implementation*

technology

stakeholders

policy

visioning

planning

barriers

monitoring