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ANALYSIS OF SMART METER FUNCTIONALITIES IN THE ELECTRICITY MARKET AND NETWORK MANAGEMENT

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ABSTRACT

Tasmia Rahman: ANALYSIS OF SMART METER FUNCTIONALITIES IN THE ELECTRICITY MARKET AND NETWORK MANAGEMENT.
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An advanced meter that provides the end-users real-time meter data and additional data to the utility company is called smart meter. Smart metering system is an important feature of smart grid. Also, in network management, operation, planning, and asset management, smart metering is playing a vital role. The whole world is now focusing on large-scale smart metering system implementation. European countries are the front-liner in the mass smart metering rollout. European Union has smart metering related legislation for the member countries, which is to install 80% of the smart meter if the country has positive cost-benefit analysis results.

This thesis analyses how smart metering is creating an impact on network management and in the electricity market. Applications and challenges of smart metering related to design and large-scale development have been described as well. Moreover, the state of the art of Nordic countries (Finland, Norway, Sweden, and Denmark), USA, and some other EU countries (Germany, Italy, France, UK) based on the country's legislation and EU legislation has described by the literature review. Different measures have been taken to analyze the differences between the selected countries.

After observing the implementation status and different implementation of smart metering deployment projects in the selected countries, few findings have been found. Such as growing concerns about meter data security, concerns about health problems among customers, etc. Selected countries came up with the idea like datahub projects and smart meter gateway to solve the raised problems. After analyzing the different measures and problems, it can be seen that the main reasons behind the differences in the large-scale rollout are mainly the legislative barrier, CBA results, and the country's overall policy-related electricity market.

Keywords: Smart metering, electricity market, network management

PREFACE

In the beginning, I would like to express sincere gratitude to my supervisor Professor Pertti Järventausta for the continuous guidance, support, and encouragement during the thesis period.

Secondly, thanks to all the people I met and my friends at Tampere University during my master´s studies. Without their help, my journey would not be much more comfortable. I am grateful to my husband, who always stands beside when needed.

Finally, my special appreciation to my mother and sister Anjuman Rahman. Who stands beside and inspire me in all aspect of my life.

Tampere, 7th May 2020

Tasmia Rahman

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LIST OF ABBREVIATIONS

SM	Smart meter
DA	Distribution Automation
CIS	Customer Information System
DNO	Distribution Network Operation
NIS	Network Information System
SCADA	Supervisory Control and Data Acquisition
QMS	Quality Monitoring System
DMS	Distribution Management System
EV	Electrical Vehicle
SMI	Smart Metering Infrastructure
MDMS	Meter Data Management System
AMM	Automated Meter Management
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
GIS	Geographical Information System
DOE	Department of Energy
PURPA	Public Utility Regulatory Policy Act
EPACT	Energy Policy Act 2005

1. INTRODUCTION

1.1 Research questions and objectives

Smart metering has been a trendy topic in the industry for many years. This research aims to help the reader to understand the importance and functionalities of the smart meter. The main research questions and objectives of the thesis are listed below:

- What is the state of the art of Nordic countries (Finland, Sweden, Denmark, Norway) and the UK, France, Italy, Germany, USA?
- What is the legislative framework of the Nordic market for smart metering technologies?
- How can smart metering effect in the electricity market and network management?
- What are the challenges and barriers for the targeted countries?

1.2 Thesis structure

This master´s thesis mainly consists of a literature study about smart metering and its functionalities on the electricity network and network management. This thesis has seven chapters. Chapter one introduces the research questions, objectives, structure, and methodology. In chapter two, the general concept of the smart meter as a part of the market and grid companies has introduced. Then the smart metering impact on network management according to LV, MV, and HV network has been described in the 3rd chapter. After explaining the state of the art of the Nordic market about the smart metering, then in chapter 4 consists of the legislations, the current scenario of the Nordic market, and plans of Nordic countries. Chapter 5 discusses the current state of smart metering with an in-depth analysis of selected countries such as the UK, Italy, France, Germany, the USA, etc. Chapter 6 outlines the author's analysis, comparison, and reasons for differences in various countries' smart metering systems. Finally, this thesis will finish with the answers to research questions in chapter 7.

The desk-based study was the principal methodology in this research. Where a brief literature review conducted using a large number of secondary sources, another method was analyzing data and legislation of target countries to compare the market situation. Various sources have been used for research such as books, journals, websites, the latest article about the smart meter. Providing authentic and useful references was a priority in this thesis as it is based on a literature review.

One of the biggest challenges was to provide up to date information and legislation of the targeted countries as the legislation there was not enough information available on the internet.

2. SMART METERING AS A PART OF MARKET AND GRID COMPANIES

It is needed to understand the topic of smart metering systems and related terms of smart metering to have a better understanding of how smart metering is having an impact on the electricity market. Therefore, the focus of this chapter is to describe the terms and topics related to smart metering. Also, the smart metering communication technologies, pros, and cons of smart metering, different applications of smart metering have been described.

2.1 Electricity meter reading

For the electricity distribution network and electricity retail business, the meter reading is a crucial part. The meter reading was extremely labor-intensive, costly, and irregular when it was analog. Before, customers billed based on estimation, and the rest of the bills were sent when the meter was read. As well as, the low voltage fault detection was slow because it was based on the telephone complaint of the customer [1].

AMR system nowadays gathers customer energy consumption data, status, and diagnostic data collected from meters. After that, it transfers collected data to the central system automatically for analyzing, to create a bill, and for the troubleshooting. Therefore, the unnecessary visit to the customer premises for meter reading reduced as well as it reduces the need for physical meter reading, which helps to accelerate the electricity distribution and retail businesses [1].

Over the years, meter reading technology has developed so, like their names. Now and then, the new functionalities have been added, and the name used in customer leaflets and scientific papers changes the name from automatic meter reading to the smart metering. Below, brief descriptions are given of different metering systems [1].

2.1.1 Automated Meter Reading (AMR)

Automated meter reading (AMR) systems collect data from consumption points via one-way communication, which means the monthly energy acquired via short-range communication devices that needs either a visit to site or drive-by in the early implementations. However, nowadays, the AMR system automatically sends data to the central database by a wireless network like LAN, mobile phone network, radiofrequency, or with a wired network like PLC, optical fiber, or with the combined (wire-based and wireless) technologies. One important advantage of AMR is on-site meter reading is not needed anymore; therefore, the customer can get an accurate bill based on actual consumption rather than the estimated one. The only lacking the AMR system compare to other advanced metering techniques is the unidirectional information flow. Meaning that the meter can communicate a one-way direction, the meter can send information, but the utility cannot take any action such as remote connection/disconnection. However, this does not prevent the meter from sending power outage or lousy power quality alarm notifications [1].

2.1.2 Advanced Metering

Advanced metering usually represents the latest smart metering solution, which allows information flow in both ways. Advanced metering management, advanced metering infrastructure, smart metering infrastructure, and smart metering terms are used one replace of others as they are quite similar. However, there is some argument that there are some dissimilarities between these terms as well. Some people note that all the AMR functions are present in AMM that adds new functionality to monitor the metering systems and the distribution networks by using two-way communication, excluding the hardware and software needed for two-way communication. The AMM supporting system is therefore considered independent and is either referred to as AMI or SMI. Then again, some people believe that AMI and SMI is a part of AMM. Even smart meter is a vague term, but similar characteristics of AMM in general present in advanced metering or AMI synonym [1].

Advanced Metering Infrastructure (AMI)

AMI system adds the communication link to the smart grid network. Bi-directional data exchange between customers and utility companies is also provided by the AMI. AMI helps to improve power quality as it offers intelligent management, high-quality maintenance, convenient, and proper additions and replacement of utility assets. AMI is a combination of three essential components: consumption points smart metering devices, the bi-directional communication link between customer and meter provider, and automatic software and a center for processing data [2].

Data Concentrator

Data concentrator is a significant AMI node connecting to a variety of central utility servers (Meter Data Management System) and smart meters. It works as a communication data enabler between the smart meters and MDMS. Also, it allows data communications between smart meters and MDMS. Figure 2.1 represents the diagram of the data concentrator. Smart meter data is obtained via the neighborhood area network (NAN) and transferred to a meter data management system via a Wide area network (WAN) [2].

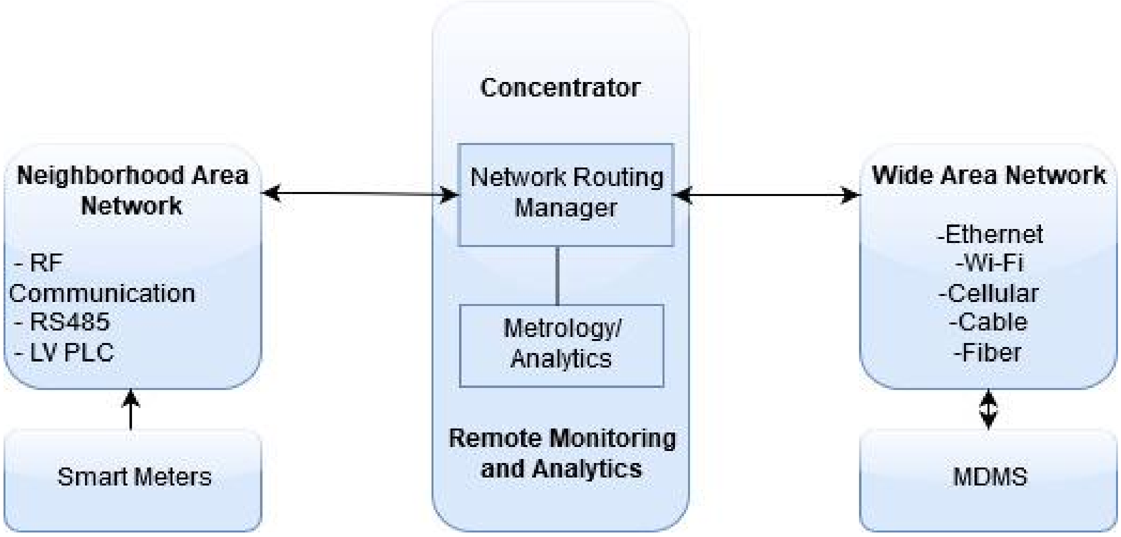


Figure 2.1: *AMI data concentrator overview [2].*

Meter Data Management System (MDMS)

MDMS considers as the heart of the AMI. MDMS system includes the compilation, sorting, and accurate handling of the data that reaches the operations center to concentrators. Therefore, the same group of information is stored in the same address, which helps to reclaim the required data very quickly. MDMS provides analytical tools that allow the system management and various operations that interact with it then gather the necessary information. The management and operation systems include the Outage management system (OMS), Consumer information system (CIS), Geographical information system (GIS), and Distribution management system (DMS). Figure 2.2 is showed how the smart meter elements interact with the MDMS system. One MDMS system is located in the central operation center in a centralized AMI communication architecture.

As the centralized MDMS stores, the customer data from all the concentrators; therefore, desired data is possible to collect from a single server by using the operation and management system or the processing units. The use of a single server for the data storage helps to process data faster. Nevertheless, the system cannot keep up with the increasing load, and therefore it renders the communication architecture non-scalable [3].

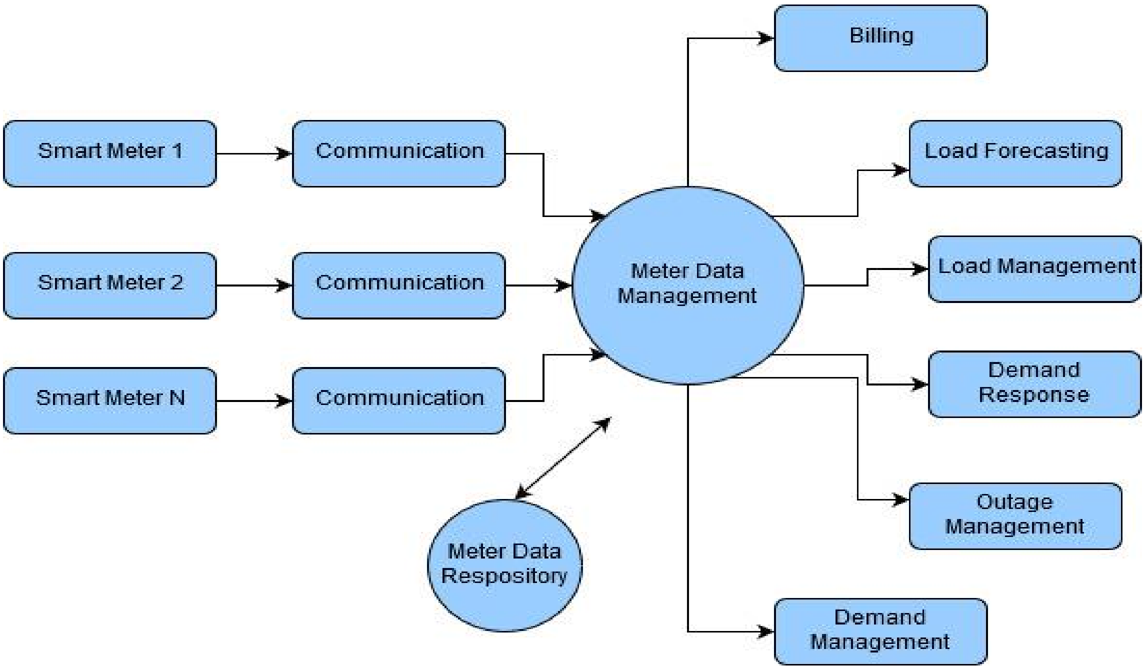


Figure 2.2: *Overview of the Meter Data Management System (MDMS) [2].*

2.1.3 Smart Meter Definition

The smart meter has many different definitions by different people and organizations. According to the researcher Depuru, "Smart meter is an advanced energy meter that calculates end-users energy consumptions and provides detailed information to the utility company compared to a regular energy meter. Smart meters have the ability to read real-time data of the customer consumption and values of the voltage, and communicates that data securely [4]." Smart meter has bi-directional data communication ability, which enables the option to gather the customer information from customer premises regarding the electricity fed back to the power grid [4].

When we talk about smart meter systems, then it is just not the smart meter itself, it includes communication infrastructure and the control devices. A smart meter can remotely and locally connect, communicate, and implement commands. Monitoring and control of customer premise devices and home appliances are now also possible by using a smart meter. Diagnostic details of the distribution grid and home appliances may also be obtained by using a smart meter, and it can also communicate and share the data with neighbors smart meter within its range. Smart meter measures customer electricity consumption, capable of calculating electricity demand from the grid as well as helping decentralizing generation, energy storage systems, and billing the user accordingly. The data obtained by the smart meter is a mix of parameters like a specific meter identifier, device timestamp, and electricity consumption values. Smart meters design or programming can be done in many ways. Such as if the customer consumes power from the distributed generation resources or the storage devices owned by themselves will not be billed, on the other hand, if the customer consumes energy from the utility grid, they will receive a bill from the utility company. It can be connected or disconnect the supply of electricity remotely for any customer as well as it can control or limit the maximum electricity consumption. Below´s figure 2.3 represents the conventional energy model and a smart meter architecture [5] [6].

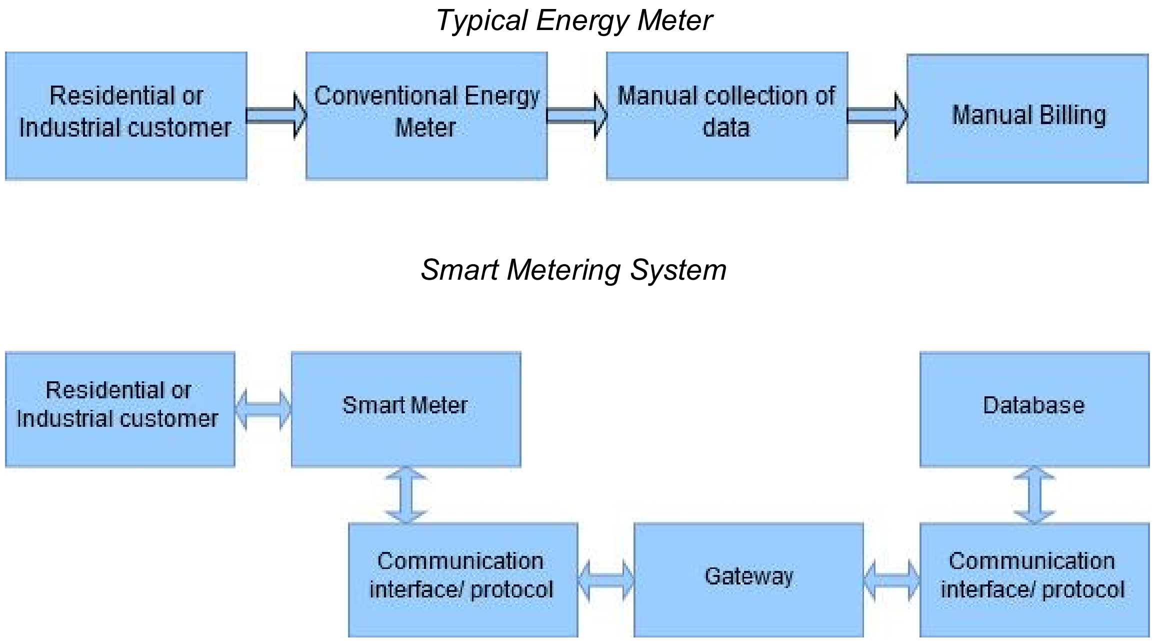


Figure 2.3: *Architecture of the typical energy meter and smart meter [4].*

Smart meter network utilizes a variety of control units, different sensors to define data transfer parameters and devices, and command signals. Nowadays, smart meters are playing an essential role in electricity distribution grids, such as performance monitoring, also the electricity consumption characteristics of the load on the grid, etc. The data collection of electricity uses from consumers helps energy companies. For example, by these electricity companies can manage the electricity demand more efficiently and also by this they can recommend to their customers about how to use their home appliances in more cost-effectively. In addition to this, smart meters may also be used to control heating systems, lights, air conditioning systems, even other devices [7]. It can be programmed in a way so that the smart meter can maintain a routine or schedule to operate the home appliances also operation control of the other devices accordingly. Other than that, the smart meters also help utility companies to protect electricity theft and uses of unauthorized energy consumptions, which helps to improve power quality and efficiency of energy distribution [8].

The design of the potential electricity grids intends to provide their customers with highly efficient, scalable, easy to access and value-effective energy supplies by leveraging the strengths of large centralized generators and small distributed power generating devices both [9]. In future household energy systems, distributed energy will be one of the essential parts. Utility providers are attempting to recognize more valuable consumers and offer alternative value-added services because smart meters may classify these customers from distributed generation sources and total energy consumption data. By using the described programs, monitoring, and management techniques and strategies, energy providers are expected to gather vast volumes of data of real-time.

2.2 Smart meter communication technology

Though smart meter systems are technologically as well as by design diverse, it functions through a primary overall mechanism [10]. Smart meter gathers data from end-users and sends this data to the data collector by using Local Area Network (LAN). The transfer process of data can be done by 15 minutes each or per day, depending on the data demand. After collecting the data, the data collector transmits it to the central unity collection points. After that, the central utility points process it further by using the Wide Area Network (WAN). Commands, instructions, or the signals can be transmitted directly to meters, customer premises, or in distribution devices as the communication channel is two-way [10]. Below´s figure 2.4 represents the underlying architecture of smart metering operations.

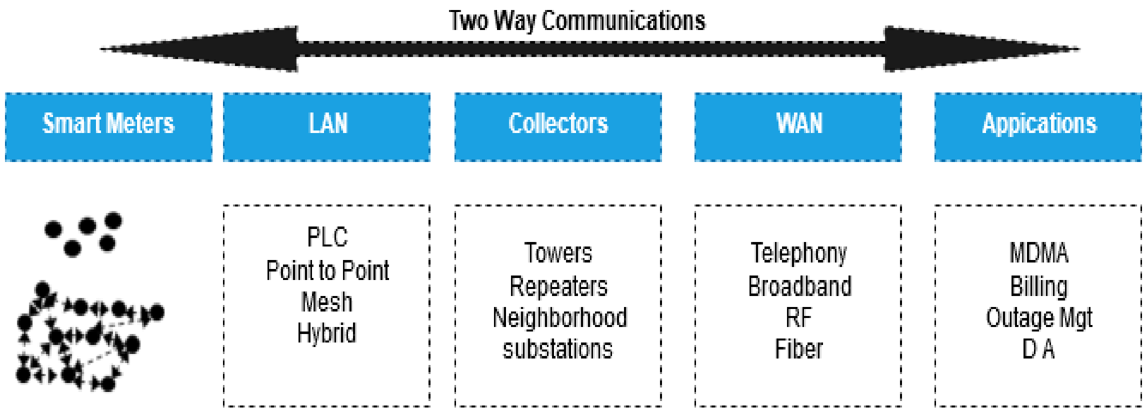


Figure 2.4: *Smart metering underlying architecture [10].*

Currently, the most common smart metering communication technologies are Radio Frequency (RF) and Power Line Carrier (PLC). They both have pros and cons in terms of smart grid applications. From these two technologies, utility companies are the ones who choose which one they want to use based on the company policy and business perspective. Taking the correct decision to the choice of technology needs a detailed analysis and examination of the company´s existing requirements and potential benefits for the future of the business. Some essential factors for the technology selection are, [10] :

- Proper evaluation and analysis of current infrastructure;
- Impact on equipment, technical requirements, functionality, and the economic effect on the utility's customers.

2.2.1 Radio Frequency technology

Smart meter gathers the measured data from the consumption point then transmits that from the meter to the data collector via using wireless radio. After that, using different methods, the data is processed and delivered to the utility data systems to a central collection location. These data are used for the business or operational purposes such as billing for energy consumption, outage management, and different system use. Point to Point technology and Mesh Technology are two different radio frequency (RF) technology widely used nowadays.

Mesh Technology: Smart meters can communicate with each other at the collector point to create a form of a LAN cloud. Then the collector transmits these data to the utility´s central location using different WAN methods [10]. Mesh RF Technology has several benefits. For instance, the appropriate latency, the large bandwidth, and the operating frequency are 915 MHz typically. Besides the advantages, the mesh RF technology has some disadvantages as well, like in the remote areas, it has some long-distance issues also the proprietary communication and topography. There is a lot of research that has been done already in mesh RF technology. A mesh-radio based solution has been proposed by Parag Kulkarni [11], which is an extended version of the Routing Protocol for Low-Power(RPL) and Lossy Network protocol (LLN) which shows self-organizing characteristics. Parag Kulkarni [12] also propose another mash radio-based solution with self-organizing features. This proposed method has the capability to increase the RPL protocol, connectivity enabling mechanism for the low power as well as lossy networks currently being standardized by the working group of IETF ROLL. Another research has been done by Danial Geelen [13]. Geelen represents and asses a real-life deployment of a routing protocol for the smart metering mesh-network grids. This model considered both technological and legislative constraints. Another researcher Hamid Gharavi [14]proposes a mesh network technology with multi-gate intended to maintain maximum efficiency, reliability during an emergency, especially when a device intends power failure alerts and exchanges to be provided. To implement a back pressure based scheduling algorithm, they include hop-count and queue length of individual mesh node both. Researcher Bill Lichtensteiger [15] explains the device design and the efficiency evaluation of a mesh-based Radio Frequency (RF) framework in Neighborhood Area Network (NAN) for the smart energy management applications. For the smart grid, Arjun P. Athreya [16] is recommending the robust and survivable hierarchical communication framework that reflects the hierarchy of the current power grid. Besides, analytical models have also suggested to research the efficiency of flattened architecture as a feature of the smart meter neighborhood size, density of smart meter, and the outage area.

Point to Point Technology: Point to Point Technology is also a type of RF technology, where the communication of smart meters happened with the tower directly. The tower collector transmits the received data from the meters to the central utility area for the analysis by different methods [10]. Point to Point RF Technology has several pros and cons. Few advantages of these technologies are large bandwidth, very little or no latency, and it can cover large distances, direct communication with endpoint, good throughput. Few disadvantages of these technologies are topography, less interface with Distribution Automation devices, long-distance problems in remote areas, and proprietary communications.

Various research has been conducted about Point to Point RF technology. Sebnem Rusitschka [17] introduced a Peer-to-Peer (P2P) home network with low-cost digital electricity meters consisting of off-the-shelf hardware with the current communication infrastructure. Another research conducted by Asma Garrab [18] proposed an end-to-end AMR solution with the enhanced application. This solution is based on a smart meter that has low-power microcontroller MSP430FE423A, also an energy metering module ESP430CEI, as well as the Power Line Communication standards. Rahman, M.M. [19] offers a description of the characteristics of a smart meter, related communication protocol, and bandwidth also examines the latency of smart meter transmission using the OPNET IT Guru to ensure the effective smart meter network operation. In another research, Cen Wei [20] proposed automated detection technology of an advanced smart electricity meter considering problems like faulty smart meter detection, massive detection task, and high working intensity.

2.2.2 Power Line Carrier technology

By using the utility power lines, data generated from the smart meters are possible to send to the central collection point of the utility. Then, the received data is processed and analyzed. These data are used to forecast future business as well as for the utility company's operational purposes [10]. Like any other technology, power line carrier (PLC) technology has some advantages and disadvantages as well. Cost-effective improvement for the rural lines and possible work in remote areas or over long distances capability are the strong advantages of power line carrier (PLC) technology. On the other hand, disadvances are that this technology takes a long time to transmit data compare to wireless technology and less bandwidth in city areas.

A lot of research has also been conducted in the field of PLC technology. Rakesh Rao [21] came up with a method for finding outliers within a series of smart meters by calculating signal strength of the power line carrier (PLC) between the communication node (transformer) and the residential smart meters. The PLC signal is used to proactively prevent local power outages as a predictor for the transmission problems. Four metrics are described based on signal strength distribution, each matric defining one outliers class. In another research, Mojtaba Rafiei [22] suggests a realistic smart metering solution that can be used by integrating PLC and Wi-Fi protocols with all forms of AMR and AMI. Researcher Liang Dong [23] presents a method where at first, the transmission and noise characteristic of the power line channel and after that, the simple power line channel model is established based on the calculated data.

2.3 Applications of the smart metering

The smart meter has several applications nowadays. Few of them are listed below,

2.3.1 Efficient billing and settlement

Smart metering provides exact and real-time data consumption information from the consumption points, which improves settlement procedures. Also, it needs to calculate utilization data and right the settlement, and charging a short time later is evacuated. In the alternative, DSOs might reduce the additional cost.

Request for the meter data is possible at any time by using the smart metering system, which considers as an essential smart meter features. There is a need for a consecutive shorter period of changing electricity suppliers. Also, it is possible to read the data remotely at any time and moment, thus eliminates the DSOs' costs. Near future will be possible to employ automatic switching of the supplier.

The importance of providing accurate billing and energy intake data is emphasized by the EU Commission with the ESD Directive 2006/32/EC. Smart metering surely increases the possibilities of it [24].

2.3.2 Reliability and power quality monitoring

The current and voltage quality of the distribution network both covered by the power quality. The maximum number of the voltage quality-related problem initiates from the consumer's end, yet the responsible party for the overall quality of the client's connection point is the distribution company—the kWh-meters at this point [24].

Constant observation of the voltage quality helps speedy and proper response to the customer fault report. This also helps to create a pre-safety reaction to power quality difficulties before any casualties to the network and customer. Monitoring and recording the voltage dips, power supply disruption, and voltage quality symptomatic experienced by consumers help distribution companies to decide where the network investment is necessary, and they also understand what kind of advice for the power quality they need to advise to the customers. There are many advantages of the power quality monitoring device and smart metering system integration—for instance, equipment sharing, network installation, network maintenance, and communication [24].

2.3.3 Networks state estimation

Power flow-related information on the LV network side of the distribution line is not accurate enough nowadays. The reason behind this is that this information is created based on the primary substation measurement, forecasted loads, and network model. To calculate more accurate network losses is possible by installing a measurement device close to the load consumption point. With the advanced technique of state estimation, a vast amount of measurements from the network are connected with the physical network models and by loads [24].

The combined method of model and measurements helps to measure unknown variables such as reactive power losses also helps to cross-check unreliable data. For the state estimation and to forecast the demand in a small period, all the smart meter samples can be used [24].

2.3.4 Demand response and limitation of peak load

“Controlling loads and enclosed generation as a response to the electricity prices is called demand response, which covers the price control and direct load control [24] .” In the case of price control, there are three types of tariffs available. Such as real-time tariffs, critical pick tariffs, and time of use tariffs [25].

Price control will be accustomed to replicate the price of electricity on a competitive wholesale market or time variable of the distribution network tariffs, otherwise the addition of those both parts. Time variable distribution tariffs came from a regulated natural monopoly, which usually levels the loading of the distribution network. Competitive energy markets offer some great value, like the spot-market value. These help to control the price.

The electricity storing process is costly and initiates losses. So, it is crucial to keep a balance between generation and consumption in the power system all the time. For the efficient electricity market operation, it is essential to have enough price flexibility. Options for the fast control of big power plants, CHP plants, and fossil bulk generation plants are limited and costly. Fastest going percolation of solar power and wind power raises the necessity of the controllable resources. Controllable generation and peak power generation are fast but pricey in terms of their efficiency and the produced energy. That is why the necessity of controlling demand and distributed generation both are rising.

The fixed time of use tariffs could also be too rigid to adapt to the predictable developments within the electricity market and infrastructure and result in stranded investments. Real-time tariffs and path tariffs both are futuristic. The smart metering could be the solution to enable demand response [24].

2.3.5 Load modeling, forecasting, and analysis

Record the energy consumption data is an essential feature of smart metering. With this data, it is possible to analyze the load. Based on hourly data and the information about the consumer type, it is possible to frame a user profile. These types of profiles can be established on a statistical sample, and it represents the type of user. It is possible to model the load based on the type of day, outside temperature, and different climate variables. With the combination of basic information such as load profile, energy use, time variations, and peak demand is possible to calculate and forecast.

This kind of information is vital for retailers, consumers, as well as for DSO´s. Especially when DSOs are planning the power distribution network and the operation. Detailed energy use information may be useful for the energy savings campaign evaluation. This will be done by combine information concerning the activity of end-user with energy consumption development [24].

2.3.6 Voltage and frequency control

The service needed for the operation of electricity transmission and distribution such as energy losses compensation, voltage control, power flow control, frequency control, balancing, and supply restoration is called ancillary services.

Smart metering could have functions like remote control features with local control outputs, local frequency measurement, voltage level, and reactive power. All of this helps the ancillary service provision with DER [24].

2.3.7 Smart metering for energy savings

Smart meter gives customers continuous information about actual electricity consumption. That gives control to the consumers over their energy consumption by analyzing the consumption data so that they can adjust their consumption patterns, finding the unexpected energy consumption caused by malfunctioning equipment, open windows, or inadequate insulation [24].

2.3.8 Embedded renewables and, the virtual power plant

The virtual power plant is a practical idea for remote operation and monitoring. Also, the joined connection of the energy market is essential for small energy resources. Small generation unit's area typically required for generation from native renewable energy sources and cogeneration of electricity and heat, as a result of the long-distance transfer of biofuels or heat, is not efficient. Some controllable loads of the hydro, solar, and wind power generation units are little.

It is easy and faster to control small generation units and loads rather than the big power plants even though their communication system is reliable and fast. Because nowadays, the distributed generation and generation from renewable energy sources are increasing so that it becomes essential to use small units rather than before as controllable resources for the electricity market and additional services of the electricity networks.

Generation measurements from the individual unit are also possible with the smart meters. Typically, the local generation control could happen independently by the meter—for example, mobile phone technology or on the internet. The possibility of using the smart meters just for the communication purpose is physible as well [24].

2.3.9 Meter management

Smart metering also helps in meter management activities. Such as installing meter asset management, a database for the vendor, age, type, tariff and configuration settings, safety, working life, and security check maintenance record. Visit rostering where necessary, also make sure that all the meters are installed correctly and work accordingly by meter fault detection and error detection in installation. Smart metering also might have options to determine meter faults and installation problem issues. Suspicious meters and models could have detected by using state estimation with redundant meters. Meter location and customer checks can be stored in the meter database [24].

2.3.10 Fraud detection

The traditional electromechanical meters have few features to cut down the fraud. For example, the meter might have a function that stops the meter from running in reverse. In the case of the smart meter, it should have few features for revenue protection. Nevertheless, this might create the situation more complicated as in AMR, the removal of physical visits considered a huge benefit. It means there is no one to inspect the meter physically, so the meter should send a notification in terms of any fraud attempts. The for the frauds, it creates new opportunities when a new updated feature added in the smart meter. However, the important thing is that smart metering can enable time to time detection of any fraud attempts. For instance, open up the meter box, changes in the connections to the meter or meter software re-program. Meter manufacturers strongly believe that it is achievable by the smart meter to generate revenue protection rather than the traditional meter. Which itself is a great motivation for them to switch to the smart meters as fraud levels are higher nowadays [24].

2.4 Advantages of the smart meter

Smart meter can play a crucial role in the SCADA system, and it can increase the operation ability of the SCADA system. The smart meter has many benefits like effective power system control and monitoring, functional decisions that need to take for reducing the outages and losses [26]. In microgrid mainly, smart meters can calculate the cost of energy as well as can support fault analysis, power quality analysis, and demand control. Preventive maintenance scheduling and check meters operation support for exact billing is possible with the smart meters.

Moreover, detecting the presence of unexpected harmonic components in current supplied from the de-centrally generated sources is possible by a smart meter, which takes an important part to identify and rectify the problem from the source [27]. Integrated micro-generators with the distribution network need to be registered. So that the smart metering system can control them, pattern recognition techniques can be used as a smart metering system part to achieve access to performance data of devices and money incentives for the client [28]. The analog energy meter reading system is laborious, slow, and upscale things nowadays. In a typical metering system, the meter reader needs to visit the metering point for reading the meter after that the bill can be issued. This entire method now becomes comfortable with the assistance of the smart metering, and the correct communication technology. Increased energy security and energy savings help the installation, and with smart meter adaptation [7]. Smart meters encourage consumers to conserve energy and help consumers to have control over their consumption and energy price.

2.5 Challenges of the smart meter

Accomplished as a function proportional to the projected increase within the energy demand and a portion of the distributed generation [29]. For utility companies, it is very challenging to replace typical energy meter to the smart meter initially because of the high installation cost. Synchronizing this latest technology with the conventional one is a complicated thing that might create an interruption to the launching of smart meters, where the main reason behind it is the lack of proper infrastructure. The devices which are synchronized with the smart metering system can be used fully only when all gadgets and devices of the distribution network and metering network are part of the communication network. When the consumer number increase in a network, then the device integration in a network becomes quite complicated. Due to terrestrial difficulties, the deployment communication network in some localities turns out into a difficult situation [30]. For example, in the USA, utility companies might not be interested in encouraging and creating awareness for their consumers to conserve energy because the companies get a bonus based on the electricity they sell to their customers [5].

Data collection and its transfer is a complex process. The smart meter has many issues and challenges when it comes to design, deployment, and maintenance. It needs several billion-dollar investments for smart metering system implementation in a distribution system and the maintenance of the network. However, after all this consideration, investment justification is difficult. Hence, this investment is a costly and slow process though it is an automatic and continuous process. In these circumstances, questions might arise about the safety, security, and privacy of several consumers. They might think that the smart meters might not secure for them as data is transferred to the utility company and other 3rd parties.

Moreover, based on data, it is possible to reveal the information about the presence of resident in-home, and what kind of devices and appliances they are using. In some cases, consumers do not want any communication and data sharing about their consumption with their neighborhood´s meter. Fundamentally, it would be a problem regarding the selection of parameters need to be transmitted and administrator verification to the access of the data [31, 32]

Moreover, transmitting the data and control signals with the base station, smart meters are needed to execute these control commands from the utility corporation. The whole operation of the smart metering system involves a vast amount of data transfer in-between the server situated in the base station and the smart meters. This massive amount of data maintenance, management, and storage of it is a slow process. Choosing a communication network is a difficult job because there are many technical issues involved which need to consider finalizing the communication network. For example, Mander et al. proposed DNP3 security enhancements by using data object security and a security layer, if DNP3 is not able to provide enough security for collaboration operations [33]. Also, because of the high cost of bandwidth, maximum utility companies use low bandwidth for smart meter communication; therefore, high traffic generates, which limits the data transmission quantities. The device integration for modulation, demodulation, and extra storage for storing the information logs might increase the expansion costs. It consists of high risk to transmit the data of energy consumption by using public communication networks such as cellular networks [34]. Weak protocols, weak authentication, error handling, poor implemented software quality, and improper session management is the possible security vulnerabilities options [35]. Despite those problems, though readying and maintenance of some communication networks cost is low, utility firms would possibly encounter some challenges such as propagation problems, network coverage limitations, and data capacity. Also, the data concentrator might lead to accommodation and safety-related issues, whereas physical damage of the cable may cause the interruption of data transmission in case of wired communication.

Different problems and challenges related to the design, utilization, deployment, and smart metering system maintenance are explained in figure 2.5-2.7. There are some people than utility companies such as a vengeful ex-spouse, terrorists, civil litigants, thieves, illegal energy consumers, extortionists, and political persons with a vested interest. They might have interested to gather and analyze the energy consumption data of consumers to get to know about the people´s presence at their home. These people might have different evil intentions to collect the data, which is a tread in terms of customer safety [36]. Quantification of the potential advantages from smart metering is incredibly troublesome because of the dearth of historical information. However, the future of the smart metering system ultimately depends on the government policies and utility companies; however, it differs from country to country. The smart metering system is also prone to physical cybersecurity risks because the customer gateways are smart and compatible with other devices easily [37, 38]. Smart meters are usually situated in open spaces, which are the most insecure. To protect any physical damage, it needs proper shelter.

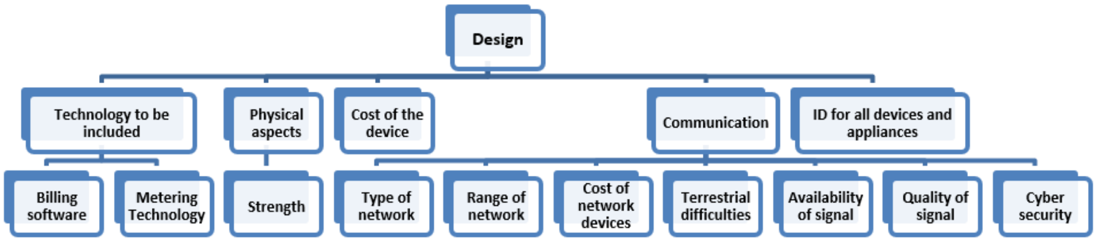


Figure 2.5: *Smart metering system's design problems [4].*

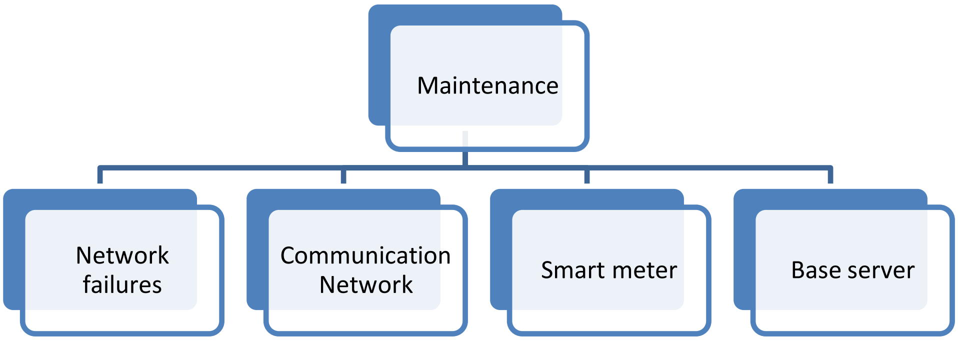


Figure 2.6: *Smart metering system's maintenance problems [4].*

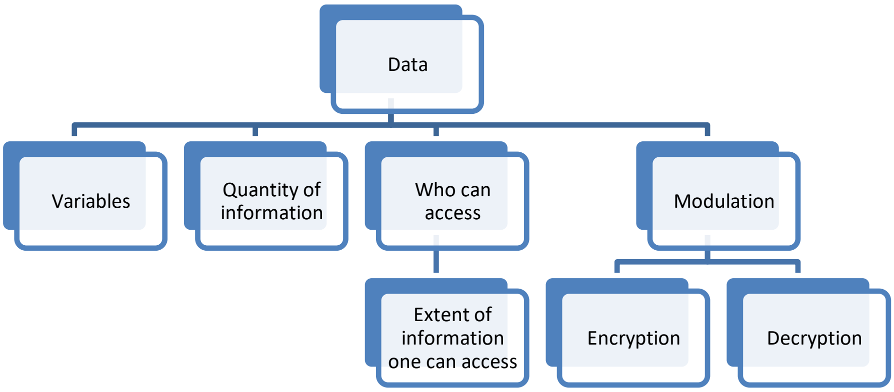


Figure 2.7: *Data transfer challenges of a smart metering system [4].*

Major design problems and constraints, including technology extent, are explained in figure 2.5-2.7. Software related to the control system, billing, and other technology-related metering is included in this technology. Positioning the smart meters and structure strength contains physical safety aspects, smart metering device cost, fixed ID to identify the smart meters and other smart metering network components, also communication system needed with a total cost for the transmission, data collectors, data repeaters, antenna system, based on terrestrial system type of network is chosen, availability of signal, cybersecurity, kind of signal and its range. Next significant issues are the maintenance of all the network element when some fault occurs. Smart meter´s software and hardware problem, electrical and distribution fault issues, energy, and data storage, server network issues are all included in network maintenance. Along with all of this, another major concern is dealing with data where the data transmission amount, variables of it, the extent and amount of data that can access by the consumers and the utilities, required parameters to present the energy consumption, modulation and demodulation of the data before and after the transmission and reception respectively [4].

2.6 EU Smart Metering Background and Legislation

During the last decade, the development of the smart metering system in Europe has been done significantly by the adaptation of different legislation. Initially, it was in the form of end-use energy savings. The introduction of the smart metering system is expected to help consumers understand their actual energy uses. Thus creating more excellent opportunities for energy efficiency on the demand side. European Commission considers the smart metering system as an excellent tool for transparency and competition increase in retail markets for electricity, because of energy market liberalization and the single European market regulations [39].

Economic development and dissemination of data are now considered as strategic and economic recourses, which prompted EU institutions to take unprecedented steps for the security of their citizen's private data [40]. This framework shall apply to the processing, collection, and data management of smart meter when it comes to private data. In terms of public data, authorized parties have non-discriminatory and open access to it, and the data management system used is assured by special provisions and rules laid down under the recast Electricity Directive [39].

2.6.1 Institutional Background

The very first directive which has some metering related recommendation was Directive 2006/32/EC [40]. This directive prescribes the use of cost-effective technological innovation like a smart meter to save energy up to nine percent in the following nine years. Article 13 from the legislation named “Metering and information billing of energy consumption” recommends that the end consumers of the electricity, gas, district heating, and cooling and water need to be provided individual meter price and it should reflect the real use of the consumption with an accurate time of use information. Furthermore, actual billing information needs to be provided. Therefore, the customer can regulate their energy consumption. This directive was the very initial step to make customers active in metering use.

Directive 2009/72/EC [41] and 2009/73/EC [42] referred to as the Third Energy Package recommends in Article 3.11 that all the member states and the responsible bodies must inspire energy enterprises to optimize the use of energy and introduce smart grid or smart meter where needed. Annex I of the directives has the instruction for long term cost-benefit analysis, and that needs to be performed by 3rd September 2012. That also specified that if the CBA results positive, then 80% of the smart meter needs to be installed by 2020.

Commission Recommendation 2012/148/EU [43] provides instructions for the member states about smart metering system design to make sure the personal data protection. It also suggests the member countries include a data protection impact assessment in the smart grid and smart metering system designs. Moreover, this recommendation provides a guideline for cost-benefit analysis methodology. Finally, a list of standard smart metering functionalities has also given in this recommendation to make sure the customer benefit and energy efficiency increase.

Then comes Directive 2012/27/EU [44] Energy efficiency and replaced the previous target with an increased 20% target. Article 9 of this directive dedicated to metering, which gives additional guidelines related to smart metering deployment, minimum standard features, and privacy and data protection of the end-users. This functional requirement for electricity metering is later merged with Article 20 of the recast Electricity Directive under the Clean Energy Package, and the Energy Efficiency Directive is accordingly amended [45] [39].

Apart from the previously mentioned provisions, a smart metering system needs to comply, being measuring instruments, also with the Directive 2014/32/EU [46]. This directive harmonizes the national law in terms of making market measuring instrument availability and abolished the old Directive 2004/22/EC [47].

A framework was developed in union level for conducting data protection impact assessment to make sure that all the member country is following previous Recommendation 2012/148/EU [43] consistently. Commission Recommendation 2014/724/EU [48] provides some guidelines for smart grid and smart metering systems for the member countries on how to use the Data Protection Impact Assessment framework. It also helps to ensure the fundamental rights of personal data protection and privacy in the smart metering and smart grid implementation (Article 1).

The Directive 2014/94/EU [49] Deployment of Alternative Fuel infrastructure states in Article 7 that, “The electric vehicles recharging at recharging points accessible to the public shall, if technically feasible and economically viable, make use of smart metering systems as defined point (28) of Article 2 of Directive 2012/27/EU and shall comply with the requirements laid down in Article 9 (2) of that Directive [44].” This provision explains the facility provided by the smart metering system. It allows electric vehicles to get charged in of-pick periods in the long-run and EVs to feed power from batteries back in the grid at the time of pick electricity demand.

2.6.2 Clean Energy Package

The European Council approved a new regulation text named “Clean Energy Package or Directive 2019/944 [45] on May 2019.” In this Directive, some specific instruction related to smart metering is available in Article 19-21 and Annex II.

Article 19 recalls the provision that member countries suggest for smart metering systems to electricity market enterprises. Specifically, the followings things [43]:

- Smart metering deployment decision need to take based on cost-benefit analysis, which should follow the commission recommendation 2012/148/EU [43];
- Member countries need to publish a minimum technical and functional requirement for the smart metering following the mandated in the Directive as well as Commission Recommendation 2012/148/EU [43];
- Member countries need to make sure that the smart metering systems are interoperable, and they are capable of delivering output for energy management systems;
- End-user needs to contribute to smart metering systems deployment-related cost, taking into consideration the long-term profits for the entire value chain;
- If the cost-benefit analysis (CBA) assessed negatively then the member country should do CBA after four years;
- A smart metering system would comply with the relevant data protection laws of the Union.

Article 20, states that all the member states need to follow the smart metering system deployment under the European standards, the commission recommendation 2012/148/EU [43], and some other specific requirements mentioned at Article 9 of the Energy Efficiency Directive 2012/27/EU [44] regarding:

- the type of data to the customer;
- data and data communication securities;
- data availability for the customer;
- proper guidance and instruction need to provide to the customer before or in the smart meter installation time.

Article 21 specifies that customers are entitled to a smart meter, even if the smart metering system deployment has assessed negatively. In this situation, the customer needs to share some cost of implementation, under transparent, reasonable, and cost-effective conditions. However, the latest Electricity Directive updates the following sections that are directly related to smart metering. Also, this use as demand-site management and flexibility:

- Equal opportunity establishment for the demand response with the independent aggregator (Article 17)
- Smart meter entitlement and how to practice its right (Article 21)
- Network charges and tariff costs paid by the customers need to be fair, which is imposed by the network operator. It must reflect on network charges associated with the smart metering rollout (Article 19).
- Customers are benefiting directly from smart meters in terms of promoting acceptance and satisfaction. It needs to be ensured that the deployment does not fill the expectation (Article 19).
- Union rules regarding data protection and security need to be followed, use, and adoption of Data Protection Impact Assessment (Article 10, Annex II).
- Opportunities come by the broader use of data, which creates some challenges as well in terms of effective competition in retail markets (Article 20).
- CBA is needed every four years in case of a negative result of CBA (Article 19).

Figure 2.8: *Evaluation of the EU Directive 2006/32/EC to the Directive 2019/944/EU [39].*

3. SMART METER IMPACT ON LV NETWORK MANAGEMENT OF DISTRIBUTION NETWORK

MV network system has many support systems, for instance, distribution management systems, SCADA, network information systems, and geographical information systems. The primary purpose of this kind of system is to help the operation of the MV network. However, different recent research has proved that smart meters can also be used in the management of the LV network if advanced AMR meters integrate with MV/LV substation monitoring devices with the current network management system [6] [5, 50-53]. Figure 3.1 describes how AMR meters can help in different functions of a distribution company, such as to support network operation (LV fault indication, isolation, and location, precise voltage, and load data), asset management and network planning, power quality monitoring, customer service, load settlement, load control and in the traditional use of billing [54].

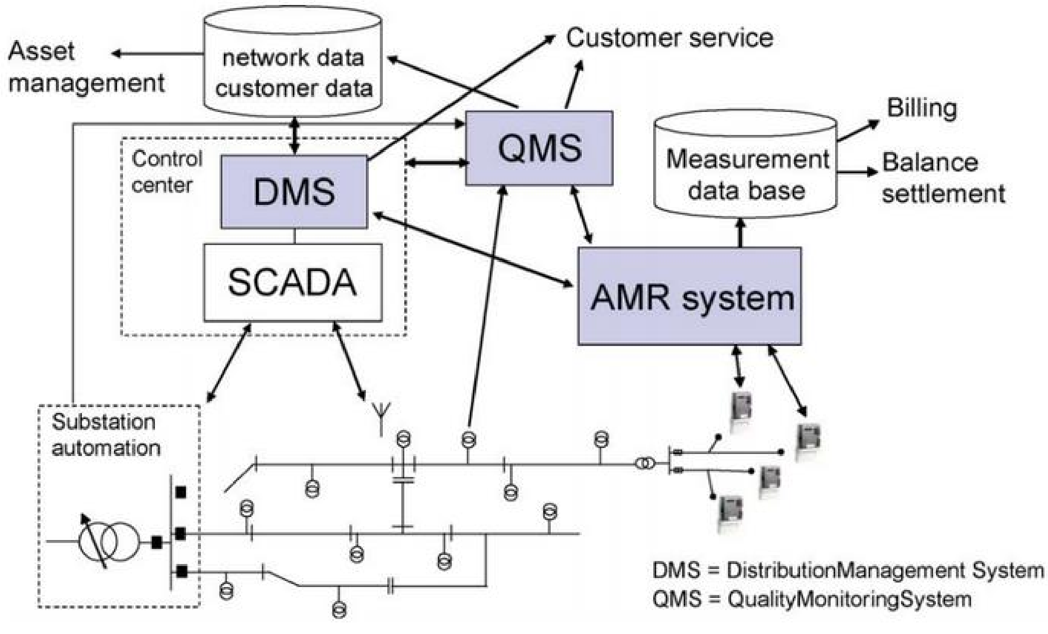


Figure 3.1: *Interconnected comprehensive network management systems [54].*

In Finland, network data is available at NIS as well as from the LV network. Network data and customer data are available in DMS because of a highly integrated system on control center information.

This chapter will focus on discussing the impact of the smart meters and its functionalities on LV/MV network management of the distribution network from the viewpoint of network operation, asset management, and planning. Figure 3.2 illustrates a detailed approach of using AMI in LV network management, which described later in this chapter.

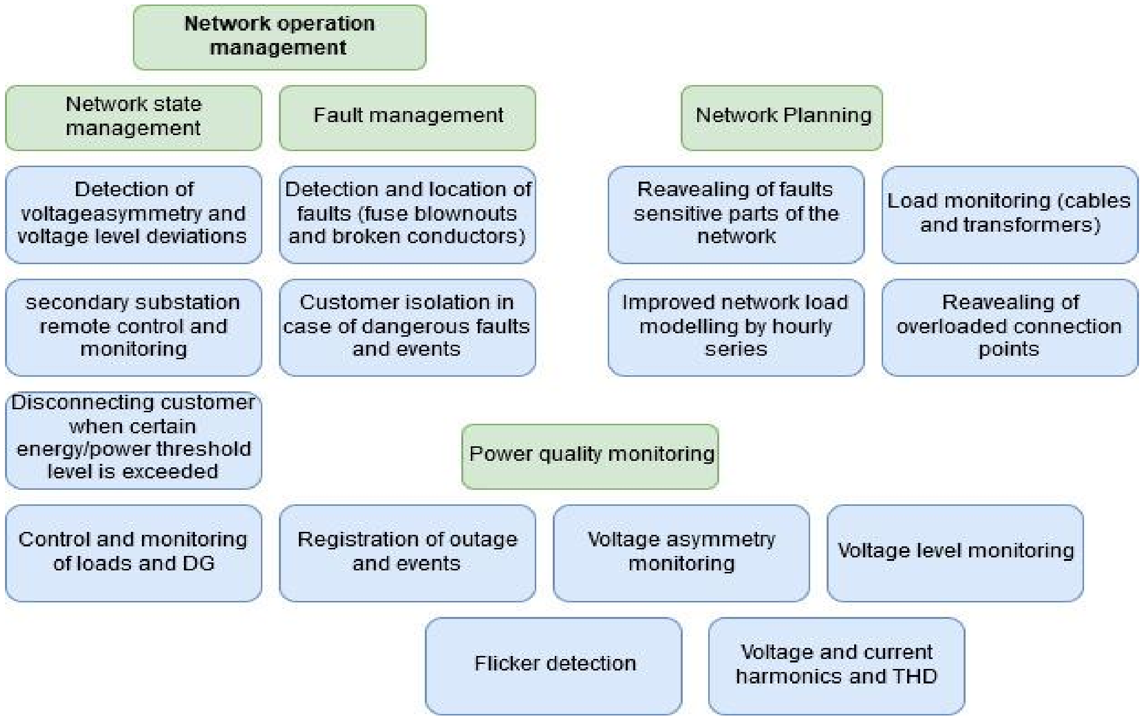


Figure 3.2: *Summary of LV network management [55].*

3.1 LV network operation

Data about the state of the distribution network is essential for smooth network operation. Real-time data about the network state should be in the control center. Before the era of the advanced smart meter, real-time data was available only for the MV network. However, now with the advanced smart metering, real-time LV data is also possible to get. Online supervision to the LV site and control of the LV network is possible because of the bi-directional communication between distribution network companies and consumer sites. The extension of distribution automation and SCADA to the LV network level has been possible because of the integration and use of the smart metering system and DMS [55].

3.2 LV Fault identification, management, and isolation

The unwanted fault which occurs in the low voltage side is known as a low-voltage fault. LV network varies from 0.4 kV to 1 kV. Conventionally the DSO´s do not have an option to detect the low voltage fault automatically. Back that time, the only option was the customer needed to report the fault or any unexceptional behavior on the low voltage side. That time the LV fault clearing method was the fuse protection, and in case of any low-voltage fault, the fault cleared by a blown a fuse. For this kind of scenario, the network control center did not´t receive any information automatically back at that time.

Due to the smart metering infrastructure development and integration of smart metering with DMS (Distribution Management system), SCADA (Supervisory control and data acquisition) and QMS (Quality monitoring system), it is now possible to monitor and analyze the fault situation of low voltage network with minimum cost, as the AMR communication system could be used [54]. It is possible to detect missing phase voltage, and other faults on the low voltage side could be detected by using an advanced smart meter so it can send fault notification and alarm to DMS. Information on missing phase voltage makes it possible to find out the reason of customer outage and which fuse has blown or damage [56]. An advanced smart meter can detect the exact location of a blown a fuse or broken LV conductor and can send an alarm to the control center about the LV fault because the smart meter covers all the customer premises, very few faults are keeping out of the smart metering system. If all the phase voltages are missing at the same time, then the alarm cannot be sent to the control center due to the communication network jam as a result of medium voltage faults. Those are seen as LV faults. Meter those are connected with only one phase cannot also send the alarm. Though an advanced DMS can send some queries to the smart meters and cross-check some information by that, it could be possible to detect some of these faults. When an MV line is under repair or re-energized after a major fault, then the control center can identify the fault place and send field crew to repair with queries, and these are incredibly beneficial [53].

An advanced smart meter provides critical information such as voltage levels, voltage abnormalities to the control center using communication infrastructure. Based on that, it can detect a broken neutral conductor, which is crucial as per the safety aspect. Smart meter has a disconnection unit by that it can automatically isolate the customer in terms of any fault. A broken neutral conductor can cause a hazardous voltage, and it can damage any device, or even it can set the fire; that is why customer isolation is critical. It could sometimes be dangerous for the surrounding people if the metal covers of the electrical devices become live [56].

The information about interruptions, fault types, start and end times of fault can all be gathered automatically by a smart meter, and they make the LV fault reporting accurate. Therefore, the compensation due to the interruption needed to pay to the customer can also be determined automatically by using AMR data [55].

3.3 Network state management

For the most efficient use of the LV network, state management has been used, which works as remotely and automatically. Nowadays, LV network control activities are done by balancing the peak demand of the power system by controlling specific loads of consumers based on the request, or by the pre-defined schedule. Advanced smart meter with the advanced programmable relay output can even enable more advanced control functionalities. For example, the frequency depends on load shedding and demand-side management. Though mentioned functionalities have an impact on the LV network but have more impact on network management. In terms of LV network sides, controlling of loads is more important to protect network assets from overloading. Due to the characteristics of the fuse protection, the momentary overloading is possible sometimes because fuse protection allows the nominal current for a short time without any blowout. Which might cause the lifetime reduction or the permanent damage of the network assets [56]. Many functionalities can work automatically and remotely from the control center based on their measurements. The reason behind this automatic functionality is the Advanced Metering Infrastructure (AMI). In the case of low voltage side residential distribution transformer overloading, the smart meter in that can send an alarm to the control center, and based on that, the control center can pre-plan, and the LV network state could be performed. However, in the case of the secondary substation measurement, the customer load is controlled by an intelligent device automatically. If this automatic control fails, then it sent an alarm to the control center [56].

Load control is crucial from the consumer point of view also. If the preprogrammed consumption limit exceeds the customer connection point than the smart meters can take over the control of the particular loads of the customer automatically, because of the power limit set abilities of the smart meter. If the smart meter has functions like a disconnection unit, then the remote disconnection of distributed generation (DG) is enabled in terms of any maintenance or fault repairing work. This automatic disconnection is helpful in loss-of-mains cases [56].

3.4 Asset management and LV network planning

From the network asset management point of view, the LV network has excellent value. Because the LV network is the most dearly owned and longer part of any distribution network, however, it is not that important in terms of reliability point of view, for example, in Finland, more than 60% of the entire network is LV network, and these 60% LV network costs almost fifty percent of the total distribution network (including MV/LV transformers) [57]. LV network is the longer part of the network so that it has more network losses than the MV, so as the secondary substation, which feeds the LV network.

Before the smart metering era, the network calculation, possible power quality restoration, and calculated value of short circuit current was the way to evaluate the state of the network [56]. A recent network planning approach is to emphasize creating a strong network that can deal with most load scenarios for at least 40 years, which needs a secure and robust network. Strengthening the LV-network depends on load growth as data about the current loading of the LV-network is not available, which is not an efficient option [58]. With the help of accurate measured data of AMI network calculations, accuracy has been improved lately. These AMI data can enable various tools for power quality and load analysis [56]. An optimistic approach to LV-network planning, better monitoring of the state of the LV-network, proper planning, and evaluation of possible network reinforcement is possible because of the introduction of AMI [58].

3.5 Enhanced network calculations

Basic information for the network calculation (for instance, power flow and fault current calculations) such as network topology, component properties, and load curves are collected from the network database and customer database. There are some challenges in this network calculation process. Such as, if the number of customers analyzed in statistical network calculations is low, then the results are more inappropriate.

The hourly data received from the advanced AMR meters help to improve load modeling and to get more perfect results of the LV network calculations. AMR data could be used to process the load curves and represent the user's classification without replacing the load curves with the hourly series data in network planning. It has been proven from a recent study[54] that the direct replacement can even cause a more inaccurate result that making the results accurate. It is assumed that the power factor is constant in network calculations, which is not valid in reality. Active and reactive power proportion changes from time to time in reality. AMR meter helps to improve the result by providing an hourly series of reactive power [56].

Peak load is the most important criterion which is possible to calculate with the improved network calculations. Every LV network point is possible to calculate more accurately. Therefore, orienting the LV network elements and fuse protection is more efficient so, as losses can even evaluate more precisely [56].

3.6 Network analyzing tools based on AMI data

AMR data-based analyzing tools that support network planning and asset management are studied in reference [53]. Using analysis tools, it is possible to inspect the network components load (for example, distribution transformer, cables) and decided on the network state—for instance, the criticality of the network renewal.

Traditional LV network design has some marginal value so that overload can be avoided, which makes the future load increment easy as well. However, customer consumption behaviors always change. Some customers might invest in new technologies such as electrical heating or cooling system or even in an electric vehicle. Therefore, the peak demand in the LV network can increase all of a sudden. Here comes the smart meter. By using a smart meter, data peak demand can be indicated. As a result, DSO´s can understand if the LV network reinforcement (for example, transformers replacement or cables replacement) is needed or not.

If any customer connection point is overloaded, that is also possible to identify using AMR data. Overloaded customer connection points can be problematic for DSO´s. This type of problem identification is tricky and time-consuming now. However, this can work automatically with an application that collects data from AMR to the fuse size information on the customer information system (CIS). Revealing the fault sensitive part of the LV network is also possible from outage information provided by advanced AMR meters. By renewal activities and clearing activities of the line in a proper way is possible more efficiently by comparing (fault sensitive part of the LV network) information with the condition information, manufacturing information, and vegetation clearing year of the line [56].

3.7 LV network power quality monitoring and management

Power quality management needs extensive measurement data from the low voltage network side. Traditionally power network management data is collected from the primary substation, not from the customer's side. Power quality measurement from customers is done if the customer ordered measurement for the bad power quality, which is a rare case [59].

LV network electricity quality could be improved by integrating special power quality meter to the customer side. With that special power quality meter, the accurate power quality information about the LV network should be available from each customer connection point of the LV network, which is extremely expensive for the network operators. Advance AMR meters nowadays comes up to the solution of this problem partly. Advanced AMR meters have some necessary power quality measurements, like as over and under voltage asymmetry measurements and voltage level in each phase. By which power quality monitoring of LV network is possible. AMR meter can also measure flicker information, a common reason for the voltage quality problems [56, 59].

Now in Finland, more than 80% of the customer has remotely readable AMR meters. As a result, power quality measurement covers the most part if the distribution network and power quality monitoring of the LV network have been improved significantly. AMR meter sends alarm about the voltage quality when it crosses the threshold limit, and the reason for this is the certain limitation of the AMR about quality measurement [60]. AMR meters have the primary power quality monitoring functionalities of the LV network, not all the power quality measurements [56].

4. STATE OF THE ART IN THE FINNISH AND NORDIC MARKET

This chapter will focus on describing mainly the situation of Finland and Nordic countries about the datahub projects around Nordic countries. Mainly state of the art and the legislation related to the smart metering described here in this chapter. Later in this chapter, a brief discussion about the Nordic datahub has been described as well.

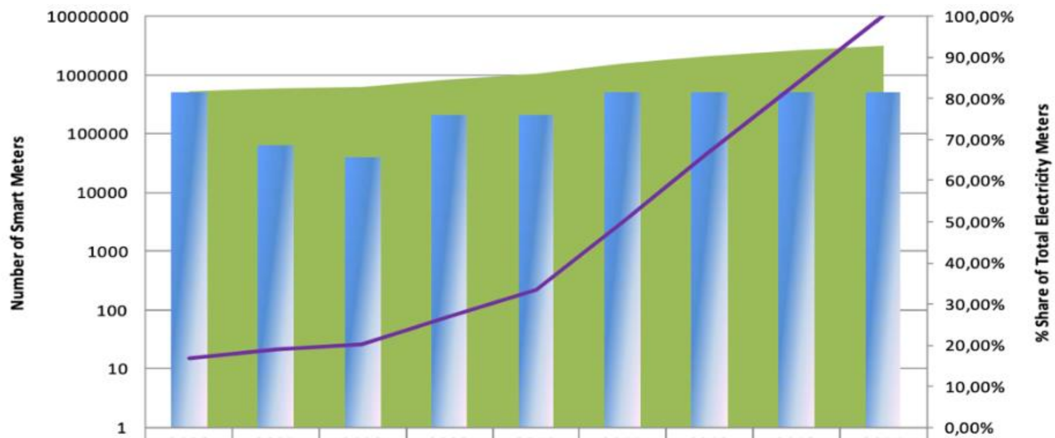
4.1 Finland

4.1.1 State of the art

Finland has been taking the leading role in terms of smart metering roll-out and hourly data use for the balance settlement. Finnish DSOs have installed a smart meter for their customers. According to the low, 80% of the customers should be provided a smart meter by the end of 2013. In reality, more than 98 percent of installation has done by the end of 2013. Almost 100 percent of consumption places have smart meters by 2019. The successful journey of the smart metering roll-out started in 2009 when Finland decided to implement hourly metering and remote reading [61].

The DSO is in-
charge of electricity metering and the delivery of metering information to the consumer, balanced settlement, and markets. Nonetheless, launching the smart metering of the first generation was a significant investment and development initiative for all the DSOs and market players in Finland [62].

Initially, there were 500000 AMR meters in Finland in 2006, according to the conference paper presented in the European Council for Energy-Efficient Economy conference [63]. Then, Industry-specific information website smartmeter.com sates in 2009 that in 2008 almost 20 percent of the 3 million Finnish households were equipped with a smart meter [64]. Thirdly, in 2010 the smart meter installation rate was over 1 million according to the 2011 SmartRegions report [65]. The final installation phase started according to the Electricity Market Act, 66/2009, which needed full-scale implementation by the end of December 2013. The graphical representation has shown in bellow's figure 4.1.



	2006	2007	2008	2009	2010	2011	2012	2013	2014
Cummulative	500000	563000	600000	800000	1000000	1500000	2000000	2500000	3000000
SM Deployed	500000	63000	37000	200000	200000	500000	500000	500000	500000
% of Total Meters	16,67%	18,77%	20%	27%	33%	50%	67%	83%	100%

Figure 4.1: *Smart metering diffusion in Finland [64].*

4.1.2 Legislative Framework

In 2009, Finland decided to introduce hourly metering and a remote reading under the new electricity market act (66/2009), which was active from 1 March 2009 [66]. Below Legislation requirements are described:

- Metering points of electricity consumption, small scale electricity production, and consumption points has the main fuse more than 3*63 A must-have hourly registered remote readable meter.
- If the delivery sides are equipped with a maximum of 3*25A main fuse or over 3*25A main fuse, and the consumption is less than 5000 kWh per year (electricity bought from seller obliged to supply) than the decree allows the exception of hourly metering no more than 20 percent of the customer.
- The electricity market act allows an exception in the implementation of small-scale production metering. Usually, a separate remote readable meter needed in all production side, but in small scale production located in a delivery site, which has main fuse max. 3*63 A does not require separate meter only if hourly registered remotely readable meter on that delivery side can register inbound and outbound energy separately.
- If the consumption measurement is done accurately for the consumption point less than 3*25A, than the consumption points and DSOs apparatus can be left without metering equipment [67].

Metering is a part of the DSO's regulated operations, but electricity retailers operating in the liberalized sector are anticipated to provide new and innovative services. It is expected that also, service providers came to the market to provide different services. In short, the measuring technology is well regulated and monopolized by DSO, but products should be on a liberalized market. Minimum functional requirements for the hourly registered remote readable meters defined by the regulator in Finland are as follows[67]:

- Data recorded by the metering equipment need to be readable from memory remotely by using the communication network.
- Data from remotely readable hourly interval measurements should be available to the market actors and the customer on the very next day. These data need to be stored in the DSOs data storage system for six years, at least.
- If the customer wants the equipment with a standardized interface for real-time consumption monitoring, then DSO´s must need to deliver this to the customer.
- Consumer needs to receive the data immediately once the electricity seller receives it.
- Meters can receive and execute load control commands or forward the commands on devices that can maintain loads in a limit. Meaning that,
    - The consumer makes a contract with the retailer to monitor the peak times when the electricity stock market is higher. Then, the seller provides a control command directly by the meter (through the mobile phone network or by the DSO).
    - The customer orders a meter from DSO, which transfers the load limiting command to the home automation control system such as HVAC after that control the system based on its programming.
- Data and data privacy of the measuring equipment needs to be adequately ensured.
- Variable time-of-use (TOU) tariffs support is needed.
- If the outrage is more than 3 minutes, than the measuring device needs to be registered, these data need to be saved in the DSO´s data storage system for two years minimum.

There is some exception allowed regarding the minimum functional requirements in remotely readable meters that installed already [65].

4.2 State of the art in Nordic countries

Nordic countries are geographically close to each other, have a similar climate, and they share a common electricity exchange (NordPool). Though Implementation of the regulations varies from country to country, yet all four countries' electricity markets are completely liberalized. The organizational structure, legislation, and the electricity markets are very similar to each other [63]. They have a common energy regulatory body named NordREG as well. Nordic energy regulators organization NordREG recommends some issues regarding smart meter based on the EU regulation. All the NordREG members followed recommendations when they were in the implementation phase. A few of them are listed below.

Metering methods: All Nordic countries should implement smart metering to all metering points for the effective, efficient, and functional Nordic retail market. Individual countries can set the time limit of this roll-out based on their legislation.

Meter capabilities: Hourly based on energy use registration, functionalities should be in the meter. However, some exception in hourly metering is acceptable for the reason of cost. Such as when electricity consumption point consumption can be estimated exactly, which means the consumption is time-wise constant (for instance: automatic traffic control camera, combustion gas fans, signal traffic lights, streetlights) [67].

Meter reading frequency: Daily meter reading is necessary. For the low consumption customers, it can be decided according to the cost-benefit analysis result. Meter reading frequency needs to be synchronized with the time limit set for the balance settlement; therefore, verified consumption data is used.

NordREG found that working towards future harmonized metering functionalities would be the most beneficial. Also, other metering related issues like harmonized rules for correction of metered data would be the import future working area for NordREG [67].

4.2.1 Denmark

State of the art

Denmark is the front-runner country in Europe to install smart metering by following the EU smart metering legislation. Denmark is expecting to finish the mandatory smart meter roll-out by 2020. These mandatory roll-out process started in 2014 as, Danish government order 783 related to smart metering roll-out released in June 2013 needed mandatory roll-out by 2020.

Liable party for smart metering, procurement, owning, rollout, and replacing the metering equipment to inspect, managing, and reporting metering data to the 3rd parties (for instance: datahub) within the electricity trading is the DSO.

Hourly metering was mandatory for the metering points since January 2003 for the metering points with a yearly consumption of 200.000 kWh/year. Then, in 2005, the limit was lower down to 100.000 kWh/year. However, the billing system was traditional like, once in a month. Nevertheless, if the grid company wants, then they can lower the limit from the declared level. But for that, the grid company must be capable of handling a safe and secure electronic switch and, they must provide the complete service of that area.

Initially, the study showed that mandatory AMR roll-out investment was not profitable. However, some of DSO´s later found investment in smart meter beneficial. By 2011, almost 50 percent of the total metering points, which is approximate 1.63 million meters, were installed voluntarily by the DSO. In 2016, 1.8 million customers, which is 2/3 of Danish consumers, have installed a smart meter [67].

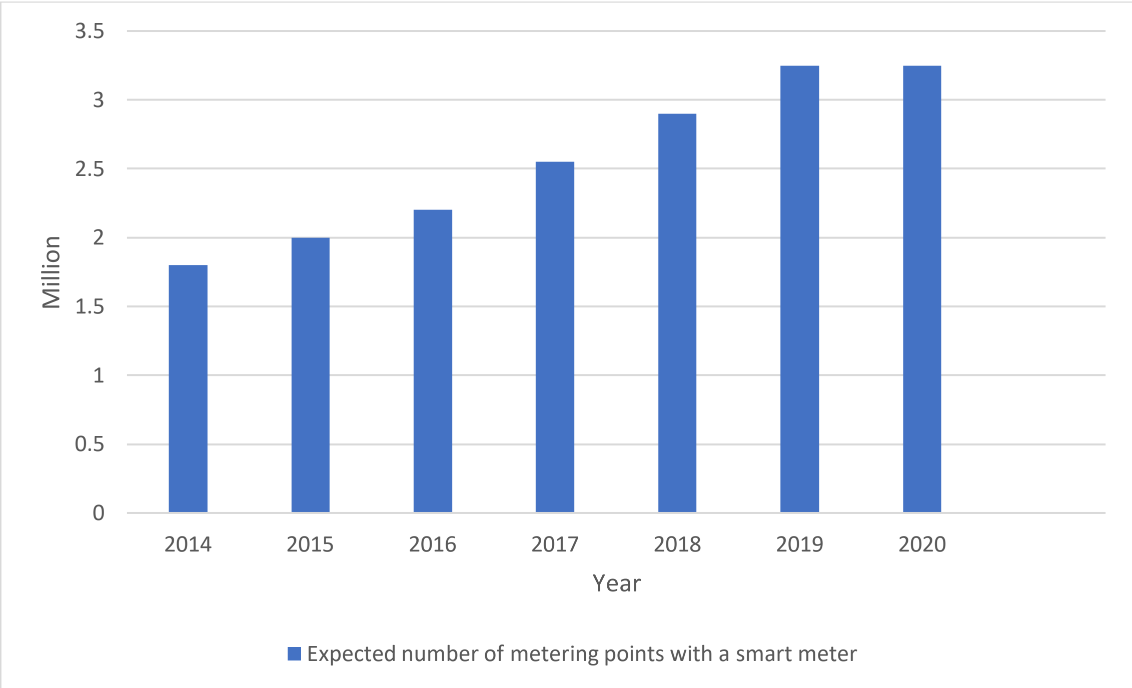


Figure 4.2: *Yearly rollout summary of smart metering in Denmark.*

In 2013 an economic evaluation of the long-term cost-benefit analysis had been published covering 1.38 million metering points, and the CBA result was positive. Therefore, the mandatory roll-out legislation came into action from 2014.

Table 4.1: *Summary of smart metering deployment and regulation in Denmark [68].*

DENMARK	
Metering Activity	Regulated
Deployment strategy	Mandatory roll-out
Number of metering points	3.28 million
Implementation speed	2014-2020
Penetration rate by 2020	100%
Responsible party- implementation and ownership	DSO
Responsible for third-party access to metering data	Central hub
Data refresh rate	15 minutes
Datahub owner	Energynet

Legislative Framework

The Danish government published the smart metering act in 2013, which came into action from January 2014. The requirements include remote reading and network entities choose their initiative about the customer premises meter installation.

Minimum functional requirements for the hourly registered remote readable meters defined by the regulator in Denmark are as follows:

- The meter should have the remote reading system by which the change of registration frequency is possible;
- Meter data need to store for future use in consumption settlement;
- The meter needs to able to register every 15 minutes;
- The collection and delivery of the collective electricity supply system need to register independently;
- The meter needs to register power supply failures data of the customer point, and based on the demands, and these data need to supply.
- The meter data need to be highly secured via and encryption;
- The meter needs to have the functionality to communicate with metering data on the incoming and uses of electricity, for every time series, to the network entity and an external unit. The meter display need to show the current electric power and total values for the received and supply of the electricity;

- Meter data transferring interval to the network entity need to be adjusted, adapted to the entity´s settlement, and the regulations issued by energinet.dk need to be settled in terms of billing;
- DSO should be able to obtain meter data all the time;
- Customers should have access to connect external units to the meter by using open standards. And to extract consumption related data all the time;
- External units should be capable of connecting by a layperson without breaking seals or similar things. Network operators are free to decide how they will activate this. Moreover, this should be done without extra cost for the customer;
- The extraction of data should not be a problem for the network operator's use of smart meter [67].

4.2.2 Sweden

State of the art

Large scale rollout of smart metering in Sweden is possible to divide into two generations. In 1st generation roll-out, Sweden was the first country in the world to fully implement by 2009. As it was too early and after that, the EU regulation came into action, so there were some functionalities in Swedish smart meter that are not that up to date.

In the first-generation rollout, all types of end-users had the remotely readable smart meters with monthly reading since 2009. Those meters were installed in 2004-2009. For that, the industry invested EUR 1-1.5 billion to replace 5.2 million metering points [54]. That time 50% of the installed meter was able to measure hourly and remotely, where 90% of them can update the information every 24 hours. 66% of the meters were able to register a short outage of fewer than 3 minutes. 66 % of the installed meters were able to register voltage deviation, and finally, 40% of the meters were able to calculate input and output energy.

End-users can access their consumption data from the websites or through the bills monthly, daily, or hourly consumption values. It depends on data availability. Therefore, some of the additional services, such as monitoring real-time and appliance specific consumption and monitoring electricity prices offered by a few suppliers [69].

As the first-generation smart meters have some limitations, and they did not meet the EU legislation. Also, the first generation's meter is about to end their life soon. Considering all the issues, Sweden is planning to roll-out its second-generation smart meters; those will meet all the necessary functionalities required by EU legislation.

Sweden is planning to finalize its 2nd generation roll-out by 1st January 2025. Based on the new regulations, the features needed for the 2nd generation roll-out are:

- Extended measurement data (per phase: voltage, current, active, and reactive power for both directions, active energy for both directions);
- Registration for active energy for per hour or fifteen minutes and power outages;
- Remote collection of the measured data and power outages;
- Remote update of the software, settings, and control the power of the meter;
- Customer interface display info according to function 1 in real-time based on customer request [70].

Table 4.2: *Summary of the smart metering rollout in Sweden.*

SWEDEN	
Metering Activity	Regulated
Deployment strategy	Voluntary
Number of metering points	5.2 million
Implementation speed	2003-2009
Penetration rate by 2020	100%
Responsible party- implementation and ownership	DSO
Responsible for third-party access to metering data	DSO
Data refresh rate	15 Minutes
Data hub owner	SvenskaKraftnät

Legislative framework

Sweden is the front runner in smart meter roll-out, as they were the first country in the world to implement 100 percent smart meter roll-out. The primary reason behind it was to improve the billing process. In 2003, a new regulation came out and metering for energy consumption needed per month for all the customers with lower consumption who have fuse size below 63A, and this should be done by 1 July 2009.

Furthermore, for the larger customers, hourly metering was needed. The DSO´s was responsible for the implementation over the time frame of 6 years. Output energy metering was not the mandatory criteria for the installed smart meters [69].

Based on new metering regulation, which came into action in October 2012, all the small consumers also need hourly metering subscriptions from DSO´s, and it should be free of charge. Summary of the 1st generation smart metering legislation has presented on bellow's figure 4.3.b

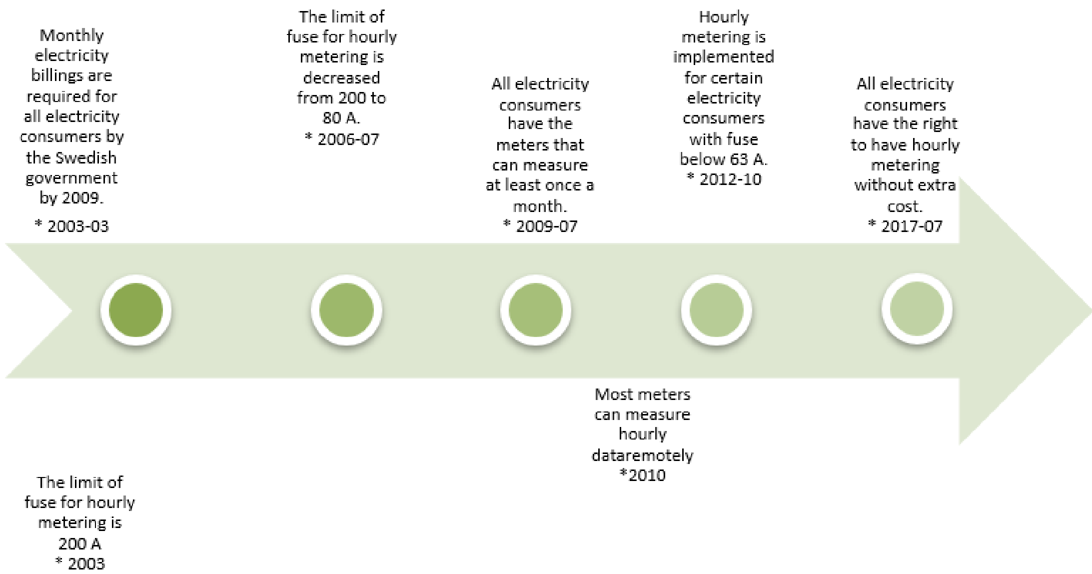


Figure 4.3: *First generation of the smart meter in Sweden [70].*

Sweden was planning to implement the 2nd generation smart meter based on the EU recommendation. Swedish energy market authority (Ei) came out with the functional requirements for 2nd generation smart meters. Based on that, the roll-out needs to be done by 2025.

4.2.3 Norway

State of the art

Nordic countries create the opportunity for Norway to develop an advanced smart metering system as they started this project a few years earlier than Norway. They learned from other countries as well [71].

The Norwegian water resources and energy director (NVE) has also been supervising the installation process. The regulation came into action from 2013 finally. Approximately 2.9 million meters in Norway were to be fully installed by 1 January 2019, and from 2019 all consumption needs to be metered hourly. Although the CBA for household-level smart metering installation was negative, nevertheless Norwegian authorities decided to install a smart meter to all households [72]. The total estimated cost for the smart metering roll-out was ten billion NOK, and the average installation cost per metering with software was 3500 NOK [73].

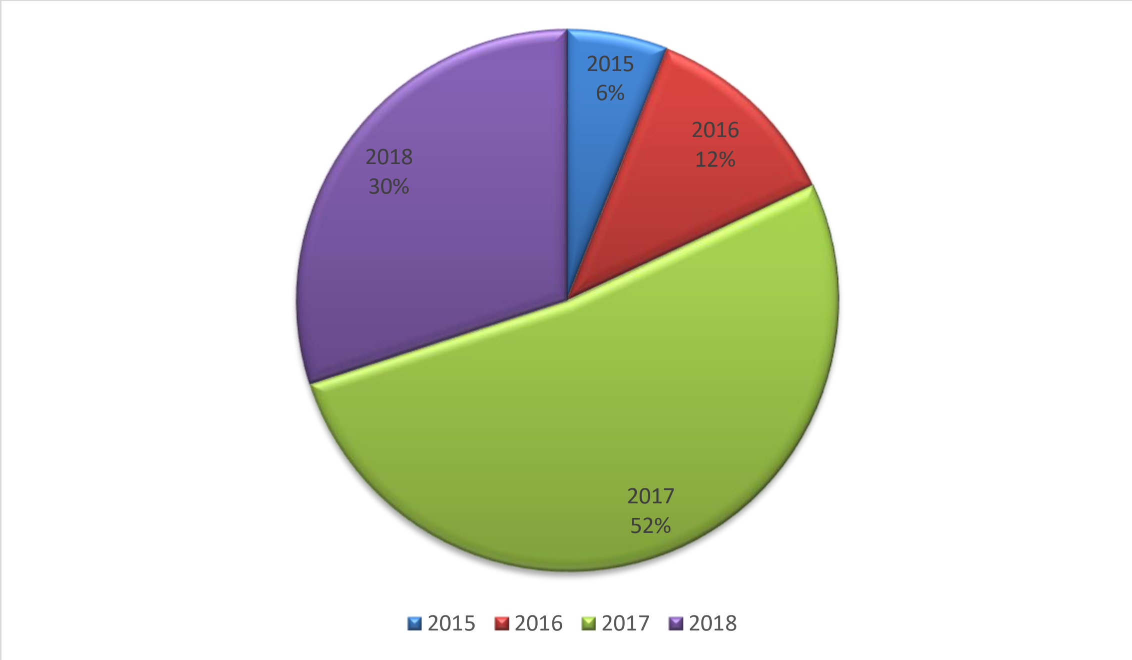


Figure 4.4: *Annual installation plan of Norway [74].*

Consumers need to pay for the smart metering cost through an increase called transmission tariff; a fee end user will pay to the DSO. DSO is responsible for setting this tariff but needs to be in a specific limit determined by the national regulator [74].

Currently, 98% Norwegian metering point has a smart meter installed following the NVE legislation. Only 2% of the metering point left behind where DSO´s could not install a smart meter. Half of them because of some technical reasons and very few (approximately 0.25%) of them left because the customer showed a medical certificate because they think that smart meter might create medical issues. Only these cases are legal except for the smart meter installation [75]. Below, an overall summary of the Norwegian smart metering described by table 4.3:

Table 4.3: *Summary of smart meter deployment and regulation in Norway.*

NORWAY	
Metering Activity	Regulated
Deployment strategy	Mandatory
Number of metering points	2.9 million
Implementation speed	2013-2019
Penetration rate by 2019	100%
The responsible party for implementation and ownership	DSO
Responsible for third-party access to metering data	DSO and Customer
Data refresh rate	60 Minutes with the option of 15 Minutes sampling
Data hub owner	Elhub operated by Statnett

Legislative framework

NVE developed the regulation to facilitate the smart metering implementation. As per the regulation, the smart metering rollout needed to start from 2013 and end by the 1st of January 2019. NVE was the supervisory body of the roll-out process [75].

NVE has clearly stated some functionalities in the smart metering act for the smart meter, which meets the EU legislation as well. Some of them are described below [76]:

- Register and store with a sampling frequency of 60 min (with 15 min option);
- Standard interface for communicating with the external equipment- Moe Area Network (HAN port);
- A Possible option for future connection with other smart meters such as gas, heat, water;
- Both input and output energy need to measure;
- Data need to be stored securely in case of voltage interruption;
- Connect and limit customer power output;
- Spot price and tariff information exchange;
- Earth fault signals control and exchange;
- Data privacy and tampering measures;
- Measure active and reactive power (input and output), for example, 4-quadrant measurements.

Other than the explained functionalities, there are few more requirements needed to fulfill the smart legislation, such as the grid companies need to provide the option to connect with the meter via display so that the electricity supplier or the DSO can send the pricing information to that display. Measured data need to be available for the users and fo the utility's on the following day. Other parties should get data access with customer permission. Consumption data need to be available via an online platform for the customer without any extra cost. Moreover, the information needs to enable comparing.

4.3 Data Hub projects in Nordic

The primary purpose of a datahub is to give suppliers a central access point for the customer metering data to faster the data exchange system and remove the hustle of communicating each DSO directly. There is no standard strategy around Europe, and it varies from country to country based on their policy except Nordics. Nordic countries have a similar approach.

Finland: Datahub pilots are already in proper use, and the first implementation of the datahub is already in process. Various stakeholders are closely co-operating in this project. Based on the amendment of Electricity Market Act 2019, retailers and DSO´s use Datahub and take the needed steps for starting the datahub operation of the services. Datahub should be introduced at the same time by all the market operators. The initial plan for the inauguration of datahub was 2021, but now it postponed, and the new plan for the inauguration of datahub is 21 February 2022. The accrues as almost 30% distribution system accounting points could not meet the previous deadline. It leads Fingrid Datahub Oy to a significant financial loss, which is nearly EUR 8-9 million per year [77].

Denmark: Denmark was the pioneer in terms of datahub implementation. In 2012, a political decision made to implement datahub. Based on that decision, Denmark implemented a data hub in 2013. On the 1st April 2013, the customer-centric model implemented after preparation in cooperation with the industry, which led to the significant development of datahub. All kinds of information related to metering, tariffs, fees, and taxes available in the datahub, and it handles the communication between the DSO and suppliers. In 2016, the second version of the datahub updated.

As the government plan is to complete a full smart metering roll-out by 2020, after that hourly settlement for all the customers would be possible [78].

Sweden: Sweden is the last Nordic country to implement datahub. The delay occurs based on some legislative problems. The government of Sweden assigned Svenska kraftnät to develop and, in the end, operate Swedish datahub (Elmarknasdshubb) in the middle of 2015. In 2016, Svenska kraftnät delivered a pre-study report and started the implementation process. 2017 and 2018 was the preparation phase, and now they are working on the implementation phase. Now they are planning to move to actual implementation from the prototype phase. Sweden is planning datahub go-live in autumn 2022 [78].

Norway: In February 2019, the electricity Datahub of Norway went live after a couple of months of delay. However, the newly implemented Datahub provides exiting and the vast amount of data sources that can be used widely. Elhub (a subsidiary of statnett) has been worked several years to complete the Datahub project in Norway.

Business Requirement Specification (BRS), along with the industry, aligned responsibilities of data management in Elhub have been defined together. Also, VEE (Validation, Estimation, and Editing) quality standard for metering data also specified by the Norwegian water resources and energy directorate (NVE). Norwegian Datahub website Elhub.no is now live, and all the needed information can be found from there [78].

The next plan related to Datahub is to test 15 minutes capability in Elhub and operation enhancement process as agreed with the market. There might be a second version of Elhub that will come where the focus will be supplier centric market model, including a single invoice, said by the regulator Elhub. Table 4.4 represents a summary of Nordic datahub project status and the futures.

***Table 4.4:** Summary of the TSOs datahub implementation of Nordic countries [78].*

Questions	Denmark	Finland	Norway	Sweden
What is the status of the national data-hub imple-mentation in 2019?	The Danish data hub has been live since March 2013	Under devel-opment	The Norwe-gian data hub successfully launched 18th February 2019	Under devel-opment
What are the overall activi-ties planned in 2019 on-wards?	**2020:** Imple-ment eSett in-tegration. **End of 2020:** All metering points will be settled hourly. **2020+:** Imple-ment 15- min imbalance set-tlement. **2021:** Fully CEP compliant	**Q3 2019:** Pilot group testing starts **Q4 2019:** Electricity mar-ket decrees are ready Q2 **2020:** Industry testing starts **Q4 2020:** Mar-ket party certi-fication	Continuously monitoring and supporting DSOs and suppliers in im-proving data quality and re-porting sys-tems. **2020+:** Acqui-sition and de-velopment of 15 min interval capabilities for imbalance set-tlement.	The plan for the next 12 months is: **1.** to move from develop-ing a prototype to developing the actual hub **2.** to initiate a renewed pro-curement of a migration solu-tion in Autumn 2019 **3.** start the in-ternal estab-lishment of an organization for the future operation.
When Is the estimated im-plementation date of data-hub comple-tion?	N/A	February 2022	N/A	It can be the earliest be op-erational by Autumn 2022

5. STATE OF THE ART OF SOME EU COUNTRIES AND USA

The focus of this chapter is to explain the state of the art and legislative framework related to the smart metering of the EU members country UK, Italy, France, Germany, and the United States of America from outside of the EU. Details about the different legislation and the current situation have been illustrated throughout the chapter with different stats, graphs, and figures.

5.1 United Kingdom

5.1.1 State of the art in the UK

The very first step which the United Kingdom took regarding smart metering installation in 2008 was the Energy Act 2008, which allows starting smart metering roll-out. Initially, the authority decided two steps for the smart meter project. Step one was the pilot or the Foundation Stage, and the timeline was March 2011 to October 2016.

The second step was the main roll-out phase, which they planned initially from November 2016 to 2019. However, in 2013 the government pushed back the deadline to 2020 as the industry was requesting them. Therefore, the government set the target to install 50 million smart meters across the country by 2020. Energy suppliers are the responsible party in terms of the roll-out, and they are free to plan the roll-out strategy according to their business policies [79].

Energy suppliers started the rollout with the first-generation smart meter. These meters are accommodated with the government definition for the initial version of standard Smart Meter Equipment Technical Specification (SMETS) to ensure minimum standard functionalities. The 1st generation meters in the UK are known as SMETS1. SMETS1 was supposed to use in the foundation state in between 2011-2016. However, even after 2016, the installation of 1st generation smart meters continued until today by some suppliers as the infrastructure for the 2nd generation smart meter was not fully ready. Though the government declared the SMETS1 would not be the part of the 2020 target from December 2018 and 15th March 2019 for the pre-payment system meters [80].

2nd generation smart meters are also acquiescent of the regulation of the 2nd version of SMETS. SMETS2 was designed to solve the lack of 1st generation meters as well as to give the customer a smooth experience when they switch the supplier. In the beginning, the plan was to start installing 2nd generation meter from November 2016. As of that time, the infrastructure for the 2nd generation meters was not ready, so the starting date pushed back. In September 2017, the government announced that the SMETS2 testing was still on the testing state [80].

One of the most important concern nowadays is the installation of the first-generation meter. Many suppliers are still installing first-generation meters. Another issue is the supplier swathing. SMETS1 is not the cooperate its best when a customer wants to switch the suppliers. A recent survey by the National Audit Office said that almost 70% of the SMETS1 would “go dumb” when the customer changes the supplier and if the supplier uses a different communication network. Because of the change of communication network, the SMETS1 smart functionalities will not work; instead, it will become a traditional meter. SMETS2 meters was supposed to install from the beginning of the main rollout stage from 2016 and supposed to have the solution for interoperability problem. Nevertheless, in reality, the first trial SMETS2 meter was installed in August 2017 [79].

At the end of Q3 2019, a total 15.6 million (8,707,300 electric and 6,611,900 gas) domestic and non-domestic smart meters have been deployed all over the UK. However, the rollout situation in the UK after 2019 indicates that they will miss their target as well as the EU 2020 target. The rollout process was slow in the 1st two quarters of 2019, but in the 3rd quarter of 2019, it increased by 4.1%. The two main challenges for the slow rollout are the physical lack of SMETS2 due to technical and development issues and the existing functional and infrastructure problem of the data communication network of the SMETS2 meters. Though the responsible companies have had the chance to fix and prepare for these two problems before 2016, they have failed to do so [80]. Year by year installation progress shown in figure 5.1. Due to administrative problems, the progress slowed down a little bit in 2018, and it started to increase from the 3rd quarter of 2019 again.

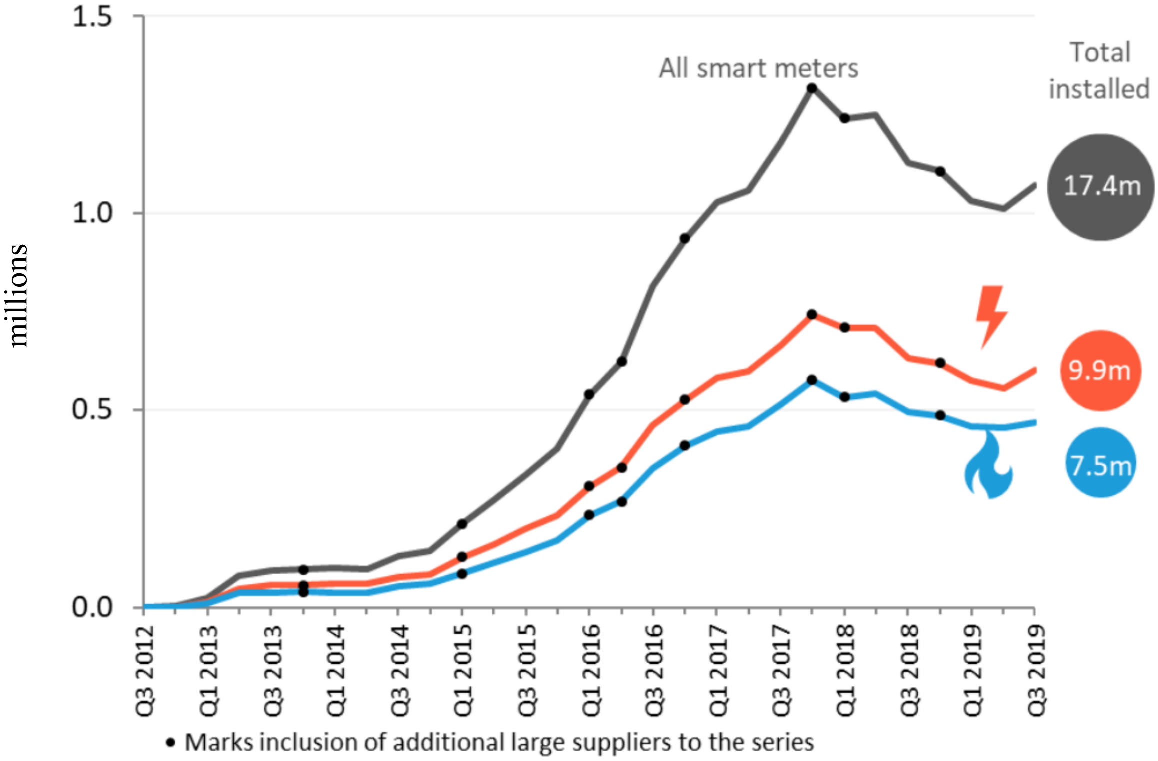


Figure 5.1: *Domestic meters installation progress by large suppliers [81].*

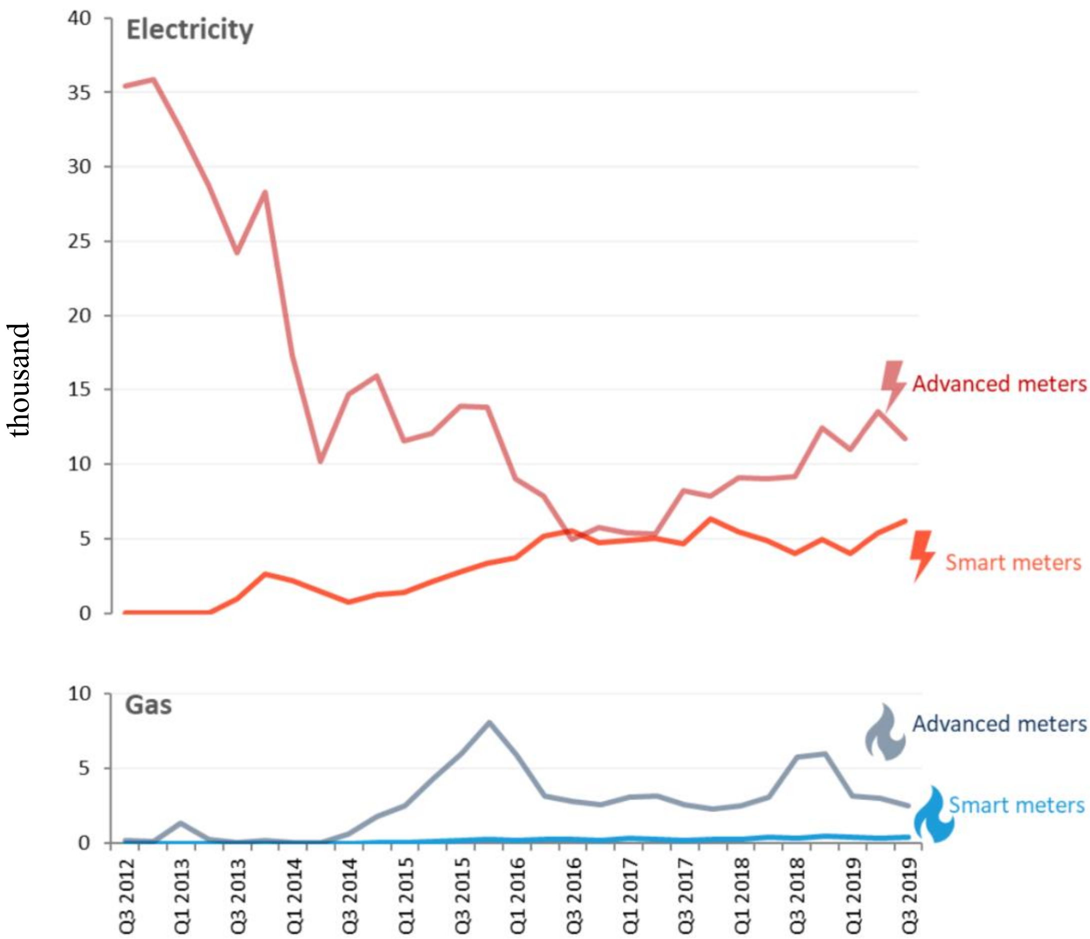


Figure 5.2: *Non-domestic meters installed by large suppliers [81].*

As the smart meter rollout is extremely slow, and it will not meet the 2020 target; therefore, the government took the initiative, which is a post-2020 regulatory framework. By a new framework, suppliers need to install 85% of the meter in their customer premises by December 2024. This new regulation will come into action from 2021. Though the deadline pushed back still, it is a challenging situation for the energy suppliers to meet. Because of the transition to the new SMETS2 in 2019, the rollout rate was slow, if the rollout progress reversed than only it will be possible to meet the new target [79].

5.1.2 Legislative Framework

The very first legislation about smart metering issues for the UK was the EU Directive 2006/32/EC, which describes that the member countries need to provide their customers "individual meters," and it needs to provide real-time consumption, if it is technical or financially beneficial, and leads to energy savings [79]. Then, in 2009, the updated EU Directive 2009/72/EC stated a specific deadline that said, "if the cost-benefit analysis of the smart meters is positive, then the member countries should have 80% roll-out complete by 2020".

Energy Act 2008 came out in the time of the labor government, which gave broad power to the Secretary of State in terms of

- Activities related to the smart metering license;
- Industry code and conduct modify, any change related to license and;
- The veto power of any proposal by the authority to consent to the transfer of Data Communications Company (DCC) license.

The UK government used the first power to create a low license for smart meter communication. To develop the legislation government used the second power. The regulatory framework is in continuous development, and the target is to facilitate the realization of a full DCC service to cover all customer premises and smart meter types. The third power given by the Energy act has not been used to date by the government, but it is important to maintain the regulation stable [80] These were supposed to expire by November 2013, but the deadline paused back by the Coalition Government. They took the initiative named national energy meter program and set a goal to install 53 million smart meters across the country by 31 December 2020. The project timeline was set by 2016 to 2020.

Then came the “Energy Act 2011,” wherein section 73 amended and the 2008 Act´s provisions extended to 2019. The license condition corrected many times under the Energy Act 2008. Some of the significant changes for the license were:

- Authority should take all the responsible steps to finish the rollout by December 31, 2020.
- Sales and marketing are prohibited in times of home visits for the smart meter installation.
- Report to the Ofgem (Government regulator the gas and electricity market in the UK) is obligatory on a regular basis regrinding cost and benefit analysis.
- An in-home display or alternative display needs to provide to the customer even if they change the suppliers.
- Energy efficiency advice needs to be provided to the customer during the installation time.
- A remote connection establishment and maintenance with the smart meter is obligatory and all the needed steps to bill customers in such a way, so it reflects smart readings.
- Vulnerable customer identification is obligatory before disconnecting any consumer.

It is mandatory to inform the customer about the implications of supplier switching and the effect of that. Also, the “Smart Metering Installation Code Practice (SMICOP)” is the regulatory body to regulate the behavior of the energy suppliers to their customers while visiting for the smart meter installation [79].

The new act (The Smart Meter Act 2018) regarding smart metering was published on 23 May 2018 as a “Smart Meters Bill.” The power of the Secretary of State regarding implementation and smart meter rollout has been extended from 2018 to 2023. This Smart Meters Bill also legislates a “special administration regime” for the communication and data service provider of the smart metering rollout projects to make sure the smooth service even there is some insolvency case.

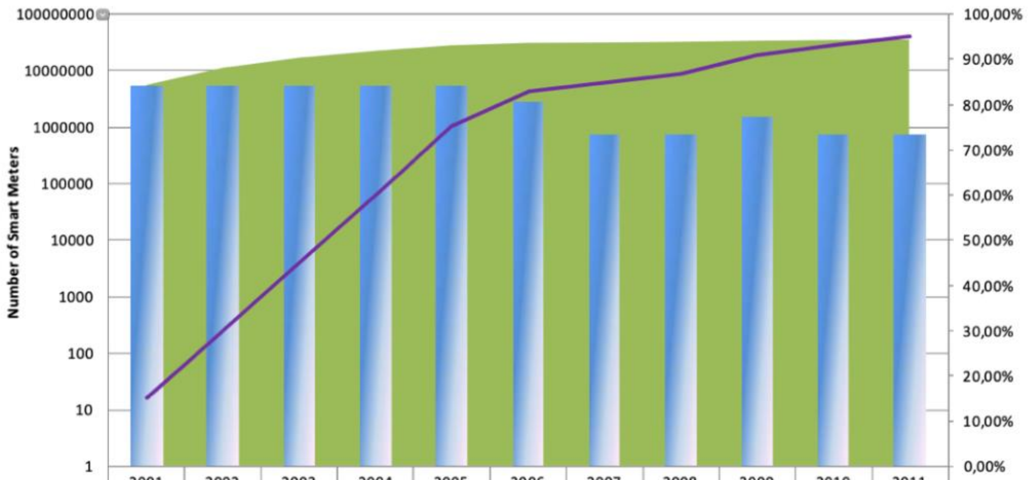
Finally, in 2019, the government published a framework named “Smart meter policy framework post-2020,” which will come into action from 1st January 2020. This states that 85% of the rollout needs to be done by 31st December 2024 [79].

5.2 Italy

5.2.1 State of the art in Italy

1st generation smart meter roll-out: Italy was the first country in Europe as well as in the whole world in terms of installed smart meter in by the company named Enel. No legislation or legal intrastation for smart meter has been there when Enal planned to roll-out smart meter in Italy. In 2001, with the project named “Telegestore” Enel installed the first utility deployed smart meter, and the initial motivation was to prevent non-technical losses, fraud as well as to reduce cost from customer service, purchasing, logistics, and on-field operation [39]. Enel installed approximately 30 million smart meters by the time zone 2001 to 2006, that covered almost 80% of the Italian household customer [64]. By the end of 2011, more than 95 percent of the end customers have received electronic meter, which meant 36 million meters in all [69].

The first-generation smart meter had functionalities like both way communication, remote connection, and disconnection, also the option of limit the load. The smart metering system was built on power line communication between the data concentrators and the smart meters. IP communication was also used for other back-end communication. The user interface, communication formats, and technology are mostly proprietary. That is why these created some interpretability problems later on. The meters were able to read data per hourly basis [82].



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Cummulative	5400000	10800000	16200000	21600000	27000000	29800000	30525000	31250000	32750000	33475000	34200000
SM Deployed	5400000	5400000	5400000	5400000	5400000	2800000	725000	725000	1500000	725000	725000
% of Total Meters	15,00%	30,00%	45,00%	60,00%	75,00%	82,78%	84,79%	86,81%	90,97%	92,99%	95,00%

***Figure 5.3:** 1st generation smart metering diffusion in Italy [64].*

2nd Generation smart meter roll-out: Though Italy was the very 1st country to install smart metering on a large scale, their 1st generation smart meter did not comply fully with the requirement set by the European Commission and the introduction of updated, specialized functionalities would not be possible to update in the 1st generation meters. This is why Italy stepped forward to the 2nd generation smart metering rollout, which can generate real-time information using a separate communication channel. The cost of the 2nd generation smart meter is almost the same as the 1st generation [39]. 2nd generation Italian smart meters has all the features recommended by the EU. Key features of the 2nd generation meters and the benefits summary represents by figure 5.4 below,

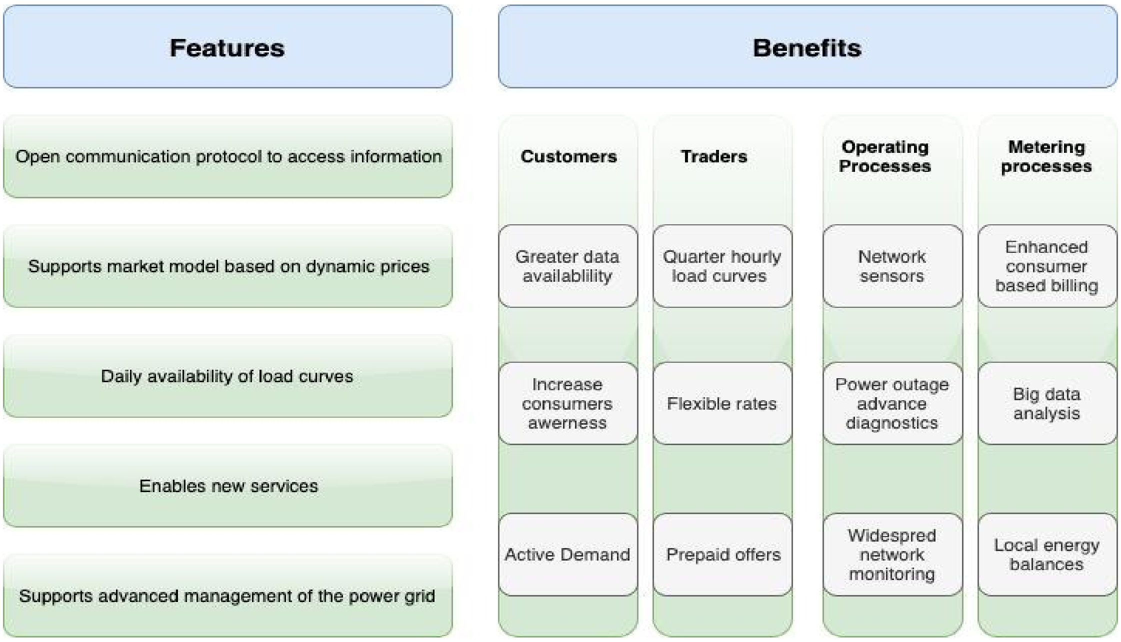


Figure 5.4: *Overview of the main features and benefits of a 2G smart meter in Italy [39].*

There are some functional differences between the 1st generation meters and 2nd generation meters. A comparison has been made and represents that by table 5.1 below:

Table 5.1: *Functional comparison of 1G and 2G meters in Italy [39].*

	1G smart meter	2G smart meter
Remote readings	• Monitoring of energy and peck consumption • Increase the number of clients with hourly readings • Monitoring of the correct functionalities of the number	• Reading and hourly based values available within 24h to the retailer via SII • Increased efficiency of the remote reading • Higher granularity
Remote management	• Remote commercial operations • Remote activation and deactivation of the meter • Reconfiguration of the setup of the meter at large scale	• 2 Channels available • Increased efficiency of remote management • Additional functionalities available

The company named E-distribuzion is the leading player in terms of second-generation smart meter rollout. At the beginning of 2017, after getting ARERA approval E-distribuzion planned 15 years long (2017-2031) project for smart meter rollout. This will replace 31.8 million old 1G smart meters with the new 2G smart meter all over Italy. They have the target to install an 80% rollout by the year 2022. By the end of 2019, E-distribuzion already completed more than 13 million roll-outs, which means they are in line with their plan. The installation plan of the Italian 2nd generation smart metering by year has been represented below with figure 5.5.

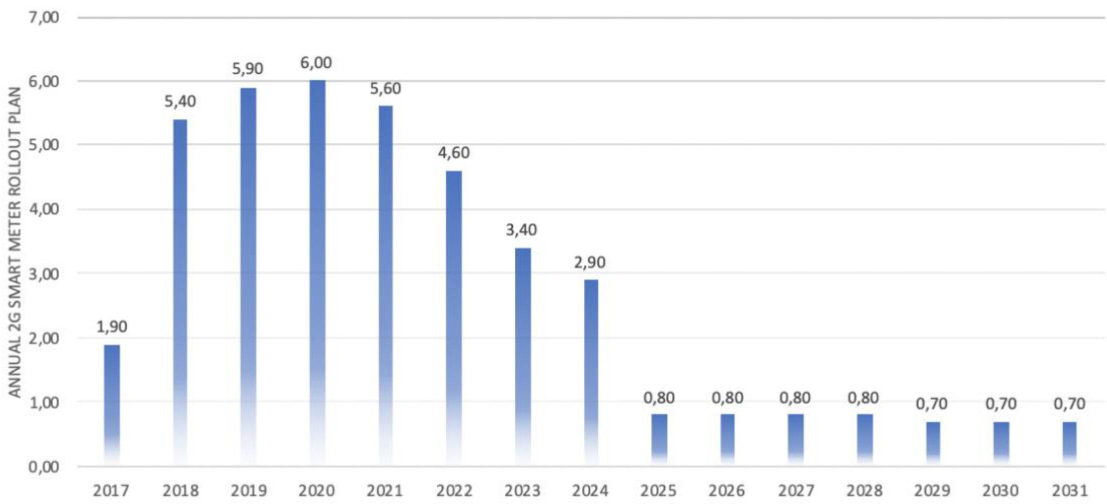


Figure 5.5: *Yearly rollout plan of the 2G smart meter in Italy [39].*

5.2.2 Legislative Framework

The Italian company named ENEK Distribuzione (now: e-distribuzion) started first-generation smart metering roll-out voluntarily in 2001. That time there was no regulation from the government. By the time of 2006, Italian regulatory authority ARERA realized the benefits of smart metering. Therefore they came with the Deliberation 292/061, which states that all the low voltages metering point must have a smart meter. This deliberation led to a mandatory roll-out for all the DSOs. By 2011, Italy crossed the EU smart metering roll-out target (for instance: 80% of the LV metering point should have the smart meter) with the 95% installed meter.

According to the reflection of the Energy Efficiency Directive 2012/27/EU by the European Union, Italy created the initial smart metering regulations under the Decree 102/2014. This Decree described that the authority needs to figure out the performance and functional specification for the 2nd generation smart metering. After that, the Italian regulatory authority ARERA issued the resolution 87/2016/R/eel and 646/2016/R/eel for second-generation smart metering roll-out in 2016 [39].

- Resolution 87/2016/R/eel described the expected 2G smart meter definition of the functional and performance level.
- Resolution 646/2016/R/eel described tariff regulation setting the requirement for the recognition of capital costs for smart metering infrastructure in collaboration with the functional and performance levels described by the Resolution 87/2016/R/eel [39].

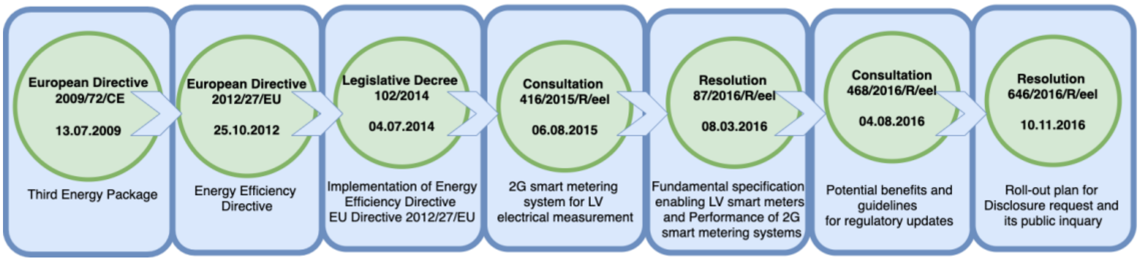


Figure 5.6: *Regulatory framework related to smart metering rollout in Italy [39].*

Later in 2017, the authority body ARERA sanctioned a second-generation metering plan for the company E-distribuzione by the Resolution 222/2017/R/eel.

5.3 France

5.3.1 State of the art in France

France started a pilot project in 2009, where 300,000 meters installed successfully, and the project finished in 2011. Soon after the successful pilot project, on September 28, 2011, the government decided to start a large-scale deployment. Where they planned to install 35 million Linky smart meter, after that, a cost-benefit analysis has been done Enedis (before it was known as Electricity Reseau Distribution France- EDRF). On that cost-benefit analysis result, two different aspects have been considered. One showed a neutral result; another was a positive outcome [83].

Though the initial target of France was to install 95% of the smart meter roll-out by 2020 (the EU requirement is 80% installation) but as per the latest information they are slightly lag of that target, and expecting to reach the 95% installation rate by 2021, if they can increase the installation rate in 2020 and beginning of 2021 [39]. However, France meets the EU target already by now.

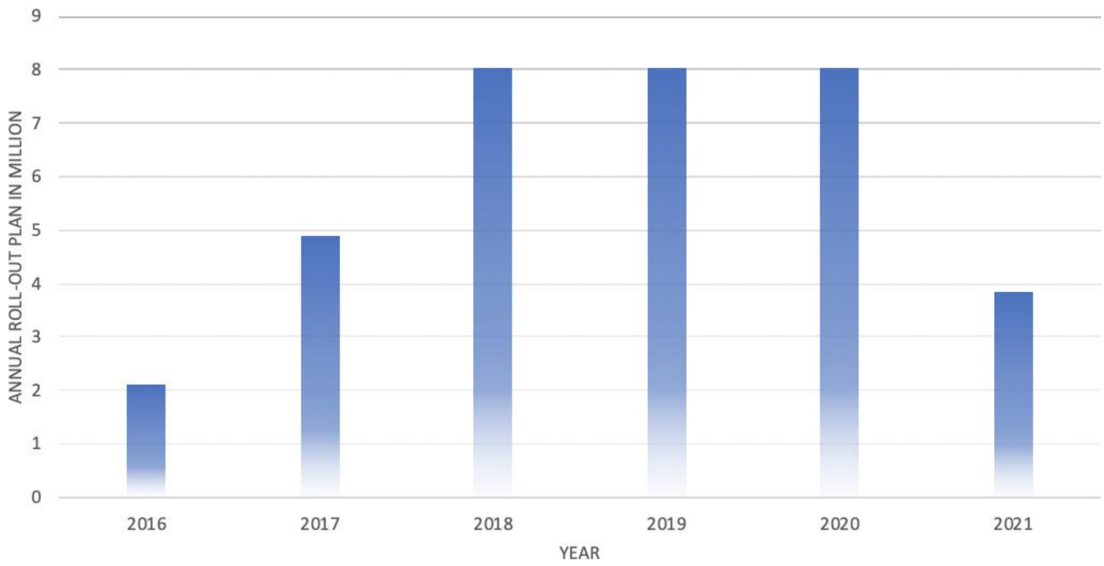


Figure 5.7: *Annual Roll-out Plan of France [83].*

France has a total of 40,743,444 actual metering points all over the country. At the end of 2018 [39]. Table 5.2 represents the summary of smart metering regulations in France below;

Table 5.2: *Summary of smart meter deployment and regulation in France [84].*

FRANCE	
Metering activity	Regulated
Deployment strategy	Mandatory roll-out
Number of metering points	35 million
Implementation speed	2014-2020
Penetration rate by 2020	95%
Responsible party- implementation and ownership	DSO
Responsible for third-party access to metering data	DSO
Data refresh rate	30 minutes

5.3.2 Legislative Framework

The very first regulation related to smart metering in the electricity sector was the "law n° 2005-781," published on 16th July 2005, which instructed energy policy. Later on, the old 2005 policy marched with the "Energy code (art. L. 341-4)" [39]. Later, in 2010 a government decree passed, and there they targeted 95% roll-out by 2020. Due to delay and correction, a new target for a 95% roll-out set by 2021 has been set. All the new electricity meters should be a smart meter in France since the beginning of 2012. The decree also defined some minimum functionalities of the smart meter, which meet the EU's given requirements as well. DSO´s are responsible for installing the meters, and those are free of charge for the end customers [69].

5.4 Germany

5.4.1 State of the art in Germany

Germany took a long time in terms of taking smart metering rollout decision. After many years of debate, assessment, and preparation, the German government has begun the process of establishing a concrete timetable for the countrywide development of intelligent meters. In July 2016, Germany passed the low on the digitization of the energy transition ("GesetzzurDigitalisierungder Energiewende"). This law set the guideline for Germany´s initial minimalistic smart meter rollout. This initial deployment supposed to begin at the beginning of 2017 and lays the other groundwork for a new phase Energiewende, which is the country´s ultimate energy transition. For initial roll-out phase need to be done by 2024, and by 2032 is the final deadline for the entire roll-out. However, in reality, the roll-out starting process delays for almost two years due to the administrative issues. The first smart meter in Germany received a license from the Federal Office for Information Security (BSI) after two years of a government decision about smart meter roll-out. In 2019, two more devices received a license [85]. Germany has 50,700,000 actual number of existing metering points, but as of 2018, the penetration rate was 0% [39].

5.4.2 Legislative Framework

Germany came out with the digitization of the energy transition legislation on 8th July 2016 named "GesetzzurDigitalisierungder Energiewende." The starting date of the smart metering rollout was January 2017. In 2013 summer, the Ministry of Economy made a contract with the company called EY (Formerly Ernst & Young) for the country wise, smart meter rollout cost-benefit analysis. The cost-benefit analysis was conducted as a function of the EU Directive 2009/72/EC, which specifies all the EU member countries should have 80% of the smart metering deployment by the end of 2020 if the cost-benefit analysis result is positive. The EY ended up with that the implementation of EU smart metering goals would result in a negative cost-benefit analysis ratio, and that would not be economically feasible for most of the German energy consumers [83].

However, this law gives required equipment guidelines for a conditional rollout with a two-tired approach consisting of a basic metering system and the metering system (basic metering system+ Smart Meter GateWay) for the customer who consumes more than 6,000 kWh/a – 10,000 kWh/a. The very first step was for the customer who consumes over 10,000 kWh/a and the renewable energy production, which has distributed generation over 7 kW of installed capacity. For these two types of the customer, the smart metering system (“intelligenteMesssysteme”) was mandatory. The consumer with an annual consumption lower than 4000 kWh needs only basic digital meter. The grid operator will decide whether to install a digital meter or the metering system about the customers who consume between 4000-6000 kWh/a. In this case, the customer does not have any right to decide about installation. The same situation is for the prosumers with distributed generation from 1 to 7 kW of installed capacity [86].

From 2020, the consumer who consumes electricity more than 2000 kWh/a will also come into the rollout scheme. Also, modern measuring devices (“moderneMesseinrichtungen”) devices seem as mandatory basic equipment, Energiewirtschaftsgesetz (EnWG) provides the obligatory deployment in the new buildings, at renovated buildings, and the usual exchange of old meters (“Ferraris”). These measuring devices are mainly digital electric meter, which gives accurate information about consumption, and it can be connected with the intelligent measurement system by using an interface if needed [69].

5.5 USA

5.5.1 State of the art in the USA

The United States was the front runner in smart metering rollout outside Europe. Smart meter rollout took off in the USA in the presidency time of Barak Obama. That time the government invested money in the smart meter projects. The reason behind that was to be an early leader in that market. Several utilities have chosen turn-key solution, which is based on proprietary RF Mesh Network technologies at that time from big smart meter vendors like Sensus or Itron. By 2025, the United States is expecting a stable growth; mainly, it will lead by massive scale rollout planned mostly by privately owned utilities. Moreover, small cooperative and municipal utilities will run deployment by small scale deployment. Also, in the next five years, many of the first-generation smart meters need to be replaced as their lifecycle will end in this period [87].

Large scale smart meter installation mainly stated in 2007 based on the “Energy Policy Act 2005”. The rollout process sped up in 2011. According to Energy Information Administration (EIA), by December 2019, it reached more than 98 million over the whole country out of 152.1 million total meters nationwide, which covers more than 80% installations. It is forecasted that by the end of 2020, smart meter installation will reach up to 107 million. Smart meter installation growth by year is presented in Figure 5.8. A total of 50 electric companies finished full smart meter deployment already by now [87].

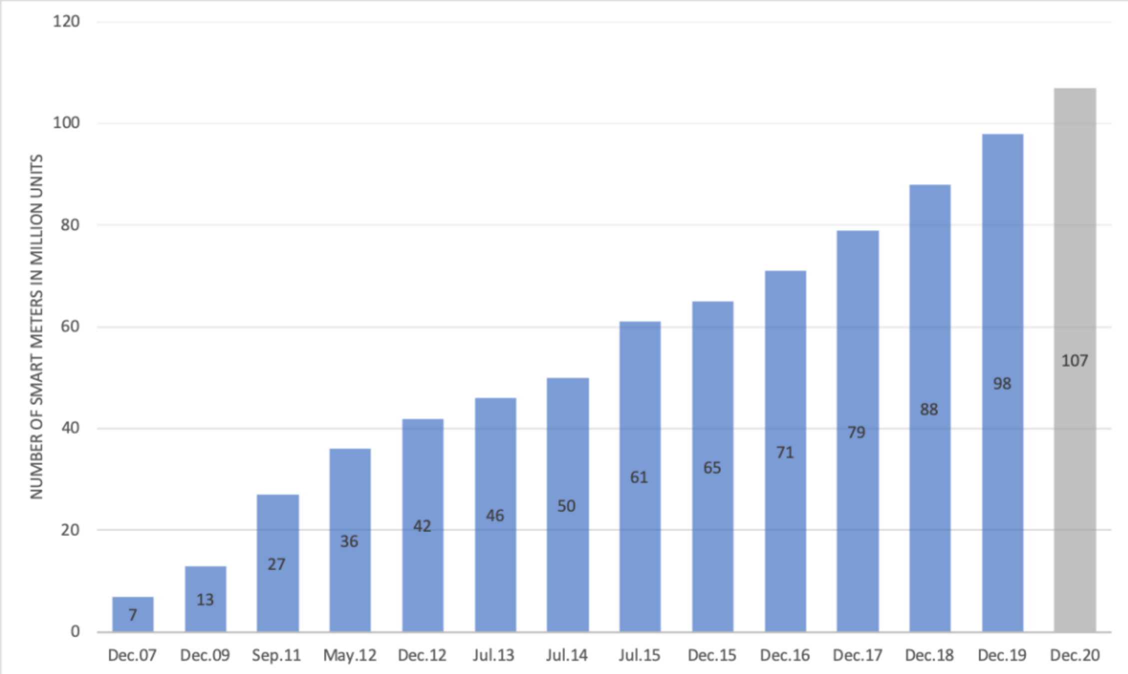


Figure 5.8: *Annual smart meter installation in the U.S. and projection for 2020 [87].*

5.5.2 Legislative Framework

In the USA, Congress party took the initiative to make legislation and policy related to the smart meter and demand response. As a part of this initiative in July 2005, a law passed named "Energy Policy Act 2005". "Section 1252 of Energy Policy Act 2005 (EPACT)" has the following statement as a part of standard "time-based metering and communications [88]":

- "Every utility company should offer of its consumer classes, and provide individual customers based on the request, a time-based rate schedule. The time-based need to enable the consumer to manage energy use and cost via advanced metering and communication technology. All utility companies should offer to the individual customer requesting a time-based meter capable of enabling the utility and customer to offer and receive such a rate, respectively [88]."

A mandatory standard for the states EPACT describes that the states can look at the standards and go with some procedural requirements. However, states are not bound to follow, adopt, or implement them. Later on, legislation named "federal encouragement of demand response devices" came out by EPACT, which assigns some responsibilities and activities for the Department of Energy (DOE). The reason for that was to exhilarate smart metering implementation without impinging upon state rules. EPACT also states that "The Secretary of DOE is responsible for educating the customer on the availability, advantages, and benefits of smart metering and communication technologies. Also, including the project funding or pilot projects, find out and address challenges of the demand response programs adaptation. Issue reports that identify and review saturation and penetration of advanced meters" as well as other measures in support of demand response [88].

Section 103 (Energy Use, Measurement, and Accountability) of the APACT include the following statement:

- By 1st October 2012, all federal buildings "for efficient use of energy and reduction of the cost of electricity used in such buildings should be metered. Each agency shall use, to the maximum extent practicable, advanced meters or advanced metering devices that provide data at least daily and that measure at least hourly consumption of electricity in the federal buildings of the agency. Such data shall be incorporated into existing federal energy tracking systems and made available to federal facility managers [89] ."

Different states of the U.S took different initiatives and had individual regulations and legislation for the smart meter project. As a part of the U.S., the state of Florida and Hawaii has a very much opposite approach in the smart meter rollout project. Florida is the leading state in terms of smart meter rollout, wherein Hawaii is the late mover in this sector. Below, the state's legislation of Florida and Hawaii´s is given:

Florida

Florida Public Service Commission decided not to implement the standard 14 of PURPA ("Time-Based Metering and Communications") as enacted in EPACT 2005 in April 2007. According to the commission, it has been committed to the PURPA standard. As well as the "spirit of efficiency, conservation, and custom options which underlay the standards" since the 1981 issuance of the PURPA standards. For its EPACT 1252 proceeding, the Commission surveyed Florida utilities, even those not subject to EPACT 2005, and found that they have "considered and implemented time-sensitive rates and load management programs that comply with the spirit of Section 1252 [89]." Therefore, the Commission finds Florida to comply. Furthermore, it states that adopting PURPA Standard 14 could mandate programs that are "not cost-effective for the general body of ratepayers [89] ."

Florida Energy Commission Report to the Legislature 2007, has the following smart meter relates recommendation:

- Establish Advanced Metering Systems and Pricing Strategies: "It is recommended that the Legislature direct the Public Service Commission to develop regulatory policies that encourage the deployment of advanced metering systems and innovative pricing strategies [89] Also, the Florida Energy Commission gave draft legislation of smart metering related recommendation to the legislators. This draft legislation seems to have informed the drafting process of two bills later introduced into the Florida Legislature, SB 1544 and HB 7135 [89].

Hawaii

Hawaii Public Utility Commission (Hawaii PUC) approved a proposal about moving forward by phase one of the Grid Modernization Strategy by Hawaii Electric company, Hawaii Electric light Company, and Maui Electric Company (in short: HECO companies) in 25th March 2019. HECO Companies took the initiative with a budget of 86.3 million US Dollar by which they are planning to install 175,000 advance meters across the state, improve the communication network as well as to deploy a meter data management system. The Hawaii PUC allowed the HECO Companies to adjust and recover the cost of phase 1 cost by rate case and by the existing adjustment mechanism [90]

The Hawaii PUC also stated that HECO Companies should improve the system of data access for the customer as well as to introduce dynamic and various rates for all customers so that the ratepayers can get the full benefit of advanced meters. The condition behind the cost recovery policy approval was, the Hawaii Public Utility Commission was needed from HECO Companies to open a file within six months of the approval date about Advanced Rate Design Strategy and Data Access and Privacy Policy [90].

Table 5.3: *Smart Meter Installation by Electric Company Type & State [87].*

State	Investor-Owned Electric Company	Public Power Utilities & Electric Cooperatives	Total
Florida	5,683,000	1,217,000	6,900,000
Hawaii	5,000	32,000	37,000

Smart Meter Opt-out Bill

The role of smart meter changed a lot in the last 20 years as well as the functions. Now the smart meter is an essential smart grid element, and it provides real-time information to the utility company. By the end of 2020, 107 million smart meters will be installed in the United States. In these situations, few people stand in the opposite of smart metering installation, claiming some health and privacy issues.

Takings claims into consideration, the state passed a law in 2019, which stated the Public Service Commission needs to settle down whether the state will go for a state-wide opt-out program or not, and the decision needs to take by 1st July 2020. By now, seven states already passed the policy so that if the customer wants smart meter opt-out, they can do it; also, the replacement of the smart meter by the analog meter is allowed. Through the public utility commissions proceeding, utility companies from another 22 states are allowed to introduce the opt-out system [91].

Smart meter opt-out policy is now different from state to state. Such as utility companies need to have written concern from customers to install a smart meter in New Hampshire, where in Pennsylvania, opt-outs are not allowed, and they have mandated that the smart meter need to be installed in all residential customers premises.

However, almost every state, customers need to pay if they go for smart meter opt-out. For that, the customers need to pay a one-time “set-up fee,” so they need to pay monthly for the meter reader who will go for analog metering. Only in New Hampshire and Vermont sates customer do not need to pay anything if they go for smart meter opt-out [91].

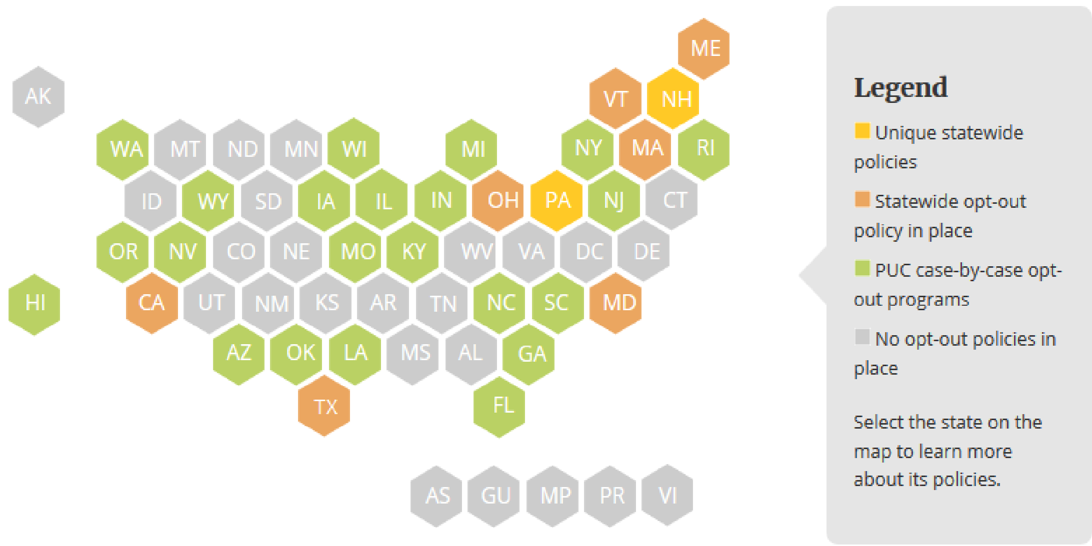


Figure 5.9: *Smart meter opt-out policies map by states [91].*

6. COMPARISON AND REASONS FOR DIFFERENCES

An overall comparison based on different aspects of the selected countries is being presented in this chapter. Comparison is made mainly in Nordic countries (Finland, Denmark, Norway, and Sweden), other EU member countries (Germany, France, Italy, and the UK) and the USA. With various tables and figures, the differences and comparisons have been made.

6.1 Comparison of selected countries

In this section, a detailed comparison has been made based on different aspects and criteria between the chosen countries using tables and figures. Comparison has been made based on the following topic: Regulatory Framework, Cost-Benefit Analysis, smart meter ownership and installation, Datahub, market drivers for the smart metering rollout, the present status of the smart metering rollout, and finally based on functional specifications.

6.1.1 Regulatory Framework

In terms of any changes and new things, legislation plays an important role. In the case of smart metering, deployment legislation plays an important role as well. Table 6.1 represents the regulatory framework summary of the smart metering for the selected countries. In Table 6.1, we can see that the different countries have different timetables and different types of legislation in terms of smart metering installation. If we compare the Nordic countries with other EU countries and the US, we can see a clear difference between them. The Nordic countries are the most advanced in terms of proper legislation also. Finland was the first country in the Nordic to come up with the official Smart Metering installation legislation, where Sweden was the first to the deployment voluntarily. Other than the Nordic countries, France and Italy had legislation related to smart meter at the beginning of this decade. The US was in the same situation; they had their first smart metering related act in 2005. One common thing with all the selected countries is that they all have a clear goal and legislation related to smart metering by now.

***Table 6.1**: Smart metering legislation summary of selected countries.*

Country	Legislation related to smart meter
Finland	"Decree of the state council 66/2009" was the first legislation related smart metering in Finland and Electricity market act 588/2013
Denmark	"Danish Electricity Supply Act 2013" which later revised in 2019
Sweden	"Electricity Act 2012" was the primary law for the smart meter; later, it has been revised at the end of 2018.
Norway	"Energy act § 4-3, Regulation concerning Metering, Settlement and Co-ordinated action in connection with electricity trading and invoicing of Network services."
UK	"Smart Meters Act 2018," which amends the previous "Electricity Act 2008."
Italy	"Legislative Decree 102/20143 was the primary law enabled smart metering in Italy which is based on the EU Directive 2012/27/EU."
France	"Law n° 2005-781 approved in 13th July 2005 was the primary low that enables smart metering in electricity which then incorporated with the Energy code (art. L.341-4)"
Germany	"Gesetz zur Digitailiserung der Energiwende" was the primary law in Germany that enables the smart metering in electricity than the law further incorporates and helps smart metering deployment for electricity is" Messstellenbetriebsgesetz"
USA	"Energy act 2005 was the first legislation in the US to start implementing smart metering."

Based on the regulatory framework and the selected country's smart metering rollout projects progress, visual representation has been made in figure 6.1 below. For this representation, six different categories have been used, such as dynamic movers, front runners, market drivers, ambiguous movers, weavers, and laggards. Front runner means the country that implemented more than 95% of the installation by the targeted time. On the other hand, dynamic movers mean the country which has clear regulations, and the implementation process is ongoing. Dynamic movers are the countries that do not have a legal framework but have a clear strategy; on the other hand, laggards are that country that does not have any legal and strategy for the rollout yet. A country with a legal and clear strategy but rollout delayed for stakeholders problems is in the ambiguous category, whereas waverers category is for the country who has an interest in smart metering legislation but not yet finalized It [69].

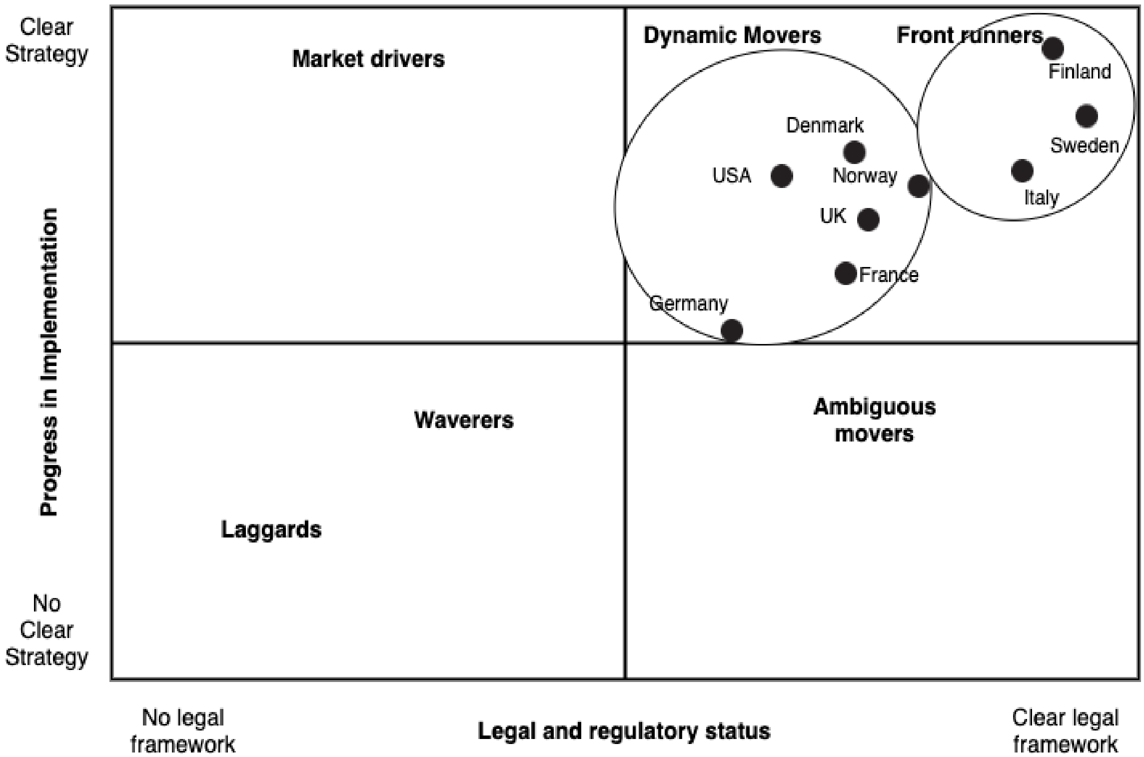


Figure 6.1: *Smart metering rollout scenario of the selected country's [69].*

From figure 6.1, it can be seen that Finland, Sweden, and Italy is in the front runner section where other countries are in the dynamic mover category, where especially Nordic countries have a clear strategy clear legal framework. They are also at the top of the implementation progress bar. On the contrary, Germany is at the bottom level of implementation progress though they have a clear strategy and legal framework.

6.1.2 Cost-Benefit Analysis

Cost-Benefit Analysis (CBA) is the most crucial parameter in terms of smart metering deployment. According to the European Union's regulation, if a country has a positive CBA result, then they should start the smart metering deployment, and by 2020, 80% of the implementation needs to be done. If the country receives a negative result than CBA need to conduct again after five years. Table 6.2 represents a summary of the CBA results of the selected countries. From the table, we can see that a major part of the countries has a positive CBA result, which conducted in 2013 except Germany and Norway. Despite having a negative CBA result in 2013 authority of Norway decided to continue smart meter deployment. Germany was the opposite. They didn´t start implementation as they had a negative result. So they conducted another CBA in 2018, where they received negative results as well. In the case of the USA, there wasn´t enough data on the internet about CBA for the overall country, but in reality, in the many states, they deployed a large number of smart meters already. After five years in 2018, all the countries except Finland, Denmark, and Norway did the CBA again, and the result remained the same as in 2013.

Table 6.2: *CBA result summaries of the selected countries.*

	Initial CBA result (as per July 2013)	Revised CBA result (July 2018)	Latest CBA conducted(as of July 2018)
Finland	Positive	Positive	2008
Denmark	Positive	N/A	2013
Sweden	Positive	Positive	2015
Norway	Negative	N/A	2013
UK	Positive	Positive	2019
USA	N/A	N/A	
Italy		Positive	2014
France	Positive	Positive	2013
Germany	Negative	Negative	2013

6.1.3 Smart meter ownership and installation

Smart meter installation, ownership, and meter reading policy are different from country to country. Table 6.3 shows a summary of it. From table 6.3, it can be seen that in Finland, Sweden, the USA, Italy, and France, the meter ownership and the responsible party for meter reading is DSO. Denmark and Norway have a bit different system. In Denmark, DSO has meter ownership and responsibility for smart meter reading, but the customer has the responsibility of the analog meter reading. In Norway meter owner is DSO, but the customer reads the meter. The UK has an entirely different system. Meter ownership, installation, and reading responsibility are all handled by the energy supplier. In Germany, it is sometimes DSO, sometimes the 3rd party.

Table 6.3: *Smart meter ownership by selected countries.*

Country	Ownership (DSO or Supplier)	Responsible for a meter reading
Finland	DSO	DSO
Denmark	DSO	Customer (typical meter) DSO (smart meter)
Sweden	DSO	DSO
Norway	DSO	Customer
UK	Energy Supplier	Energy Supplier
USA	DSO	DSO
Italy	DSO	DSO
France	DSO	DSO
Germany	DSO or 3rd party meter operator	DSO or 3rd party meter operation

6.1.4 Datahub

The primary purpose of the datahub is to give a central access point to the suppliers so that they can access the customer metering data fast, which will speed up the data exchange system as well as to reduce the hustle of communicating with each DSO directly. That's why the Nordic countries come up with the datahub project implementation. From table 6.4, it is clear that only Nordic countries have datahub. Other countries, as well as the USA, don´t have any kind of data hub project. Which, indicates that the Nordic countries are way ahead in the smart metering infrastructure overall. Danish and Norwegian datahub is already in live, and Finnish and Swedish datahub is expected to be in function by 2022.

Table 6.4: *Summary of the datahub projects of the selected countries*

Country	DATAHub	DATAHub Owner	Current Status
Finland	YES	Fingrid	Under development (2022)
Denmark	YES	Energinet.dk	Live
Sweden	YES	Svenska Kraftnät	Under development (2022)
Norway	YES	Elhub operated by Statnet	Live
UK	NO	N/A	N/A
Germany	NO	N/A	N/A
Italy	NO	N/A	N/A
France	NO	N/A	N/A
USA	NO	N/A	N/A

6.1.5 Smart metering implementation drivers

Six primary market drivers decided by EU commission played an essential role in terms of smart meter deployment, which are [39]:

- Enabling dynamic tariffs for the households and SME´s,
- Digitalization of the distribution grid and optimization of the network operations,
- Digitalization of the retail market to foster innovation and new services by private actors,
- Integrating decentralized energy resources with flexible access, such as load shedding or infeed curtailment,
- Supporting actions for tackling fuel poverty,
- Supporting energy efficiency.

These six primary driver roles in smart meter rollout in the selected countries have been described in figure 6.2 below. From the chart below, it can be seen that in Finland and Sweden, the first three points are considered where France follows the first four points. Italy considers all the market drivers to except point five. There is not enough data about Denmark, Norway, and the USA. However, Germany and Italy did consider the marker drivers "Enabling dynamic tariff for the households and SME´s; and Digitalization of the distribution grid and optimization of the network operations [39] ."

On the other hand, "Support energy efficiency and Support actions tackling fuel poverty" are rarely considered by the selected countries except for Italy. The 4th most raked important driver for the smart meter rollout "Integrating decentralized energy resources with flexible access, such as load shedding or infeed curtailment" is considered only by France and Germany. On the contrary, Germany did not consider one of the most important drivers, "Digitalization of the retail market to foster innovation and new services by private actors [39] ."

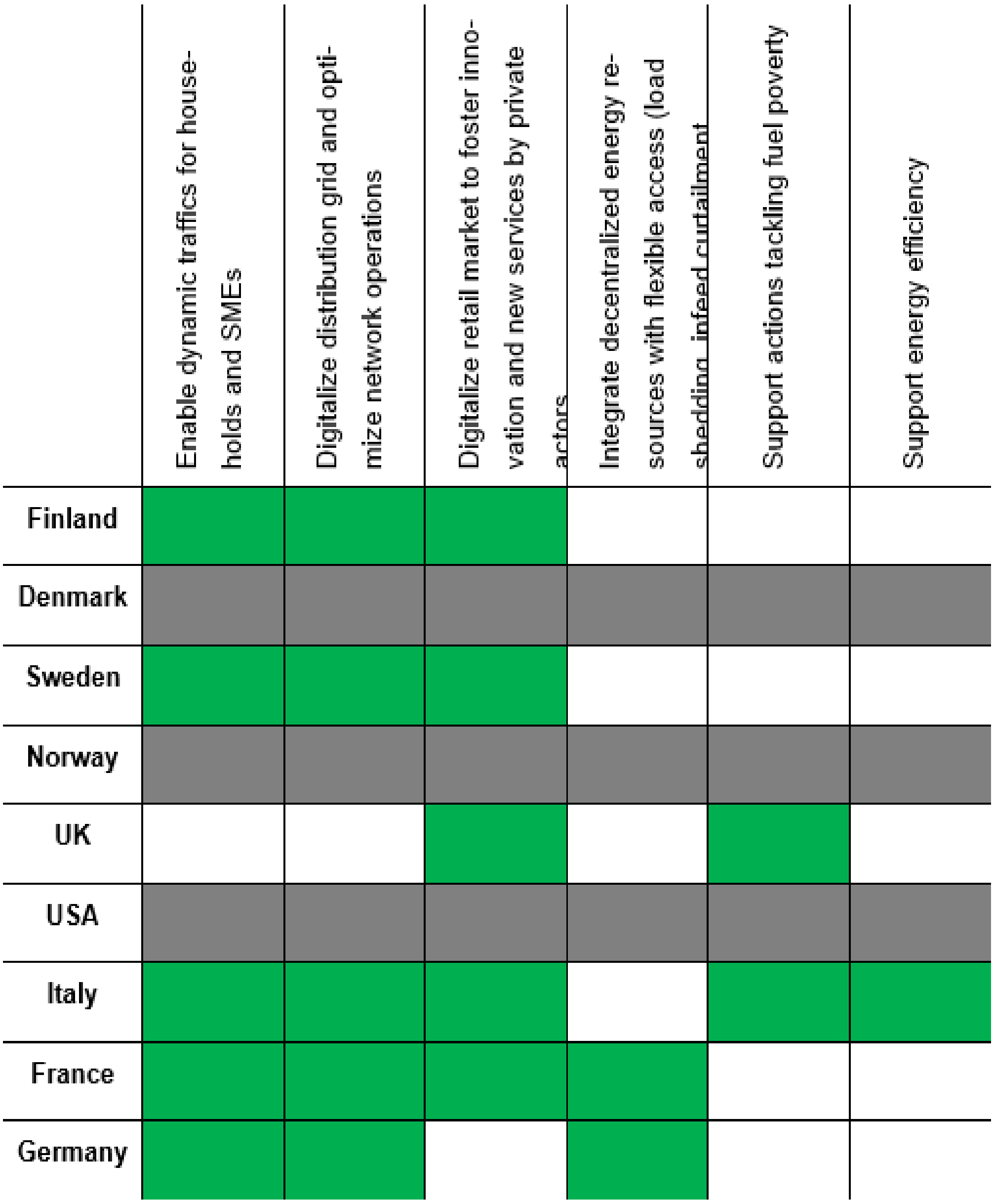


Figure 6.2: *Smart meter rollout market drivers (legend: blank = not considered, green = considered, grey = couldn't find the data)*

6.1.6 Present status of smart meter rollout

Table 6.5 represents the exact number of existing metering points, overall smart meter installed (in 2019), and the percentage of the penetration rate of the selected countries. From table 6.5, we can see that Finland, Sweden, Norway, and Italy have installed more than 98% meters by 2019 already. The USA has the highest number of smart meters installed outside Europe, which is almost 65.5%. France also reached the EU target by the beginning of 2020. Other countries are on the process of installation, such as the UK is far behind than the initial expectation, though the rollout project is ongoing. The worst scenario is in Germany; due to their different policy than the other EU countries. They have not started the massive scale rollout yet. From this table, we can see that the Nordic countries are way ahead in terms of large-scale deployment, and they all meet the EU 2020 target.

Table 6.5: *Summary of smart meter penetration rate (2018), existing electricity metering points (2020), and installed smart meters in selected countries (2019).*

	The actual number of existing metering points	Total Smart Meters installed (2019)	Overall smart meter penetration rate (2018)
Finland	3,557,500	3,551,500	99.8%
Denmark	3,361,816	3,250,000	98.0%
Sweden	5,300,000	5,300,000	100%
Norway	2,900,000	2,800,000	98%
UK	29,807,531	5,935,202	19.9%
USA	152,100,000	98,000,000	65.5%
Italy	36,789,000	36,237,165	98.5%
France	40,743,844	32,000,000	79.9%
Germany	50,700,000	2	0%

A graphical representation shown by figure 6.3 of the chosen countries installed smart meter by comparing the real metering points.

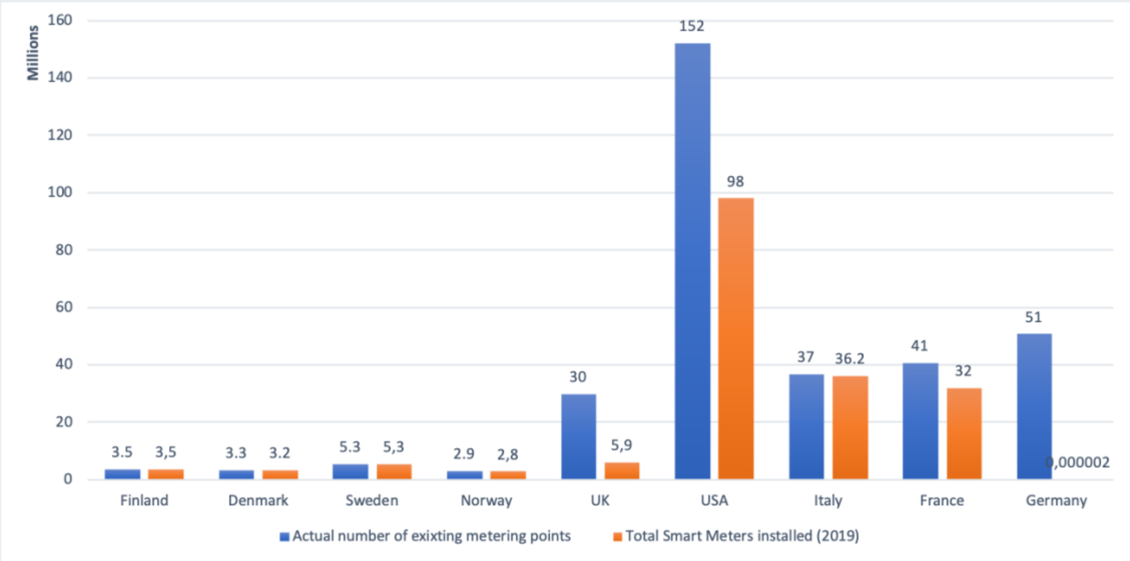


Figure 6.3: *Actual metering point vs. installed smart meters as of 2019.*

From figure 6.5, we can see that according to the EU recommendation, every selected country from the EU had an initial target in 2013 to achieve by 2020. The USA had its target as well. After the end of 2019, the maximum selected countries had achieved their initial goals- Such as Finland, Denmark, Sweden, Norway, Italy achieved their initial goal already even before their targeted year. There is some exception to the UK and France. They failed to achieve their goal, so they both set a new goal. As the UK set a new goal to rollout 95% by the year 2024, and France set a new goal to finish 95% by the year 2021. The USA is on the same track, and they are progressing based on the target and expect to complete the rollout by the deadline.

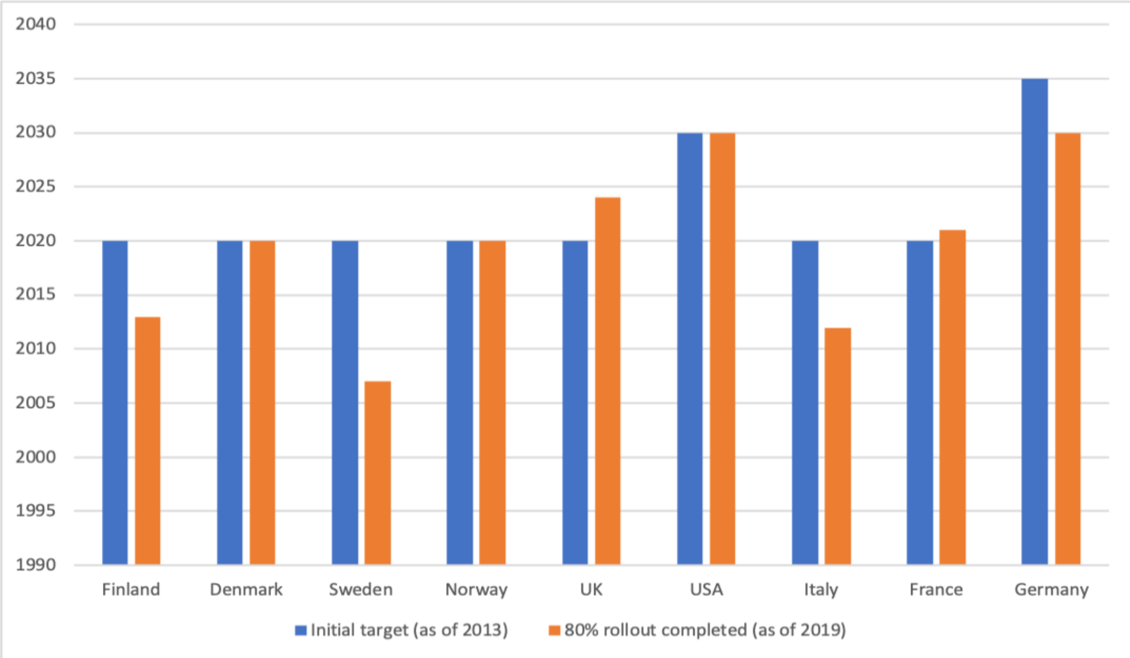


Figure 6.4: *Compare between the 2013 target and 2019th situation.*

6.1.7 Compare based on functional specifications

EU recommends ten standard functionalities for the smart meter in the recommendation 2012/148/EU, which is described below with the figure 6.5 by organizing relevant actors.

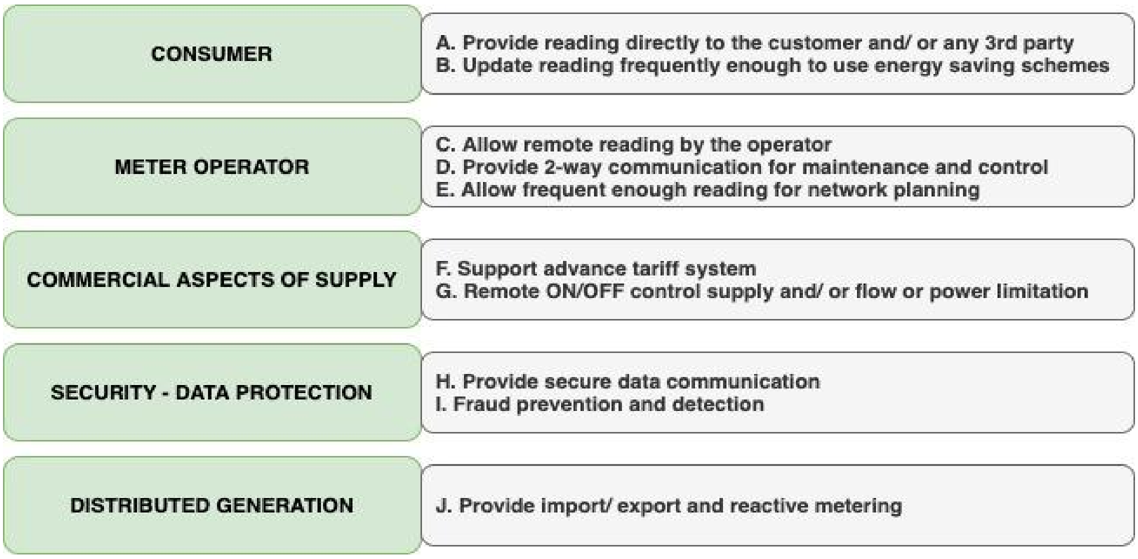


Figure 6.5: *Smart meter basic functionalities recommended by EU [39] .*

Based on the basic features, a comparison figure 6.6 has been given. From figure 6.6, it can be seen that Denmark and the USA don´t have any proper data. Almost all countries have all the standard functionalities in their smart meters. Sweden and Germany have some exceptions. German and Swedish smart meter has all the recommended features except one. Fraud prevention and detection are missing in the Swedish smart meters because they installed first-generation smart meters even before EU recommendation came. But in the 2nd generation, Swedish meters have all the basic functionalities, and Sweden is now on the phase of 2nd generation smart metering installation. However, in German smart meter, "remote control ON/OFF supply, flow, and power limitation" functions are missing.

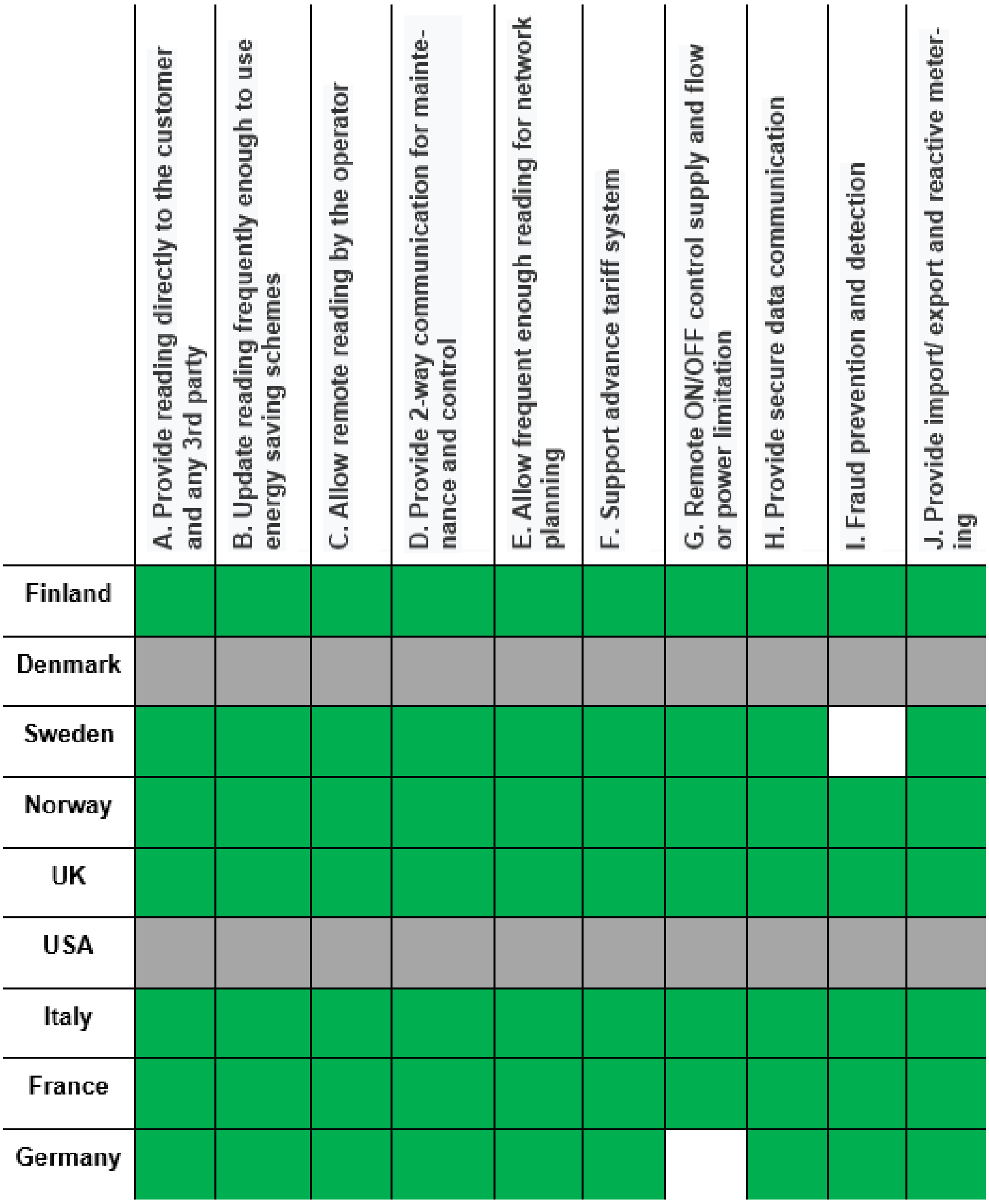


Figure 6.6: *Available smart metering functionalities in selected countries based on EU recommendation.*

6.2 Discussions

Working in this thesis and after analyzing the selected country's overall smart metering situation, I have found some exceptions and differences between selected countries. Those are mainly described below:

Managing smart meter data is complicated and challenging. Many parties are using the data for their own business and policy purpose. To manage the Nordic retail market efficiently, Nordic Energy Regulators (NORDREG) came up with a solution to establish datahub in all the Nordic countries. TSOs were the responsible party to develop and operate datahub in the respective market. Now in the Nordic market, datahub has a vital role in the electricity retail market development. Some main functionalities of data hub are meter point management, customer data management, contract management, meter value management, managing third-party access to data, providing settlement data to NBS, etc. Unfortunately, this extremely efficient datahub project is available only in Nordic countries. Other selected countries like Itlay, Germany, USA, UK, and France don´t have this kind of project yet. Smart meter is a crucial element of the smart grid, and the installed number of smart meters is growing every day. In this situation, a small number of people are against the smart meter installation claiming the health and privacy issues as the smart meter provides real-time data to the utility company. In this situation, few states in the USA passed a regulation so that if people don´t want to install a smart meter on their premises, they are allowed to do it. Same in France, they have this opt-out option. Also, in Norway, 2% meters have been left out because the resident doesn´t want a smart meter in their home. All the other selected countries like Finland, Sweden, Denmark, Germany, Itlay, and the UK don´t have an opt-out policy yet.

Data privacy and protection are a growing concern over the world as smart meter provides real-time consumption and other data to the utility. Considering these, Germany took a different approach than the other countries. They came up with smart meter gateway technology to protect customer data, which is a communication unit that connects the measurement system with the electricity meter in the customer premises with the meter provider. With the gateway device, it is possible to protect the data, reduce cyber-attack in the smart meter. The primary specialty of the gateway technology is that the collected data is sent directly to the smart meter gateway connected to the measuring system. Firstly, after that, the data is sent to the 3rd parties so that the data could be protected. In other countries, the collected metering data is being sent directed to the utility companies and processed there.

7. CONCLUSIONS

This chapter will mainly cover the research questions and answers to them one by one. The research questions are presented in the introduction chapter of this Thesis. Also, a short discussion on the possible research options related to smart metering is included.

7.1 Research questions answers

What is the state of the art of the Nordic countries (Finland, Sweden, Norway, Denmark) and the UK, Italy, France, Germany, the USA?

Nordic countries are the pioneers of the world in the mass rollout of smart metering. All the Nordic countries had their initial target to complete the large-scale deployment, and they all met the goal comfortably. Sweden was the first country to finish rollout, and they complete their first-generation smart meter by 2009, and Finland completes its deployment by 2013. Following the neighboring countries, Norway and Denmark finished their roll out at the end of 2019. They all fulfilled the EU target as well.

Other than the Nordic countries, Italy was in the leading role in large scale rollout. They now have 36.2 million meters installed, which is more than 98% of their total existing metering points. Now they are about to start even to install second-generation smart meters. If we look at France, they also meet the EU target though they couldn´t meet their goal. They had their initial goal to complete 95% of the rollout by 2020, but it extends a little further, and now the new target is 2021. UK and Germany have the worst situation in large scale rollout. UK and Germany both failed to fulfill their goal, also the EU target, which was to complete 80% rollout by 2020. However, the UK is on progress, and they are continually installing new meters. Now they have a new target to complete 95% rollout by 2024, where Germany has not yet started massive scale rollout.

Lastly, in the USA, they have different legislation and different policy in different states. Overall, the USA has installed 98 million smart meters across the country, where they have a total of 152.1 million metering points. Where California, Texas, and Florida have the highest number of installed smart meters; on the other hand, Hawaii has the lowest number of installed meters among the entire USA. But it is clear that the USA is on the right track and they are planning to finish the rollout by 2030.

What is the legislative framework of the Nordic market for smart metering technologies?

All the Nordic countries are collaborating, and they share a common platform in the electricity market. Now all the Nordic legislation is based on the EU recommendations.

In terms of smart meter installation, Nordic countries have different policies and laws. Sweden started the large-scale smart metering rollout as the first country among Nordic countries. The very first legislation about smart metering in Sweden came in 2003, and after a few updates, the hourly metering related act came as “Electricity Act 2012,” which was later revised in 2018. Finland was the 2nd Nordic country to start a large scale rollout. “Decree 66/2009” was the first legislation which later amended with as “Electricity market act 2013”. The primary legislation related to smart meter deployment was the “Danish Electricity Supply Act 2013” in Denmark, which was later revised in 2019. Norway has been a bit exception in large scale rollout. Even though they had a negative CBA result yet, they decided to start large scale rollout according to the rule “Energy act § 4-3, Regulation concerning Metering, Settlement and Co-ordinated action in connection with electricity trading and invoicing of Network services.”

How can smart meter affect in the electricity market and network management?
Smart meter plays a vital role in improving LV network management, operation, planning, and asset management. Also, the smart meter has a great impact on the distribution network system, which is a smart grid vision. Smart meter can be used in network management by integrating the substation monitoring device and AMR meters to the current network management. Smart meters are playing a crucial role in fault management. Missing phase voltages and other voltage problems can be detected by using smart meters and modern substation monitoring devices, and they can send an alarm to the DMS system after detecting any fault. The integration of smart meters with DMS is a kind of extension of distribution automation and SCADA to the LV level, which is crucial for LV network management. Furthermore, the smart meter provides accurate data by using the data. A more accurate network calculation is possible, and the data is vital for load analysis.

What are the challenges and barriers for the targeted countries?
Though the large-scale smart metering rollout project is a success in most of the selected countries, there are some problems and barriers as well. Such as, meter data security is a considerable concern to some customers and activists. Though nothing has happened till now, still some people are worried about it. The same things happened in terms of health issues. Some people think that the smart meter can create health issues due to the radiation. But this is ultimately a false calm as it is not proved scientifically. Still, in Norway, 2% of the Norwegian people don´t want to install smart meter as they think this could be a health problem if they install it to their premises. The opt-out decision by a few customers is done in France and the USA. If the customer does not feel interested in installing a smart meter, then the authority can not install 100% of the smart meter.

Even in some states, now they have an opt-put policy so that if any customer doesn´t want to install the smart meter, they can do it by law. The USA had 50 different states where every state has various regulations, which is one of the main challenges. Some states completed more than 80% of the rollout, whereas, in some states, the percentage is less than 5%. The UK has some problems with first-generation and 2nd generation meters. They are supposed to install 2nd generation meters as 1st generation doesn´t have enough features, but due to some issues, some companies are still installing 1st generation meters. Due to changes in laws and legislative problems, the smart metering project of the UK has been slowed down. Due to the administrative issue, the German smart meter project delayed. In Germany to install a smart meter, they first need to get a license from the Federal office of Information Security (BSI), which is a slow process and complicates the whole thing.

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