PhD Thesis

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By

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Smart Grid deployment and use in a large-scale demonstrator of the Smart and Sustainable City (SunRise):

Comprehensive analysis of the electrical consumption

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Titre

Déploiement et utilisation des Réseaux Intelligents dans un démonstrateur à grande échelle de la ville intelligente et durable (SunRise): Analyse intégrée de la consommation électrique

Résumé

Smart City et Smart Grids constituent une excellente occasion pour relever l construire des villes inclusives axées sur la qualité de vie. Cependant, ces concepts sont complexes et récents. Leur implémentation nécessite de l'apprentissage à travers des grandes expérimentations. Ce travail concerne s'inscrit dans ce cadre. Il est réalisé dans le cadre du démonstrateur à grande échelle de la Smart City (SunRise) qui est réalisé sur le Campus Scientifique de l'Université de Lille. Il comprend trois parties :

La première partie comporte une analyse bibliographique sur les recherches menées dans le domaine de la Smart City. Elle présente les défis de la ville, ensuite, elle traite la mutation numérique et son rôle dans la transformation de la ville en une ville intelligente et la transformation des réseaux urbains en réseaux intelligents.

La deuxième partie décrit le système électrique du campus. Elle présente le projet SunRise, qui consiste à construire un démonstrateur des réseaux urbains intelligents sur Campus Scientifique, qui équivaut à une ville d'environ 25 000 habitants. Ensuite, elle présente le campus le système électrique et sa gestion.

La dernière partie concerne l'analyse de la consommation électrique. Elle présente la méthodologie développée qui comporte (i) l'enregistrement des consommations et leur transmission au serveur de réseau électrique, (ii) la transmission de données au serveur SunRise, (iii) le nettoyage et le stockage des données, (iv) la construction des profils de consommation des bâtiments et l'analyse de ces profil. Cette méthodologie est appliquée pour l'analyse de la consommation des différents trois bâtiments du campus.

Abstract

Today, the Smart City and Smart Grid concepts constitute a great opportunity for humanity to meet the rising threat of environmental challenges, and to build inclusive cities that focus a greater deal on the quality of life of citizens. However, the Smart City and the Smart Grid are vast topics. They are also new and complex. Their implementation requires learning from large experimentation, a way to study the approach of transforming a fully operational city. This research concerns this issue. It is carried out within a large-scale demonstrator of a Smart City (**SunRise),** which is located at the Scientific Campus of the University of Lille.

This thesis includes three main parts:

The first part (Chapter 1) focuses on the literature review of the research and achievements in the fields of the Smart City and Smart Grids. It presents the city challenges such as the population growth, energy consumption, greenhouse emission and climate change. Then it discusses the digital mutation and its potential role in transforming the City into a Smart City and the conventional Electrical Grid into a Smart Grid.

The second part (Chapter 2) describes the Electrical Grid of the Scientific Campus. It presents project SunRise, that represents the creation of a Smart City (including a smart grid) demonstrator, digitally transforming the service (utility) networks of the Scientific Campus, which is equivalent to a town of around 25 000 inhabitants. Then, it presents the features of the scientific campus, the scientific campus's electrical grid, management of the grid and data visualization.

The last part (Chapter 3) concerns analysis of the electrical consumption data of the scientific campus. It presents the methodology developed for data analysis including (i) record of the electrical consumption and transmission to the electrical grid server, (ii) Data transmission to SunRise server, (iii) Data cleaning and storage, (iv) construction of buildings' consumption profiles and consumption analysis. This methodology is applied for analysis of the global consumption of the campus and three buildings.

General Introduction

Energy and climate change challenges

According to the United Nation Report, the world population increased from 3 billion to around 7 billion over the last 60 years. In the future, the pessimistic predication indicates an increase in this population up to 15.5 billion in 2100, while the optimistic estimation indicates that this increase will continue, but at a lower rate up to 2050, then it will decrease down to 6 billion in 2100. Nevertheless, an increase in the world population in the coming 35 years is a fact; hence, the need for more infrastructures, buildings and urban services (transport, energy, water, municipal waste, education, health, entertainment, culture...etc.) to meet the needs of the new population. This fact is to inevitably lead a higher demand for energy as well as the natural resources, such as water and raw materials.

The International Energy Outlook 2016 indicates that the world energy consumption will expand from 549 quadrillion Btu in 2012 to 629 quadrillion Btu in 2020 and to 815 quadrillion in 2040. The increase in the energy consumption in the period 2012 - 2040 will reach around 50%. The part of the energy generated from fossil fuels in the world energy consumption is very important. In the period 1993- 2011, it accounted for 82% of the world energy consumption. The World Energy Outlook special report 2015 indicates that the energy production and use account for 66% of the world's greenhouse gas emissions, which in turn is responsible for the global warming and climate change. The objective of the COP21 to stay below the 2°C climate limit; this requires a reduction in fossil fuel energy consumption through the reduction of the overall energy consumption and losses, the development of renewable energy systems, and the increase in the performances of the energy systems.

Energy transition

Energy transition designates the change pattern in energy systems. It aims at the reduction of the energy generated from fossil fuels in order to reduce the greenhouse gas emissions, and the reduction of the reliance on nuclear energy. First of all, energy consumption is to be reduced. This issue concerns the major sector of energy consumption such as buildings, transport and industry. This goal could be achieved through the modernization of these sectors.

Buildings are responsible for nearly 40% of the total energy consumption. The potential energy savings in this sector could range between 20% and 40%; hence, the need to build low-energy consumption buildings, and renovate existing buildings to reduce their energy consumption.

Transport is also responsible for a large part of the energy consumption; thus, it is essential to develop and encourage public modes of transport, and reduce the use of individual cars. The transport sector energy consumption could also be reduced through the introduction of a new social model, such as the development of teleworking and the urbanization model by constructing mixed districts that host both habitation and economic activity. Industries also consume a large amount of energy; using more efficient industrial processes that implement both digital and industrial innovation can reduce the energy consumption.

Energy efficiency is of major importance in the reduction of energy consumption, consequently in the reduction of the energy-related greenhouse emission. Energy efficiency stands for “energy resource”; this is because it leads to a decrease in the use of primary energy resources. It concerns the entire energy value chain. The 2013 World Energy Perspective report[1] provides recommendations for achieving energy efficiency. Energy efficiency should combine efficient technologies and economic issues. Its success is strongly related to economic viability and to the absence of implementation barriers. Energy efficiency concerns all the components of the energy system. In power generation, the average efficiency of power plants is around 35% for

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[1] https://www.worldenergy.org/wpcontent/uploads/2013/09/World_Energy_Perspective_ Energy-Efficiency-Policies-2013_Full_Report.pdf

coal installations, compared with best available technology of 45% for coal and 60% for gas units. There is an important amount of energy lost in the generation process.

Urban infrastructure management

The quality of any city is related to the quality of its services such as transport, drinking water, sewage, electricity, district heating, telecommunication, municipal wastes, health and education. Urban services lie on complex urban infrastructures, generally embedded in the underground sections of a city. These infrastructures are built for a given service time, which depends on the initial investment, operating conditions, maintenance and modernization factors.

The City, just like a human body, operates efficiently when all actors are functioning in harmony. If one area is hurt, or damaged, it directly affects the efficiency and overall capacity of the host, hence, stressing the importance of the 'healthy' operation. Control, maintenance and monitoring of a city's core features, systems and networks will identify the weaknesses, limitations and detect any gaps in the overall structure, as well as help guide in its restoration.

However, today's organization of urban services and infrastructures is not in harmony with the vision of a living city where all the components are in harmonious interaction. Urban services are organized in silos with weak interaction, and sometimes without any interaction. This system of organization is maintained because of cultural and professional conformism and a lack of awareness of the impact of this organization on the efficiency as well as security of urban services and infrastructures.

With the increasing urban concentration, cities meet large challenges: (i) How to ensure basic urban services such as transportation, water supply, sanitation, energy supply and management of solid wastes; (ii) How to ensure the safety, security and resilience of urban infrastructures and services regarding natural, human and industrial risks and disasters; (iii) How to contribute to the sustainable development so as to reduce natural resources consumption and greenhouse emission as well as the pollution of soils and water resources; and (iv) How to involve citizens in the sustainable development of their city as well as in the city's governance. The capacity of cities to address these challenges depends on the quality of urban infrastructures such as the transportation infrastructures, electrical grids, drinking water, sewage, gas, and telecommunication networks. In developed countries, cities have large urban infrastructures, which were mainly built in the 20th century. The maintenance and upgrading of these infrastructures to meet the sustainability and resilience requirements need large financial investments.

The management of urban infrastructures is crucial for the city development. It should ensure an optimal use of the urban infrastructures as well as their interoperability. The infrastructure management requires a good knowledge of the infrastructures' asset and operating performances.

Smart Electrical Grid

The Electrical Grid is composed of interconnected generators and networks, that generate, transport and distribute electricity to supply customers such as habitation, commercial buildings, industries, hospitals and other urban services such as public lighting and transportation. In the beginning, electricity was primarily utilized by lighting systems. As more industries shifted from oil and gas to electricity, there was an enormous increase in the demand for electricity. In addition, modern buildings, both residential and commercial, constitute a major portion of this demand. It is estimated that around 73% of electricity in the US is consumed by buildings. Since electricity concerns vital issues of the daily life, the industry and services, reliability is one of the major challenges of the electrical system. It consists of the capacity of the electrical system to deliver continuous power to consumers within accepted standards. It is mainly related to loss of voltages. It can also be evaluated by frequency, and duration, of interruptions, as well as magnitude of adverse effects on the electrical supply. Power quality may be defined as the measures, analysis and improvement of bus voltage to maintain that voltage at rated voltage and frequency, to meet the requirements of the consumers' devices.

The majority of the world's electricity system were built when the cost of energy was reasonably low and there was a near absent concern for environmental protection. Since minor upgrading has been made to meet rising demand, the grid still operates the way it did almost 100 years ago: energy flows over the grid from central power plants to consumers, and reliability is ensured by preserving surplus capacity. Consequently, today, most of the electrical power systems are not eco-friendly.

General Introduction

Because of their low energy efficiency and major dependence on energy generated from fossil fuels, they produce a high amount of greenhouse gases. In addition, they are not built to account for the integration of renewable energy systems, as well as to meet the increasing demand for energy.

The electrical grid faces the challenges of ageing infrastructure, continued growth in demand, greater integration of renewable energy systems, the need to improve the security of supply and the need to reduce carbon emissions. In the United States, the number of outages exceeding 100 MW increased from 65 in 1991-1995 to around 140 in 2001-2005. It faces also new challenges such as higher demands, the lack of the grid reliability with frequent outages in the recent years and a higher concern in the environment, particularly for the reduction of the greenhouse emission. As a result, the electrical power system (generation, transmission and consumption) has been the focus of investigations to address the above challenges and for transforming the power grid into a more efficient and reliable system. The digital revolution presents a great opportunity to achieve the goal of the modernization of the conventional electrical system by transforming it into a “Smart Grid”. The Smart Grid offers the possibility of greater monitoring and control throughout the power system, and therefore a more effective, flexible, and lower-cost operation. Smart Grid does not have any single, or obvious definition. It combines several technologies, customer solutions and addresses several policy and regulatory drivers.

Objective and outline of the research work

Today, the Smart City and Smart Grid concepts constitute a great opportunity for humanity to meet the rising threat of environmental challenges, and to build inclusive cities that focuses on higher efficiency, and a better quality of life for citizens. However, the Smart City and the Smart Grid topics are vast concepts. They are also new and complex. Their implementation requires learning from large experimentation, a way to study the approach of transforming a fully operational city. This research concerns this issue. It is carried out within a large-scale demonstrator of a Smart City (**SunRise),** which is located at the Scientific Campus of the University of Lille.

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Table of Contents

Chapter 1

Smart City and Smart Grids – Literature Review

Chapter 1. Smart City and Smart Grids – Literature review

This chapter is a literature review of researches, achievements and perspectives in the field of Smart City and Smart Grids. It starts by a presentation of the major world challenges such as the population growth, the natural resource consumption, particularly the energy consumption, and its consequence on the greenhouse gas emissions, global warming, and climate change as well as the pollution of air, water and soils. The chapter also presents the position of the smart city concept regarding world challenges as well as city challenges concerning urban services and life quality. The chapter also gives an overview of the digital mutation and its potential role in the transformation of a city into a Smart City. Finally, the chapter delineates the development of the Smart Grid concept as to the modernization of the electrical grids; a process achieved by combining the digital technology with that of the current electrical power technology.

1.1 World Challenges

1.1.1 Population Growth

One of the basic challenges that face the development of a Smart City is the population growth. Figure 1.1 shows the variation in the number of the world population since 1800 and the prediction of this growth rate by the year 2100 (UN, 2015). The depicted result show that in the in the last 60 years, the number of the world population increased from 3 billion to around 7 billion. In the future, the pessimistic predication indicates an important increase in the world population, which could reach around 15,5 billion in 2100, while the optimistic estimation indicates that the increase in the world population will continue, but at a lower rate, up to the year 2050, then it will decrease to 6 billion by 2100.

Nevertheless, an increase in the world population in the coming 35 years is a fact; hence, the need for more infrastructures, buildings and urban services (transport, energy, water, municipal waste, education, health, entertainment, culture…etc.) to meet the needs of the new population. This fact is to inevitably lead a higher demand for the natural resources, such as energy, water and raw materials.

Figure 1.2 shows the division of the world population in urban and rural areas in both developed and less developed countries (UN, 2015). We observe that in the coming 15 years, the increase in the world population would be more apparent in the less developed countries, whereby the number of the inhabitants is expected to be around 2 billion; concurrently, the number of the population in developed countries is stable but is on the decrease in the rural area in less developed countries.

This important increase in the world population in the coming years requires the construction of huge infrastructures and buildings as well as the development of large urban services such as transport, water, energy, health, education…etc. This growth is expected to also incur an increase in the demand on natural resources such as water, energy, raw materials and construction materials; a fact that would inevitably result in negative consequences on the environment, leading to its deterioration.

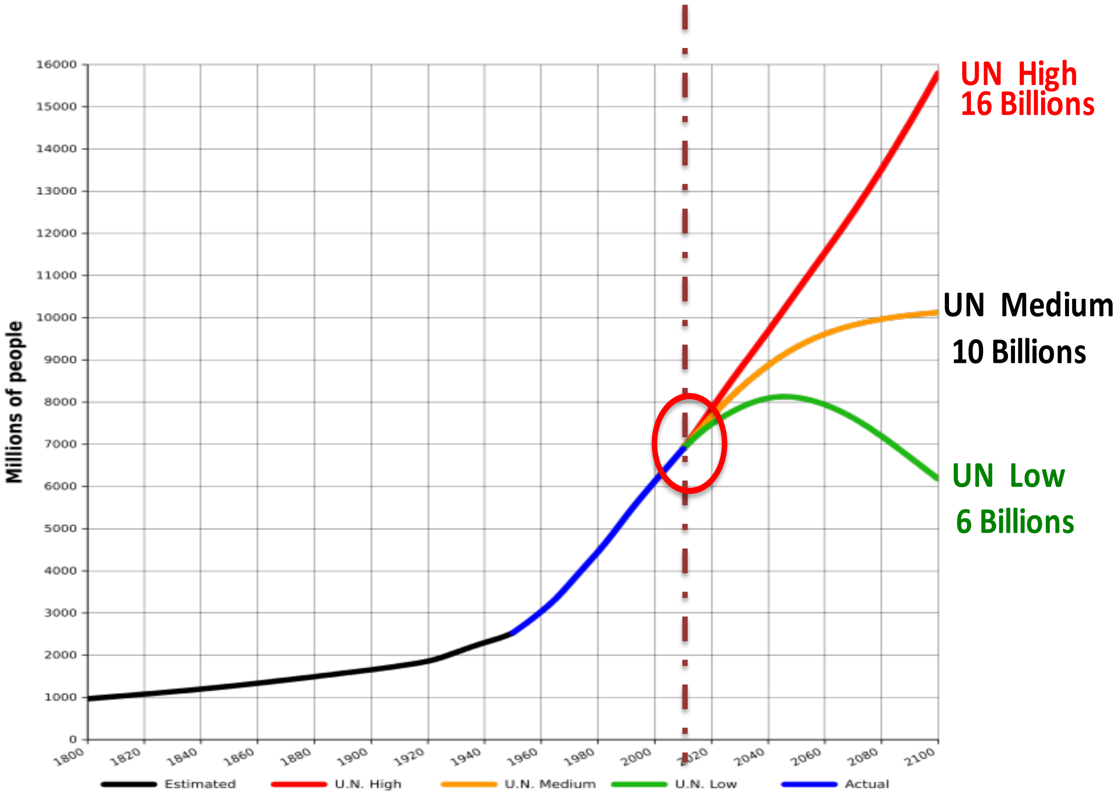

Figure 1.1 Variation of the world population (Source United Nation –2015)

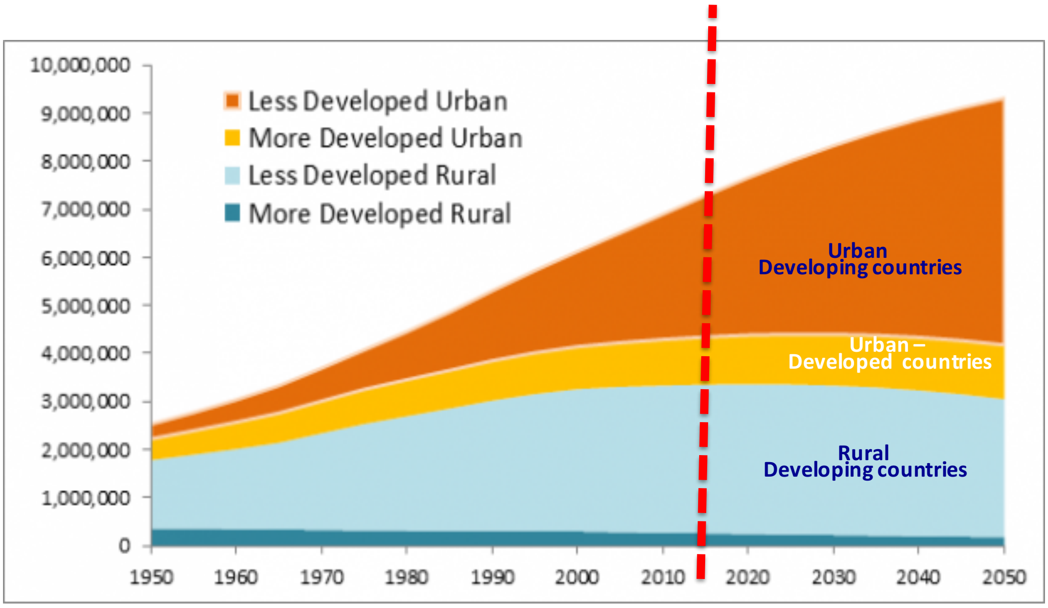

Figure 1.2 Division of the variation of the world population in urban and rural areas, developed and less developed countries (Source United Nation, 2015)

1.1.2 Energy Demand

Figure 1.3 shows the variation of the energy consumption in the world since 1990 and the projection of the energy consumption over the period from 2012 to 2040 (International Energy Outlook 2016 IEO2016)[2]. The depicted results indicate that the total world energy consumption will expand from 549 quadrillion Btu in 2012 to 629 quadrillion Btu in 2020, and to 815 quadrillion Btu in 2040. The increase in the energy consumption in the period 2012 - 2040 will reach around 50%.

Figure 1.3 also shows that the part of the Non-OCED in the world energy consumption will increase from 56% in 2012 to 65% in 2040. It also indicates that projection in the increase in the energy consumption in OECD countries in the period 2012 – 2040 is around 18%, while it reaches 72 % in the OECD countries. The high projected increase in the energy consumption in the Non-OECD countries is related to the high increase in the urban population in less developed countries as discussed in the preceding section (Figure 1.2) as well as accounting for the legitimate larger part of the population in these countries wanting/having access to energy and comfort living conditions.

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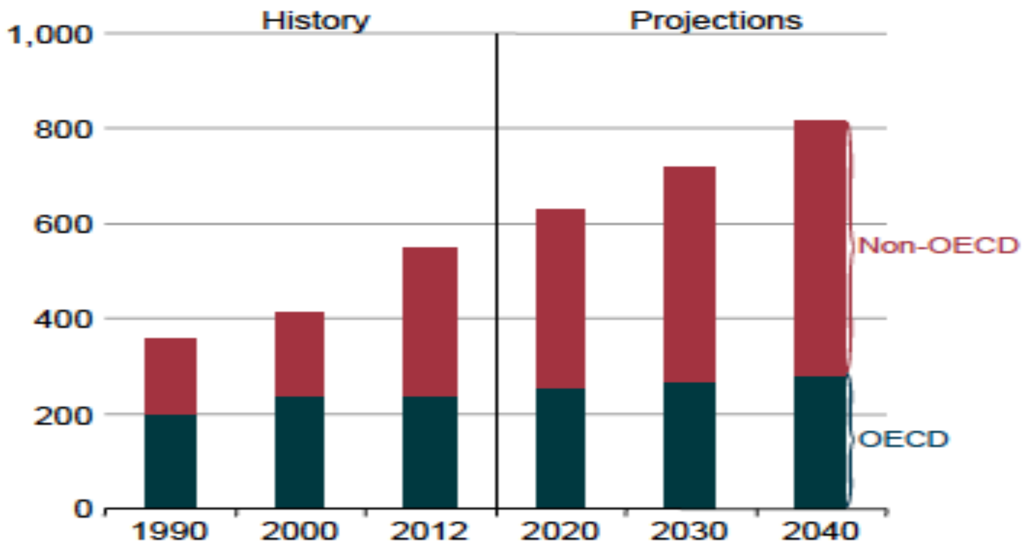
[2] http://www.eia.gov/forecasts/ieo/pdf/world.pdf



3. ***Figure 1.3 World energy consumption (1990 – 2040)***
4. ***Source: International Energy Outlook 2016 (IEO2016)***[3]
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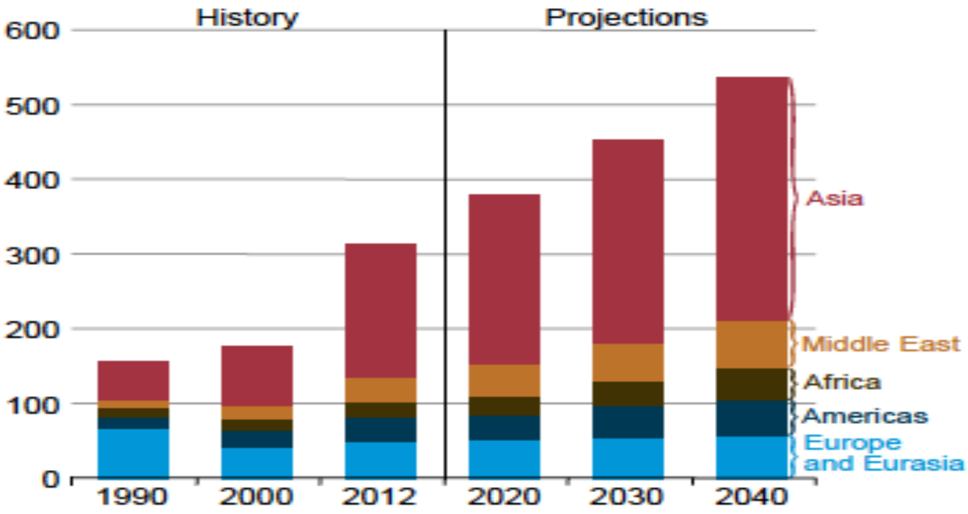
Figure 1.4 details the projection of the energy consumption in the non-OECD countries during the period 2012 – 2040. It shows that the consumption rate of countries in Asia will increase from 56% in 2012 to 62% in 2040, while in same period of time, the energy consumption in the Middle East will increase from 32 (BTU) to 62 (Btu) (94%), while in Africa the increase will be from 22 (Btu) to 38 (Btu) (72%).



6. ***Figure 1.4 Non-OECD energy consumption by region, 1990–2040 (Btu)***
7. ***Source: International Energy Outlook 2016 (IEO2016)***

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[3] http://www.eia.gov/forecasts/ieo/pdf/world.pdf

Figure 1.5 shows the percentage of fossil fuel energy consumption in the world (World Energy Resources, 2013 Survey). We observe that in the period 1993- 2011, the energy generated from fossil fuels accounted for 82% of the world energy consumption, while the renewable and nuclear energy accounted for 10% and 6%, respectively. However, since the pollution from fossil fuel generation is particularly responsible for the greenhouse gas emission effect, the world's main concern is to dig deeper into renewable energy systems, with an aim to reduce this greenhouse effect to 76% of the world's total energy by the year 2020.

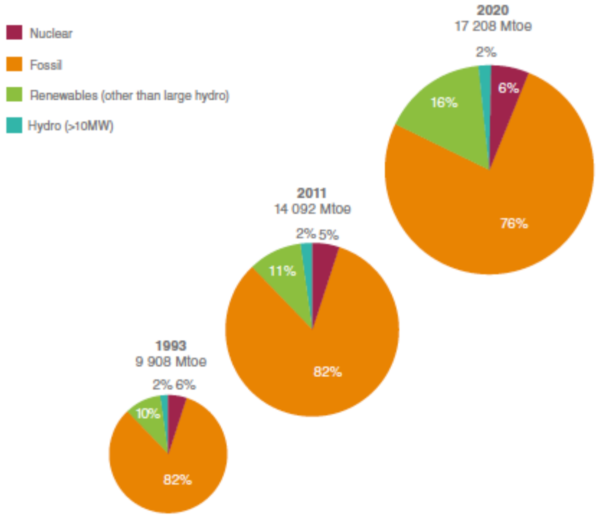

Figure 1.5 Percentage of the fossil fuel energy consumption in the world energy demand Source WORLD ENERGY COUNCIL «World Energy Resources, 2013 Survey »[4]

1.1.3 Greenhouse gas emission, global warming and climate change

According to the World Energy Outlook special report 2015 - Energy and Climate Change of the International Energy agency[5], the energy production and use account for 66% of the world's greenhouse-gas emissions; a fact that is responsible for global warming and the current changes in the overall climate. The objective of COP21 is to stay below the 2°C climate limit; this requires a reduction in fossil fuel energy consumption through the reduction of overall energy consumption and losses, the

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[4] https://www.worldenergy.org/wpcontent/uploads/2013/09/Complete_WER_2013_Survey.pdf

[5] https://www.iea.org/publications/freepublications/publication/weo-2015-special-report-energy-climate-change.html

further development of renewable energy systems, and an increase in the efficiency of the energy systems.

Figure 1.6 illustrates the economic sector's part in the global energy-related CO_2 emission. It shows that the generation of power accounts for the major part, followed by that of the transport, the industry and the construction of buildings. The role that each sector plays varies significantly from one region, and country, to another.

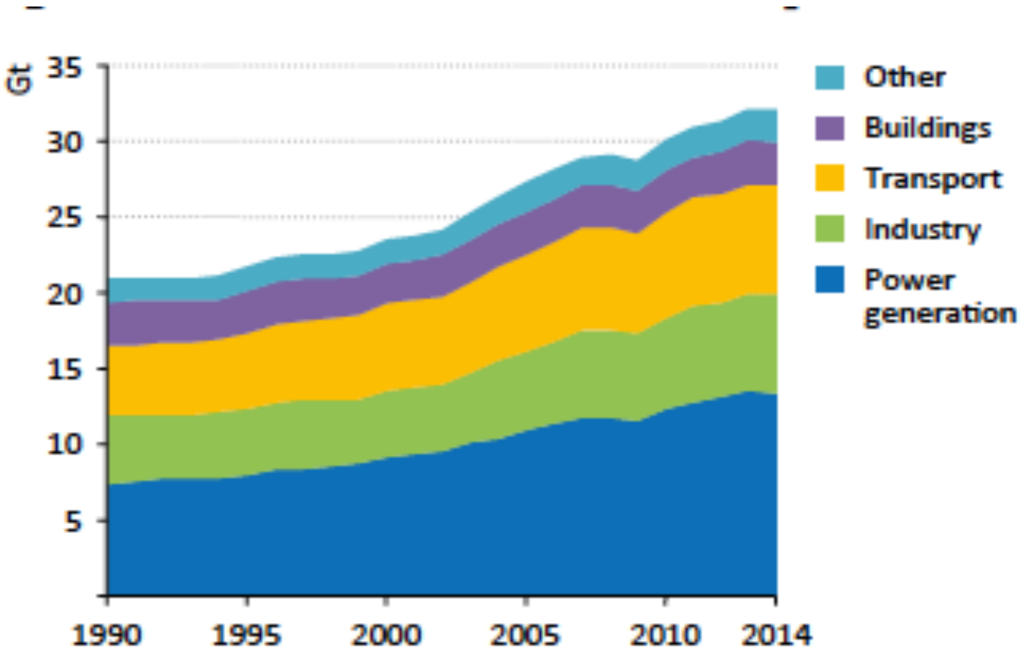

Figure 1.6 Global energy-related CO_2 emissions

8. Source: World Energy Outlook special report 2015 of the IAE

1.1.4 Energy Transition

1.1.4.1 The need to tackle the energy transition

Despite the efforts taken by countries around the world to reduce their dependence on fossil fuels, the energy consumption as well as the greenhouse emission continues to increase. Some of the most powerful advanced, and developed countries in the world, such as the USA and China, are still leaders in pollution and emissions, for they rely heavily on traditional approaches to generation. This is disturbing when compared to the efforts of smaller countries that have reached a higher percentage of their consumption from renewable, or alternative energy sources.

In 2015, the United States generated roughly 4 trillion kilowatt-hours (kWh) of electricity; 67% of this energy came from traditional methods (fossil fuels – coal, petroleum and gas), only 7% came from renewable energy. Coal-fired generation is the highest in China; it continues to grow. Coal plays a vital role in electricity generation worldwide, and is currently responsible for 41% of the world's electricity demand.

The world cannot completely let go of its dependence on coal, because of difficulties to develop other alternatives. However, there are low-emitting alternatives, which will reduce greenhouse gas emissions; for example, countries such as the United States, France, Russia and China use nuclear energy for electricity generation. This could be considered as an alternative to fossil fuel energy generation because of its carbon-friendly nature. However, the safety and security issues surrounding nuclear generation constitute today serious issues, in particular after the Fukushima-Daiichi Nuclear Disaster. Consequently, there is a need for new solutions to address the growing demand for safe and less-pollutant forms of energy sources, knowing that digital technology as well as industrial and social innovations could greatly help in developing new alternatives to the usage of high-polluting forms of energy generation.

1.1.4.2 The implementation of energy transition strategy

Energy transition designates the change pattern in energy use. It aims to decrease the fossil fuel energy consumption in order to reduce the greenhouse gas emission levels and the further adoption of nuclear energy, for safety issues. As such, there is an imperative need to change the method of dealing with energy. First of all, energy consumption is to be reduced. This issue concerns the major sectors of energy consumption such as buildings, transport and industry. This goal could be achieved through the modernization of these sectors.

Accordingly, the European Union energy strategy (EU 20/20/20)[6] was introduced; it aims to attain the following three objectives by 2020:

- 20% reduction in the greenhouse gas emissions (compared to 1990 level).

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[6] https://ec.europa.eu/energy/en/topics/energy-strategy/2020-energy-strategy

- 20% reduction in the primary energy consumption (compared to 1990 level) through energy efficiency measures.
- 20% increase in the renewable energy share in the total energy consumption (compared to the 1990 level).

Buildings are responsible for nearly 40% of the total energy consumption. The potential energy savings in this sector could range between 20% and 40%; hence, the need to build low-energy consumption building and renovate existing buildings to reduce their overall energy consumption.

Transport is also responsible for a large part of the total energy consumption; thus, it is essential to develop and encourage public transport and reduce the use of individual cars. Transport's energy consumption could also be reduces through the introduction of a new social model such as the development of teleworking and the urbanization model by constructing mixed districts that host both habitation and economic activity.

Industry also consumes a large amount of energy; using more efficient industrial processes that implement both digital and industrial innovation can reduce the energy consumption.

Energy efficiency is of major importance in the reduction of energy consumption, consequently in the reduction of the energy-related greenhouse emission. Energy efficiency stands for "energy resource"; it leads to a decrease in the use of primary energy resources. It concerns the entire energy value chain. The 2013 World Energy Perspective report[7] provides recommendations for achieving energy efficiency. Energy efficiency should combine efficient technologies and economic issues. Its success is strongly related to economic viability and to the absence of implementation barriers.

Energy efficiency concerns all the components of the energy system. In power generation, the average efficiency of power plants is around 35% for coal installations compared with best available technology of 45% for coal and 60% for gas units; knowing that there is an important amount of energy lost in the generation process.

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[7] https://www.worldenergy.org/wpcontent/uploads/2013/09/World_Energy_Perspective_Energy-Efficiency-Policies-2013_Full_Report.pdf

Hence, it is of utmost importance to improve the efficiency of energy generation through the use of modern control systems.

Losses in electrical transmission and distribution could exceed 12%. The modernization of electrical infrastructures in particular, using Smart Grids, could significantly reduce energy losses.

1.1.4.3 Electrical Energy

Electrical energy plays a major role in the energy system, because of its ease of use and flexibility. According to the IEA "2014 Key World Energy Statistics", electricity accounts for around 18% of the world final energy consumption. Considering the energy losses in the electricity generation process, the corresponding part in the primary energy is much larger.

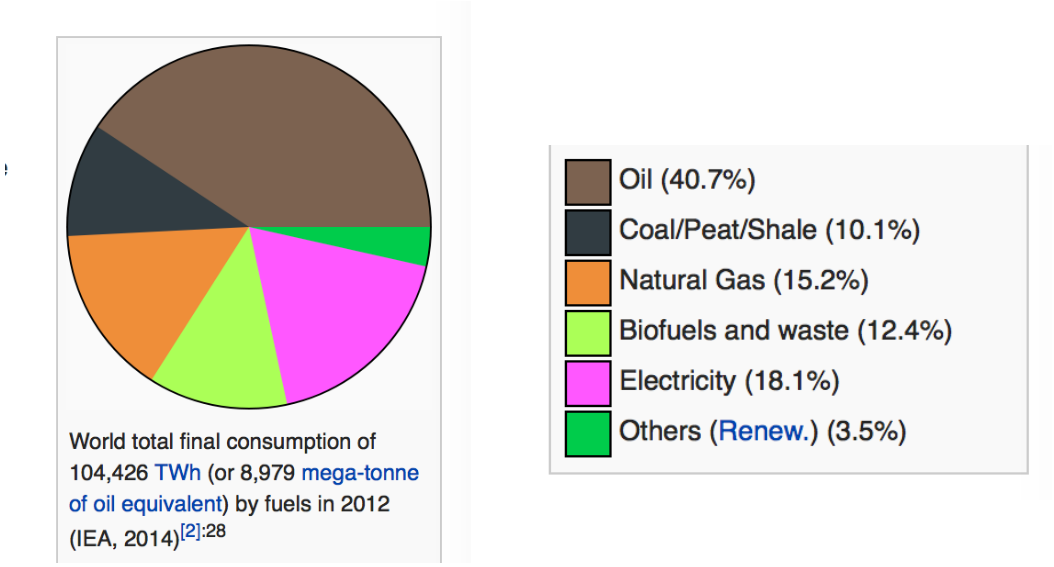

Figure 1.7 World total energy consumption
Source: IEA "2014 Key World Energy Statistics" [8]

According to the to the U.S. Energy Information Administration Report, “International Energy Outlook 2016”[9], the world electricity generation is expected to increase in the period 2012 – 2040 by 70%. Electrical power systems have continued

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[8] http://www.iea.org/publications/freepublications/
[9] http://www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf

to evolve from isolated, small grids to integrated national markets and even international markets.

Figure 1.8 shows the projected world's net electricity generation using fuel. It shows that the share of the renewable energy in the electricity generation will increase from 22% in 2012 to 30% in 2040, while the share of the coal energy will decrease from 40% in 2012 to 30% in 2040, and that of the natural gas will increase from 22% in 2012 to 28% in 2040.

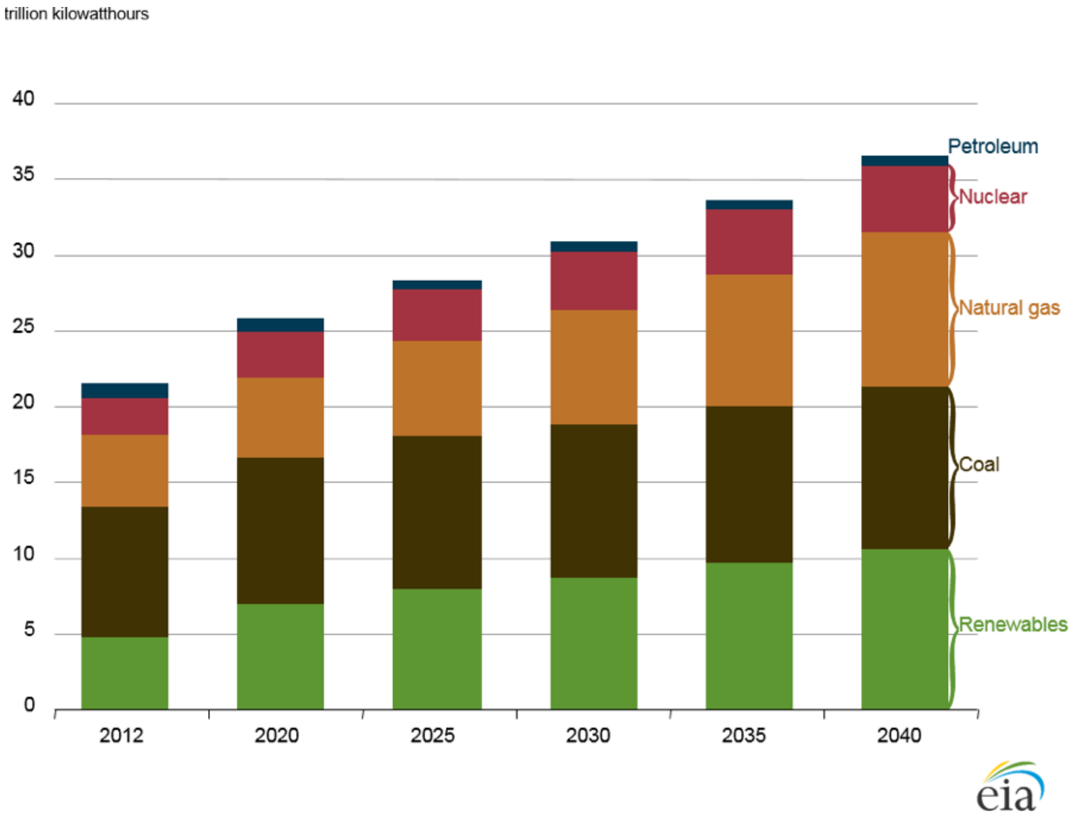

Figure 1.8 World net electricity generation using fuel
Source: US Energy Information Administration report
"International Energy Outlook 2016"[10]

However, the electrical energy system faces major challenges, namely:

- The growing power demand due to the world population growth as well as the demand for a better quality of life and population comfort in developing countries.

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[10] http://www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf

- The integrating of renewable energy, which requires the development of innovative solutions (technology, storage, software, management skills) for an effective integration of different sources into the electrical grid.
- The increase in the efficiency of the electrical system: around 66% of the primary energy are lost in power generation and up to 15% of the energy are lost in some countries in the energy transport and distribution.
- The decrease in the peak demand, which leads to significant savings in the infrastructures used for electricity generation, transport and distribution.
- The increased reliability and stability of the grid, which is vital for the industry, services and life quality. The supply faults cause huge disturbance and economic lost.
- The introduction of an updated electrical grid to the new market: in an open electrical market, the price of electricity could fluctuate widely by hour or even by minute; hence, innovation is required to help users to beneficiate from these opportunities or (and) reduce their impact.

1.2 City Challenges

1.2.1 Urban population increase

City populations are growing at an exponential rate. According to the World Urbanization Prospects of the Unites Nation in 2011[11], currently over 50% of the world's populations live in cities. Estimates show that by 2030, this number will rise to 60%, and then to 70% by 2050, inferring that urbanization is increasing exponentially.

Currently, 70% of the global energy demand comes from urban areas, making up for 80% of greenhouse gas emissions (GHG).

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[11] http://www.un.org/en/development/desa/population/publications/pdf/urbanization/WUP2011_Report.pdf

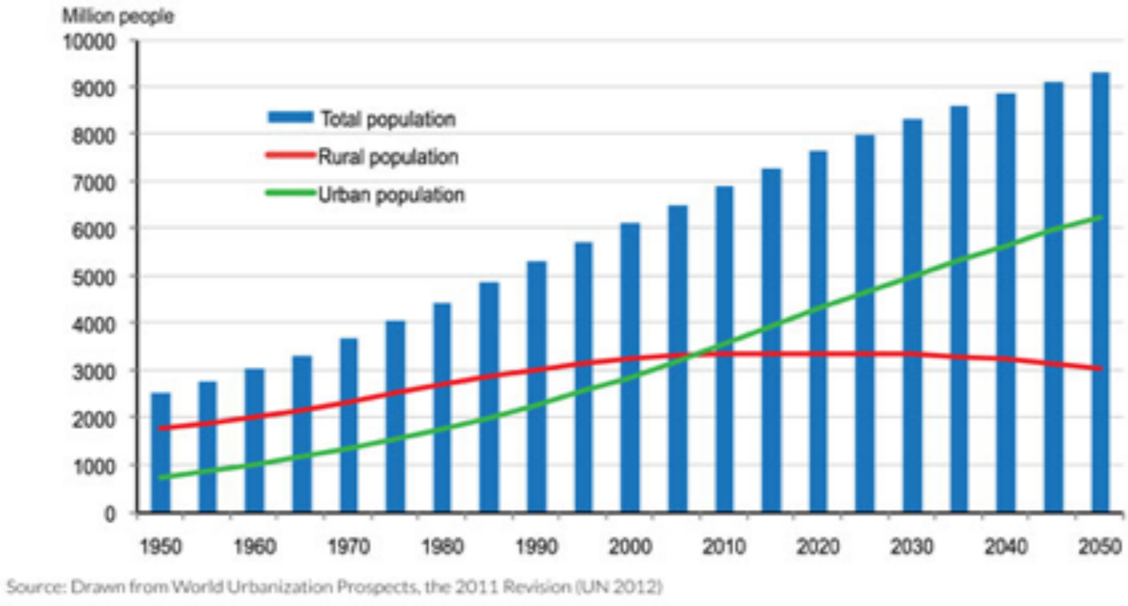

Figure 1.9: Urban population growth in the world
Source: UN, 2012, World Urbanization Prospects

1.2.2 The City: a complex and living system

The quality of any city is related to the quality of its services such as transport, drinking water, sewage, electricity, district heating, telecommunication, municipal wastes, health and education. Urban services lie on complex urban infrastructures, generally embedded in the underground sections of a city. These infrastructures are built for a given service time, which depends on the initial investment, operating conditions, maintenance and modernization factors.

One could see similarities between a city and a human body. Both are an infinite link of systems and networks, most vital of which are not seen by the naked eye. They are hidden under layers of infrastructure. If one system is hurt, or damaged, the overall efficiency and capacity of the entire body of life is directly affected. They both require a certain balance among their natural resources to maintain survival, and to ensure their sustainability into the future. As the size and complexity of urban areas grow, so does their demand for and dependence on these resources, which in return stimulate a parallel dependence on the energy needed to produce them. The daily life of a regular individual has become more harmful to the environment when considering the types of different products with harmful chemical output, energy and resource consumption used in their production and transport to every corner of the globe, and most dangerous of all, is the ignorance and not accepting responsibility of the consequences.

Every element, or section, in a body has a unique role to play to ensure its healthy, and continuous operation. For this reason, the actors that comprise the body, as well as the general function, are continuously being monitored, allowing the detection of any abnormalities, or changes to the normal function. In the case of a human body, after the host decides on a course of action, the brain, or control center, sends signals through its networks to perform requested tasks. If the body becomes ill, or hurt, the body sends signals to make the host aware of the condition, usually through exterior marks and other irregularities, or through unusual changes to different blood levels. After the body is healed, the method and actors used in the healing process are stored in memory, and if the situation demands it, the body is equipped with and prepared to handle it with ease.

The City, as a human body, operates efficiently when all actors are functioning in harmony. If one area is hurt, or damaged, it directly affects the efficiency and overall capacity of the host, hence, stressing the importance of the ‘healthy’ operation. Control, maintenance and monitoring of a city’s core features, systems and networks will identify the weaknesses, limitations and detect any gaps in the overall structure, as well as help guide in its restoration.

However, today’s organization of urban services and infrastructures is not in harmony with the vision of a living city where all the components are in harmonious interaction. Urban services are organized in silos with weak interaction, and sometimes without any interaction. This system of organization is maintained because of cultural and professional conformism and a lack of awareness of the impact of this organization on the efficiency as well as security of urban services and infrastructures.

Accordingly, the emergence of the digital transformation constitutes an excellent opportunity for the transformation of this “non-cooperative” organization mode into fully-cooperative mode. In the following section, the role of the digital revolution in the transformation of the City is presented.

1.2.3 Urban infrastructure management

With the increasing urban concentration of both the population and economic activity, cities meet large challenges, particularly in

- How to ensure basic urban services such as transportation, water supply, sanitation, energy supply and management of solid wastes;
- How to ensure the safety, security and resilience of urban infrastructures and services regarding natural, human and industrial risks and disasters;
- How to contribute to the sustainable development so as to reduce natural resources consumption and greenhouse gas emissions as well as the pollution of soils and water resources; and,
- How to involve citizens in the sustainable development of their city as well as in the city's governance.

The capacity of cities to address these challenges depends on the quality of urban infrastructures such as the transportation infrastructures, electrical grids, drinking water, sewage, gas and telecommunication networks. In developed countries, cities have large urban infrastructures, which were mainly built in the 20th century. The maintenance and upgrading of these infrastructures to meet the sustainability and resilience requirements need a large financial investment. In less developed countries, cities, huge investments in the construction of urban infrastructure to ensure the basic urban services are provided.

The management of urban infrastructures is crucial for the city development. It should ensure an optimal use of the urban infrastructures and their interoperability. The infrastructure management requires a good knowledge of the infrastructures' asset and operating performances. The use of the Geographic Information System (GIS) constitutes an excellent tool for an efficient management of the infrastructures. A monitoring program is also required to understand the operating performances of the infrastructures. Numerical modeling could also enhance the understanding of the infrastructures' state and operation, and consequently reinforce the capacity of acquiring optimal city management level.

1.3 Urban Digital Transformation

1.3.1 Digital Transformation

1.3.1.1 Emergence of the Internet

According to the United Nation Report "The New Digital Revolution: From the consumer Internet to the industrial Internet" [12], in 2014, it was estimated that 3.6 billion people around the world were subscribers to mobile phone services; 2.923 billion individuals, (40%) of the population, used the Internet; over 3 billion had fixed and mobile broadband subscriptions; Internet Protocol (IP) traffic amounted to 60,000 Exabyte per month; and, 179 billion applications had been downloaded, in other words about 25 per person. These key figures summarize the vertiginous expansion of the digital transformation in our daily life (Figure 1.10). We live in a totally connected world made feasible by the ease through which a user can access the Internet from almost anywhere.

The commercial development of the Internet in the 1990s, using narrow band, has led to radical transformation in terms of communication and access to information, through e-mails and proliferation of websites. Later, between 2005 and 2010, the development of broadband increased the transmission speeds and allowed convergence between networks, devices and contents. Recently, the emergence of smartphones and tablets has enabled the development of applications in the Cloud, thus facilitating the access to information from everywhere.

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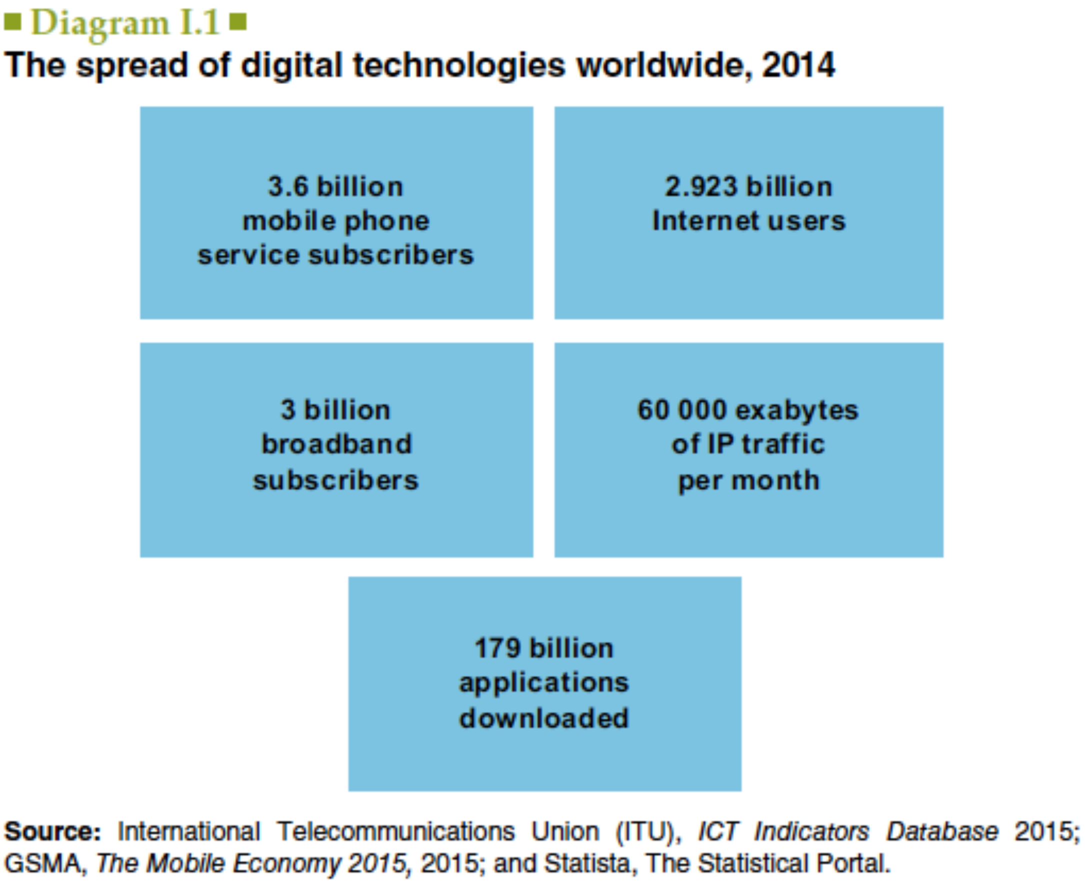
[12] http://repositorio.cepal.org/bitstream/handle/11362/38767/S1500587_en.pdf;jsessionid=160F3DD011A9E3BBEB7EAC36C75A429B?sequence=1



■ Diagram I.1 ■

The spread of digital technologies worldwide, 2014

3.6 billion mobile phone service subscribers

2.923 billion Internet users

3 billion broadband subscribers

60 000 exabytes of IP traffic per month

179 billion applications downloaded

Source: International Telecommunications Union (ITU), *ICT Indicators Database* 2015; GSMA, *The Mobile Economy 2015*, 2015; and Statista, The Statistical Portal.

Figure 1.10: Spread of Digital Technologies, worldwide, 2014.

1.3.1.2 Emergence of Social Media

The digital transformation was fostered by the rapid development of social media. In the last decade, the rapid expansion of social media such Facebook, YouTube, Twitter, LinkedIn, Google$^+$, Tumblr and Instagram allowed people to be connected at large scale from almost anywhere in the world. Communities are created for both personal and business issues. Figure 2.11 shows the estimation of Growing Social Media for the major actors in social media, which could be summarized as follows:

- Facebook: 1.6 Billion
- YouTube: 1 billion
- Twitter: 325 Million
- LinkedIn: 429 Million
- Google$^+$: 440 Million
- Instagram: 430 Million

The huge development and expansion of social media is an important factor in the digital revolution. Together with the large development of broadband transmission technology and the smartphone penetration, people are connected everywhere and at a large scale.

Figure 1.11: Social media users' statistics, 2016 (Source Growing Social Media[13])

1.3.1.3 Internet of Things

According to Wikipedia[14] "the internet of things is the network of physical devices, vehicles, buildings and other items—embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data." In 2013, the Global Standards Initiative on Internet of Things (IoT-GSI) defined the IoT as "the infrastructure of the information society. The IoT allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit".

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[13] http://growingsocialmedia.com/social-media-facts-and-statistics-for-2016/

[14] https://en.wikipedia.org/wiki/Internet_of_things

Thanks to the emergence of this technology, every object "Thing" could be identified and connected. It could transmit and receive data using wireless communication technology. In addition, it can also store and analyze data and manage actions. Things could be connected and operate in networks at different scales.

According to the HIS Quarterly (Figure 1.12), the number of connected devices (IoT) will increase from 13 billion in 2013 to 50 billions in 2015.

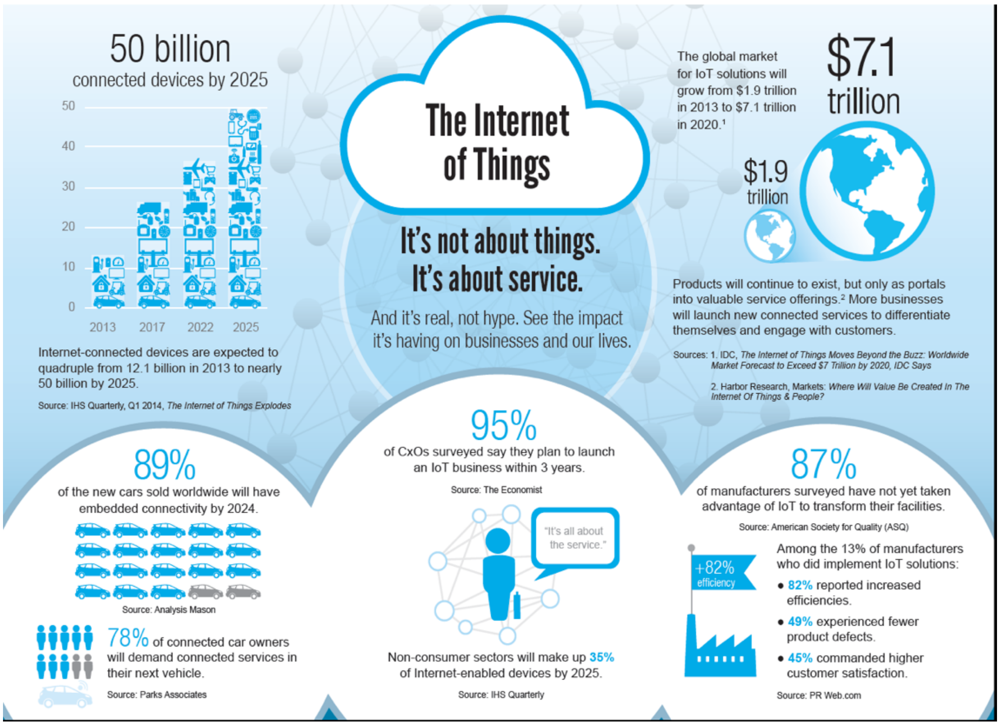

Figure 1.12: Perspective of the Internet of things (IoT) development (source Internet)[15]

1.3.1.4 Smart sensors

A smart sensor is a device that takes input from the physical environment, and performs predefined functions upon detection of specific input. Smart sensors include the following components (Figure 1.13):

- The central unit: Microprocessor, which manages the tasks.
- Battery: Source of energy

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[15] https://www.jasper.com/sites/default/files/pdf/IoT_Infographic.pdf

- Transceiver: Interacts with the environment and collects data.
- Memory: Storing data
- Communication module: Transceivers and forwards queries and data to and from central module.

Smart sensors can therefore ensure the monitoring of physical system through measurement of physical parameters as well as analysis storage and communication of data to other sensors. Thanks to embedded software, smart sensors can operate more complex tasks such as the control of devices.

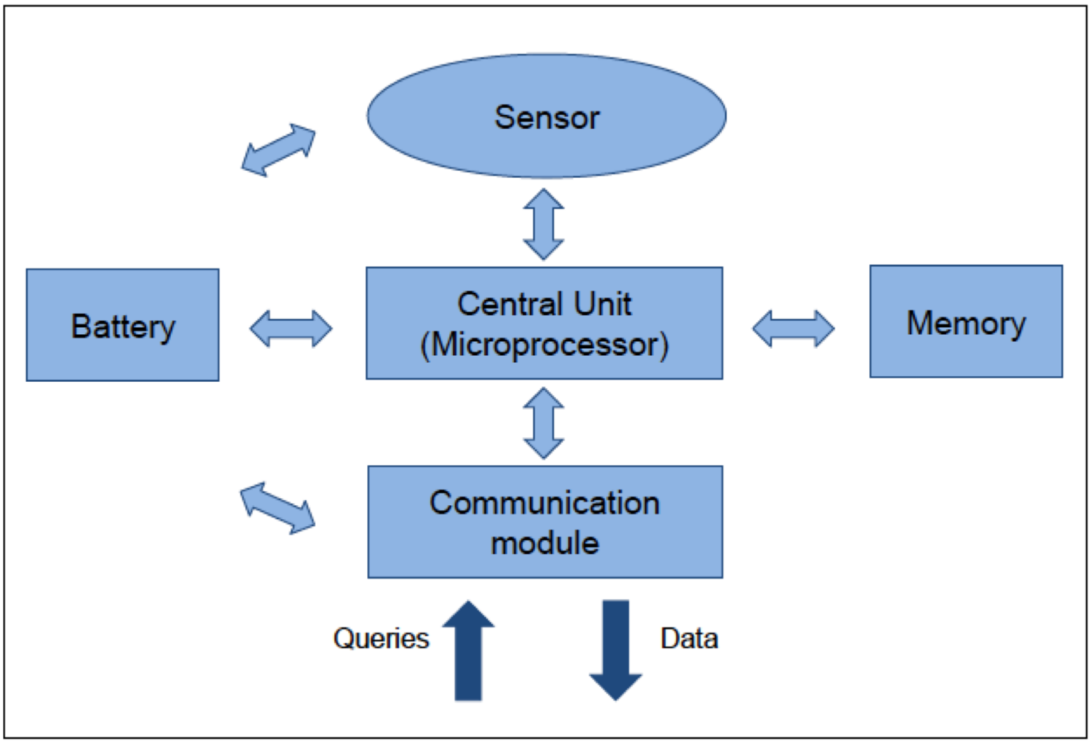

Figure 1.13: Architecture of Smart Sensors (Source OECD Report - Smart Sensor Networks: Technologies and Applications for Green Growth[16])

Figure 1.14 shows the main domains of environmental application of smart sensors. They cover large areas such as smart grids and energy control systems, smart buildings, smart transportation, agriculture and infrastructure and environmental monitoring.

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[16] https://www.oecd.org/sti/ieconomy/44379113.pdf

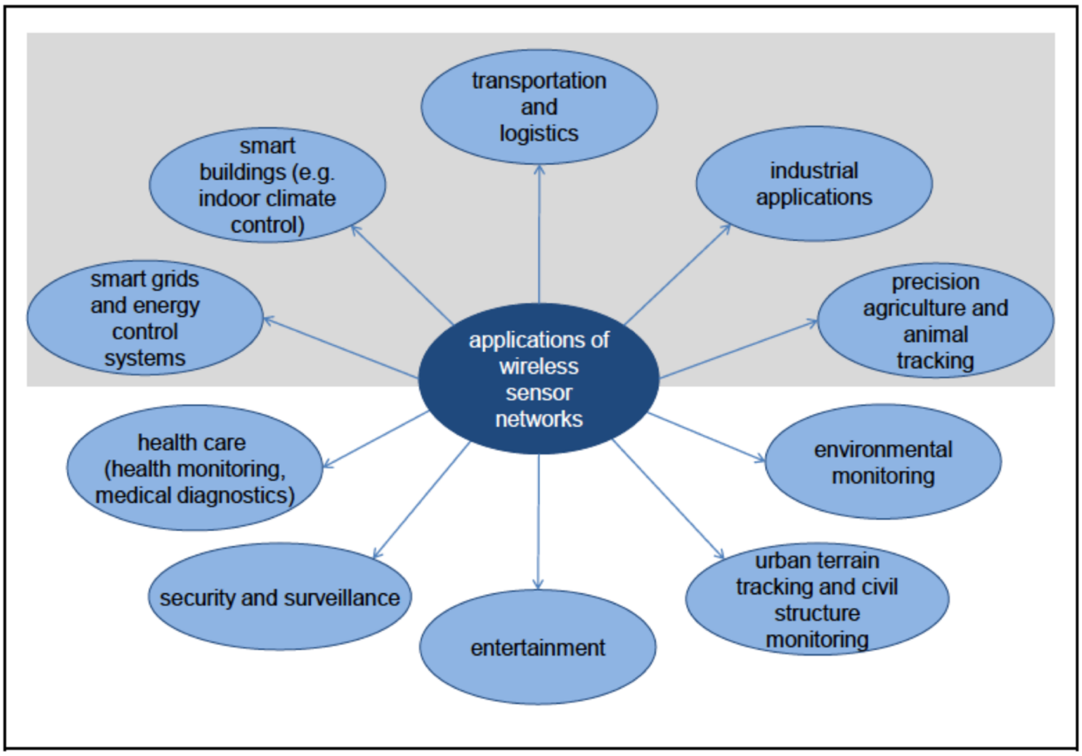

Figure 1.14: Domains of application of smart sensors (Source OECD Report - Smart Sensor Networks: Technologies and Applications for Green Growth[17])

Smart devices can be designed to support a variety of form factors, a range of properties pertaining to ubiquitous computing, and be used in three main system environments: physical world, human-centered environments and distributed computing environments.

1.3.2 Smart City Concept

1.3.2.1 Objectives and domains

The Smart City concept aims to use the digital technology, presented in the preceding section, for an optimal and safe management of the City with a special focus on the citizens' quality of life, and on a friendly urban environment that reduces the consumption and losses of natural resources and the emission of pollutants.

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[17] https://www.oecd.org/sti/ieconomy/44379113.pdf

Smart City can be viewed broadly; it concerns a more interdisciplinary approach (Anthopoulos and Fitsilis 2013; Anthopoulos and Vakali 2012). In a recent literature review, Anthopoulos (2015) classified the academic researches conducted on Smart Cities into four domains: Information and Communication Technology (ICT), eco or green city, urban planning, creative industry and living labs. To these domains, important concerns in urban infrastructure engineering, economy, management, safety, and urban governance can be added. A successful Smart City project should combine these scientific domains to well address the complexity of city challenges.

The European Innovation Partnership on Smart Cities and Communities (EIP-SCC)[18] aims at "Bringing together cities, industry and citizens to improve urban life through more sustainable integrated solutions". The goal of the Strategic Plan of the EIP-SCC[19] aims at "Striving a triple bottom line gain for Europe: a significant improvement of citizens' quality of life, an increased competitiveness of Europe's industry and innovative SMEs together with a strong contribution to sustainability and the EU's 20/20/20 energy and climate targets. This will be achieved through the wide-reaching roll out of integrated, scalable, sustainable Smart City solutions – specifically in areas where energy production, distribution and use; mobility and transport; and information and communication technologies are intimately linked".

The European objective of the Smart City concerns the development of an integrated strategy for the improvement of the quality of life, the reinforcement of the industrial competitiveness, and the achievement of the European sustainability energy and climate objective (EU's 20/20/20).

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[18] http://ec.europa.eu/eip/smartcities/index_en.htm

[19] http://ec.europa.eu/eip/smartcities/files/sip_final_en.pdf

Figure 1.16 shows the Strategic Implementation Plan of the EIP-SCC. It includes three 'vertical' domains: (i) Sustainable Urban Mobility, (ii) Sustainable Districts and Built Environment, and (iii) Integrated Infrastructures and processes across Energy, ICT and Transport.

The strategic plan covers eight "horizontal" themes: Citizens, Policy & Regulations, Integrated Planning, Knowledge Sharing, Matrics & Indicators, Open Data, Standards and Business Models.

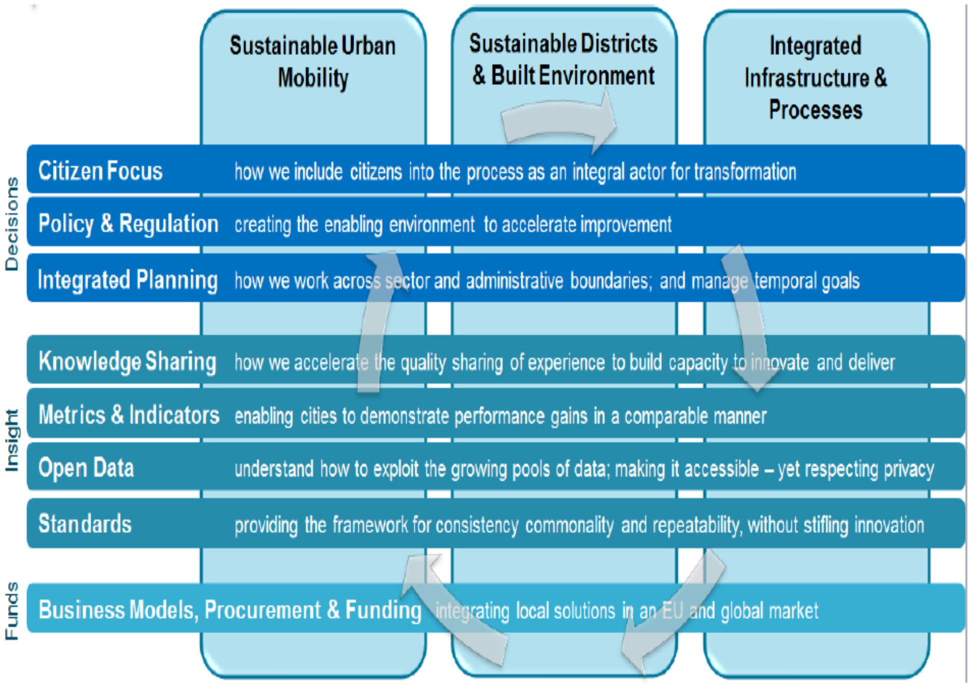

Figure 1.15: Strategic Implementation Plan of the European Innovation Partnership on Smart Cities and Communities (EIP-SCC) [20]

The International Communication Union (United Nations specialized agency for information and Communication Technologies (Focus Group on Smart Sustainable Cities) adopted the following definition for Smart City[21]: "A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services,

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[20] http://ec.europa.eu/eip/smartcities/files/sip_final_en.pdf

[21] http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx

and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects". ITU definition of the Smarty City focuses on the use of the Information and Communication Technologies to build the Sustainable City.

Figure 1.16 summarizes the vision of ITU for the Smart City. It is viewed as a system of subsystems, which address different smart sustainable city service categories such as waste management, buildings, tourism, health service, safety and emergency, energy service, water service, transport, education, e-business, e-government…etc.

Figure 1.16: Smart City Concept of ITU (Source ITU [22])

Figure 1.17 summarizes the IBM concept for Smart Cities. This concept covers large areas and services, particularly:

- Planning and management concerning public safety, government and agency administration, city planning and operations and buildings.
- Urban Infrastructures concerning water, energy and transportation.
- People with concern for social program, healthcare and education

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[22] http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx

The Smart City concept of Siemens focuses on energy optimal management. According to Siemens [23] "smart cities will be characterized by power grids that will be able to balance electricity supply and demand. This will start with buildings that learn occupants' energy needs, integrate vehicle batteries into their energy forecasts, respond to changing weather conditions, and automatically alter their behavior to maximize their efficiency".

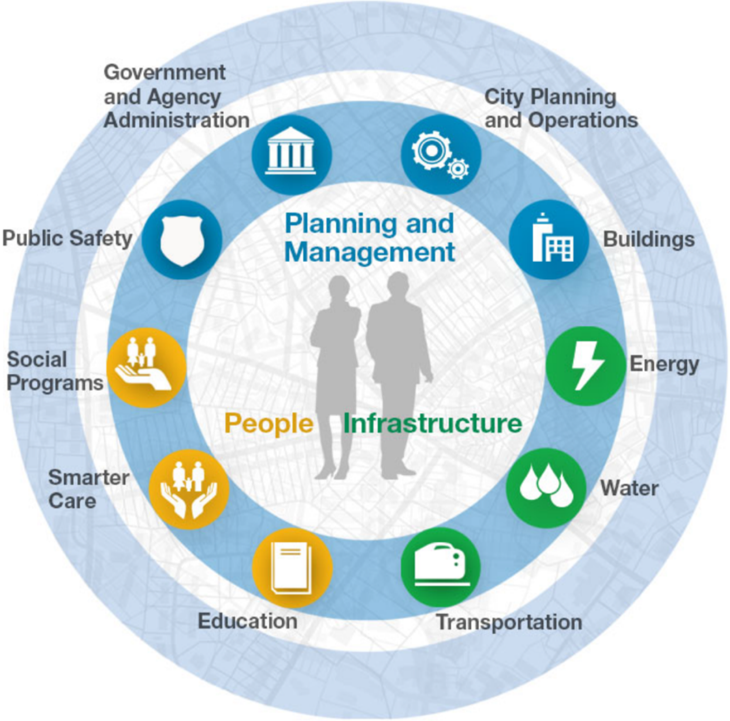

Figure 1.17: IBM Concept for Smart Cities (Source IBM[24])

Figure 1.18 shows the application of the Smart City concept on the City of Dubai. It is based on the application of the IoT technology in various areas such as safety and security, parking, education, lighting, aviation, environment, financial services, e-government and waste management.

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[23] http://www.siemens.com/innovation/en/home/pictures-of-the-future/infrastructure-and-finance/smart-cities-smart-buildings.html

[24] http://www.ibm.com/smarterplanet/us/en/smarter_cities/overview/

Figure 1.18: CISCO Concept for Smart Cities Dubai - (Source CISCO [25])

Figure 1.19 shows Huawei's Smart City concept. It focuses on three areas:

- Smart Government, which aims at the use of a cloud-based data center to share and integrate data, and collaborates with different sectors to optimize resource utilization and improve governmental efficiency. It allows for open and transparent government by using a unified database management platform.

- Smart Life, which aims at improving unban services and citizen satisfaction and enhancing the quality of life. It covers various areas such as social inclusion among real-time traffic information, health care and education.

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[25] http://blogs.cisco.com/digital/experience-the-smart-city-of-the-future-at-the-iotwf-dubai

- Smart Industry, which aims at promoting economic growth as well as intelligent and digital innovations to attract strategic investment and innovative enterprises. Smart Industry provides professional IT services and cloud-based data centers to help enterprises develop businesses and urban economy, while Smart Tourism provides technical support to the tourism industry chain, serves the tourism market, and encourages tourism economy in the city.

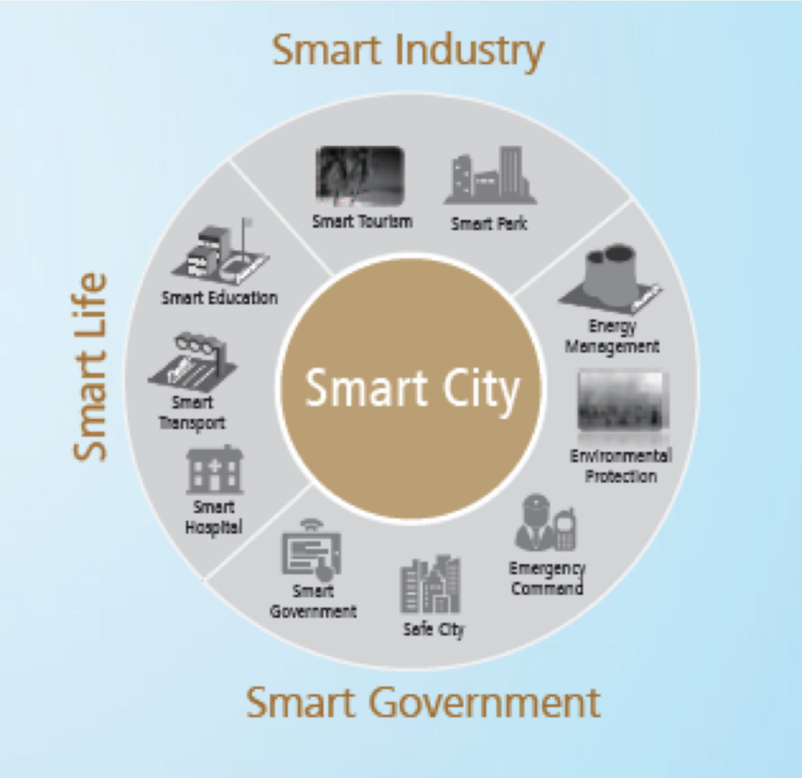

Figure 1.19: Huawei Smart City Concept - (Source HUAWEI [26])

1.3.2.2 Smart City concept – Real Time Data

The Smart City concept is based on a real-time monitoring of urban infrastructure including water and energy networks, transportation infrastructures and buildings (Buchholz and Styczynski 2014, El-Hawary 2014, Momoh 2012, Tuballa and Abundo 2016). Monitoring includes smart sensors and actuators connected via wired and wireless communication networks, which allow a real-time following and control of

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[26] https://www.google.fr/#q=huawei+smart+city

urban infrastructures. The sensors readings are stored in large data sets together with information on the infrastructure asset and other useful data such climate information, traffic, users' profiles and consumptions. The data could also be enhanced by images, videos and audios, resulting in the construction of urban Big Data (Chen et al. 2014, Mayer-Schönberger and Cukier K 2013).

The analysis of the real-time and historical data results in an enhanced understanding of the infrastructures performances. It allows also an optimal management of the infrastructures by reducing the energy and water consumptions as well as the polluted emissions. In addition, the system can detect abnormal events, which could be related to a fault in infrastructures or unusual consumptions. Consequently, rapid intervention could be conducted to ensure the security of the infrastructure.

1.3.2.3 Smart City – Innovative solution for complex urban problems (unstructured, intertwined with multiple physical and social factors)

Furthermore, the Smart City concept is based on the interaction with citizens. It provides citizens with pertinent information about the city services, infrastructures' operation and safety issues. Citizens also enhance the urban information system by providing their observations and reactions as well as by spreading useful information through their social networks. Thanks to the interaction with users, social networks could enhance the Smart City system, and consequently highly increase its capacity in the sustainable and resilient management of cities. In the case of urban disasters, citizens could be informed and mobilized in the organization of the emergency actions.

The Smart City concept provides authorities with pertinent data about the real performances of urban infrastructure as well as the citizen behavior during any urban crisis or disaster. Analysis of this data is crucial to having a good understanding of the real behavior of the City (infrastructure, citizens, public services, emergency) during an urban crisis, or disaster, and consequently improves the city's capacity to address the challenge of resilience.

Strategies to make cities smarter include both technological and social policies. Cities are concerned with emergent technologies to achieve a more agile structure that improves the quality of the life of citizens, enhance the economic development, and improves the city attractiveness and to reinforce the implication of citizens in the city government. In a Smart City, sensor networks, geographic information technologies, social media and other emergent technologies should act together like a nervous system that captures, distributes and analyzes urban information about the resources, the demand, the infrastructure capacity at different scales.

According to Rodríguez-Bolíva (2015) "Highly structured city problems may have clear necessary actions that require little analysis; other times cities face problems that are related to complex sociotechnical issues where multiple sources of data and complex analytics might be involved. When a problem is relatively simple and structured, automatic responses could be deployed. In contrast, when a problem is very complex, unstructured, and intertwined with multiple physical and social factors, the response normally needs a significant amount of time, intensive human intervention, huge amounts of data, and sophisticated analytics capability". Through the collection, sharing and analysis of data by the city stakeholders at different urban scales, the Smart City concept provides an innovative and powerful framework and tools to deal with complex urban problem; a framework that generally combines technological and social issues.

1.3.2.4 Implementation of the Smart City concept

The implementation of the Smart City concept constitutes a complex and long process, which should be conducted by all the city stakeholders: City government, city services, citizens, private sector, urban services providers, academic… It should not be made blindly and universally. Every city is unique. Similarities may exist between neighboring countries, or countries in the same region, concerning design and layout; however, each city has its own needs and necessities.

Figure 1.20 summarizes the steps followed in the implementation of a Smart City. The first step concerns the diagnostic phase, which can be considered as one of the most vital parts of the smart city transformation process. Prior to implementing smart digital technologies, the situation and challenges of the City should be analyzed as well as the goal to be achieved. After analyzing the gaps, the effectiveness of the Smart City solution to meet the City challenges is to be explored. Systems implemented in urban areas may not be as efficient when implemented in other places; transformations should not be mimicked. This phase should also analyze the legal, economic, social and government issues of the Smart City Solution. Diagnosing each city by examining all the elements and functions that comprise it, is crucial to achieving complete awareness. This phase results in establishing a “Road Map” for the Smart City Implementation.

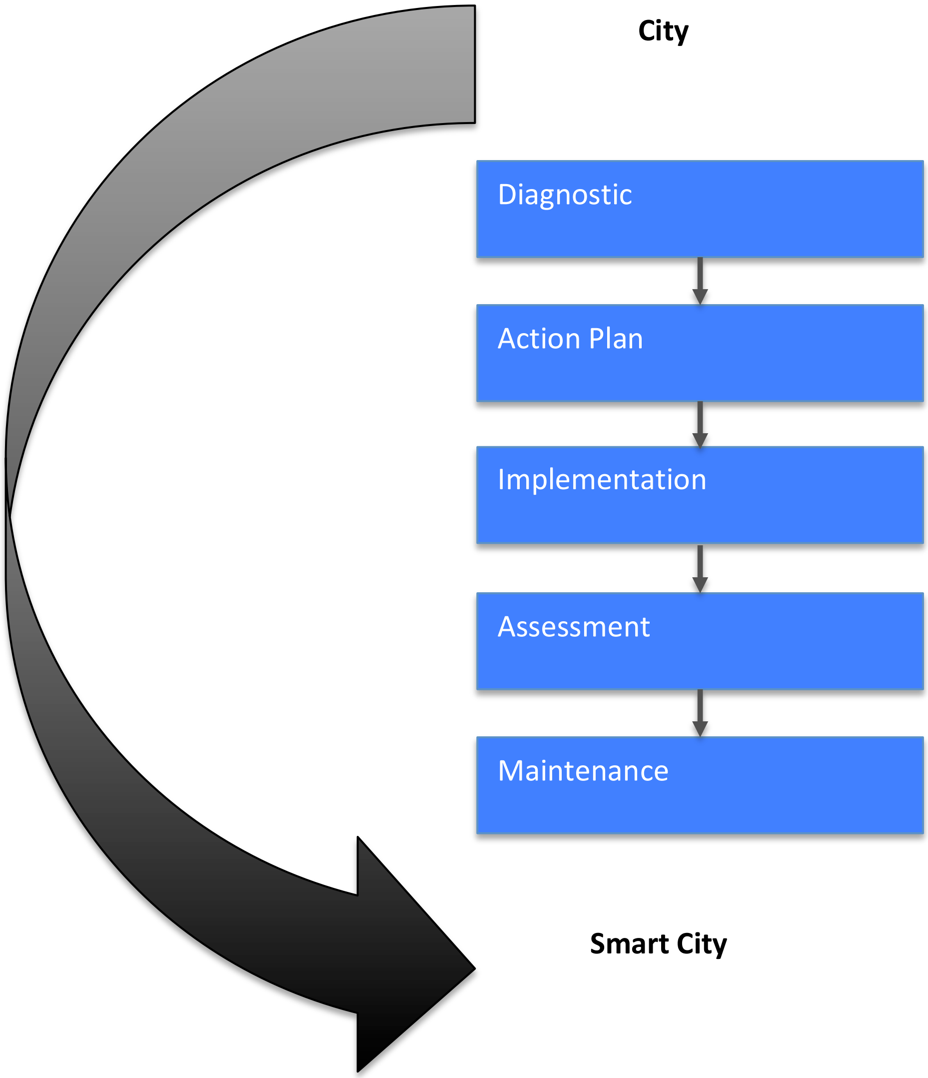

Figure 1.20: Steps for the Smart City Implementation

The second step concerns the *action plan*, which provides the gaps to be addressed and the way to achieve the goals of the city transformation. The action plan is composed of a set of actions to be carried out; it gives the objective, sub-actions, calendar, quality control, milestones, and deliverability of each action.

The third step concerns the implementation phase, which refers to the execution of the action plan. It includes different tasks such as (i) construction of urban information system using GIS and BIM tools, smart monitoring using smart sensors and actuators, data transmission using both wired and wireless technology, data storage, data analysis using engineering, social, mathematical, computational and Big Data tools, graphic visualization using 3D graphic tools as well as augmented and virtual reality techniques, infrastructures control for both safety and optimal management, interaction with users. All of these tasks should be centralized and conducted in the Smart City platform, such as the used by SunRise Smart City large-scale demonstrator (Figure 1.21).

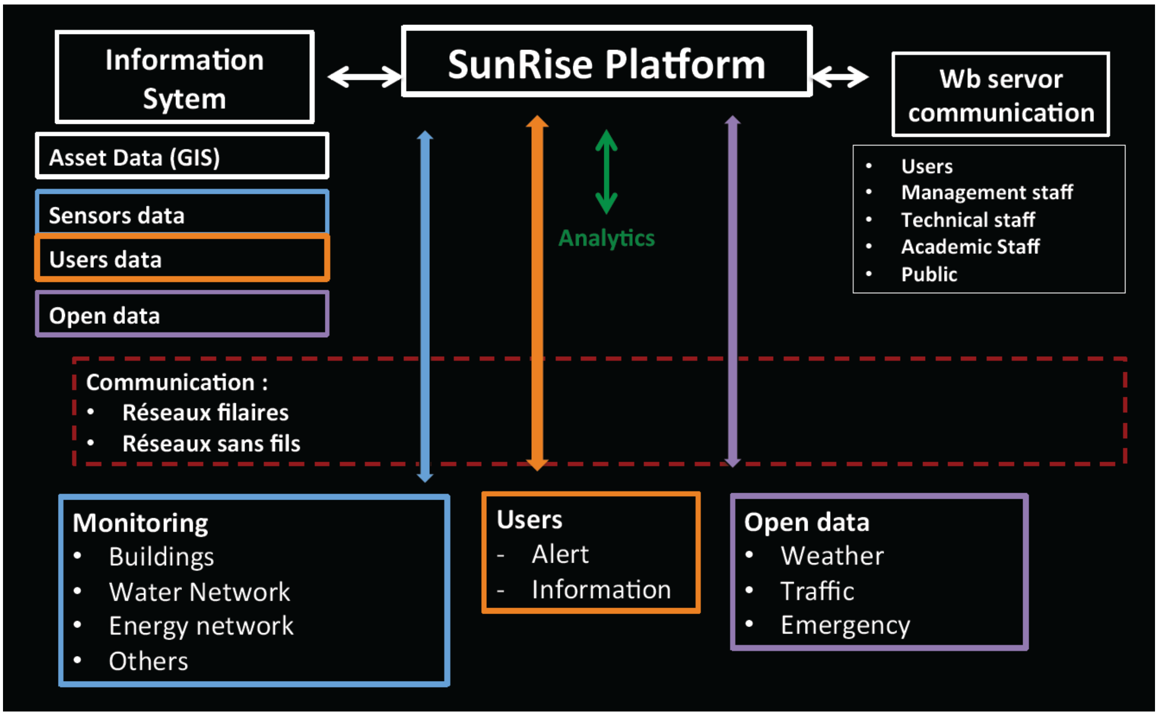

Figure 1.21: SunRise Smart City Platform (Large Scale Demonstrator of the Smart City)[27]

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[27] http://sunrise-smartcity.com/fr/site-du-projet/

The fourth step refers to the assessment of the implementation of the Smart City Solution. It concerns the verification of the implementation of the Smart City components through technical tools as well as end-users' feedback and economic return. The sustainability of the solution should also be addressed. This phase is complex, because the smart solutions need a decent amount of time to take effect and become advantageous. Most people are programmed to being resistant to alteration of their daily routine, especially the older generations that were not raised in the digital age. This is a struggle faced by Smart City researchers as to designing their innovations in a way to appeal more to the consumer; by finding original ways of grasping their attention, and encouraging the acceptance of the presented concepts. The inhabitants of the city will need time to adapt to the furthering of, or to the newly digitized environment surrounding them. Their lifestyles will likely change, but history presents proof that with time comes change; if we don't evolve with time we will be left behind. It is imperative to the smart city transformation process for the citizens to be directly involved with the procedure; the acceptance and validation of this concept by city residents is directly linked to its success.

The final phase in the road to smarter cities concerns the "maintenance" and the development of physical components as well as platforms used in the Smart City solution. It also concerns the achieved individual and collective knowledge developed in the different areas of the Smart City domains. This phase does not concern a short period of time, as do other steps in the transformation process; it becomes the new way of life. Monitoring and maintaining the smart city solutions is the only way to ensure the continued climb to overall and complete optimization on all fronts.

1.3.2.5 Standards for the Smart City Implementation

The Smart Cities preliminary report 2014 of the International Organization for Standardization (ISO)[28] provides an overall review of the specified topics of Smart Cities, while exploring standardization opportunities. This report includes:

— A description of key concepts related to Smart Cities, establishing the definition of Smart Cities based on the key concepts, and a description of relevant terminology;

— A study and document of the technological, market and societal requirements for the ICT standardization aspects of Smart Cities;

— A study and document of current technologies that are being deployed to enable Smart Cities;

— An assessment of the current state of standardization activities relevant to Smart Cities.

— An identification and proposal as to how to address the ICT standardization needs of Smart Cities.

Figure 1.22 shows the Smart City Standards models proposed by the ISO- JTC 1 Smart Cities preliminary report 2014 [26]. This figure shows the large areas concerned by the smart cities as well as their interactions and the complexity of establishing standards for the Smart City.

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[28] http://www.iso.org/iso/smart_cities_report-jtc1.pdf

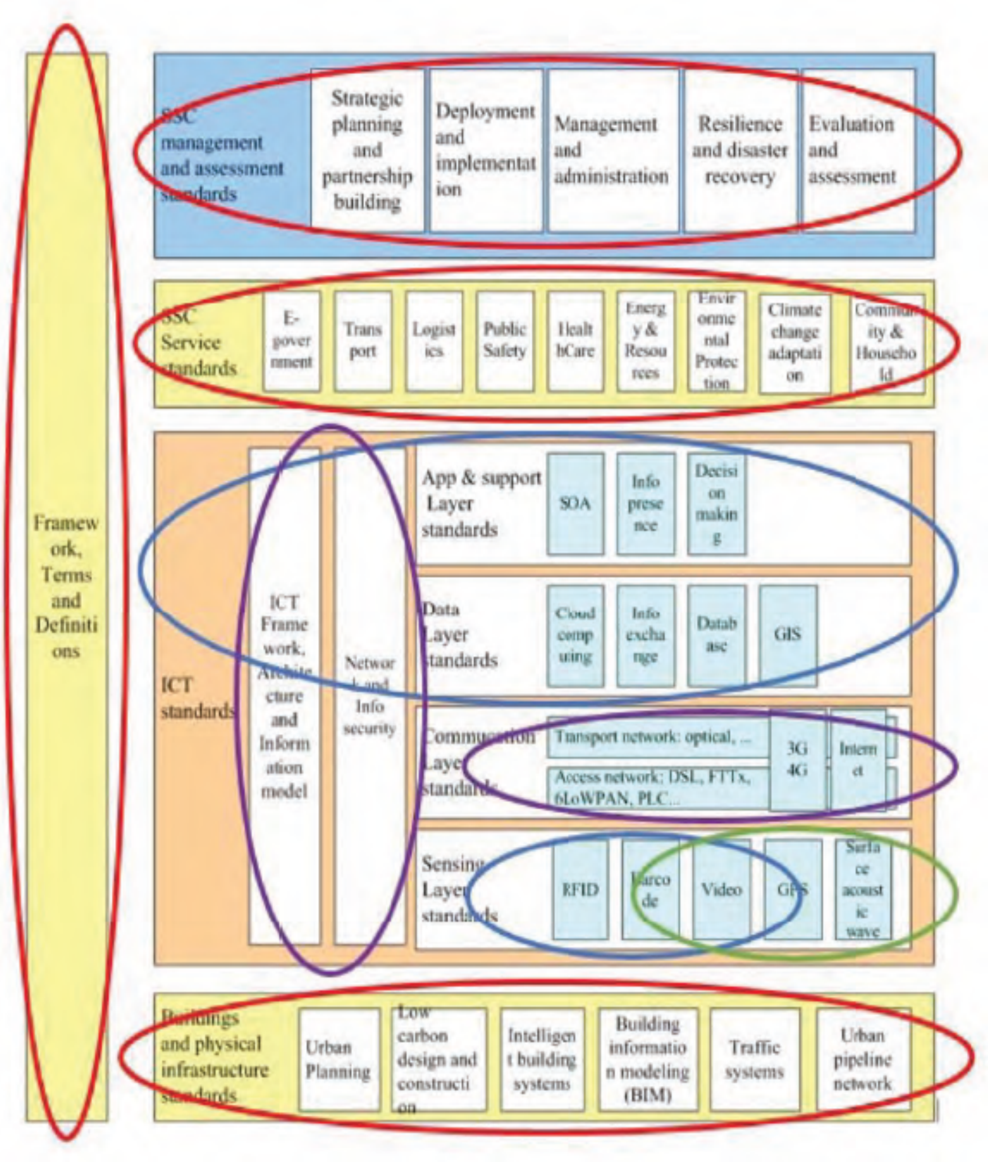

Figure 1.22 – ISO – Smart City Standards models
(Source – ISO Smart Cities preliminary report 2014[29])

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[29] http://www.iso.org/iso/smart_cities_report-jtc1.pdf

Appendix 1 summarizes the ISO Standardization Work on Smart Cities. It includes the following ISO standards:

- ISO/TC 268 for Sustainable development in communities
- ISO/TC 163 and ISO/TC 205 for Building environment design and Thermal performance and energy use in the built environment
- ISO/TC 257 for energy savings in renovation projects,
- ISO/TC 242 for Energy management
- ISO/TC 59 for Buildings and civil engineering works,
- ISO/TC 223 for Social Security
- ISO/TC 241 for Road traffic safety management systems,
- ISO/TC 204 for Intelligent transport systems
- ISO/TC TMB for sustainability management

The following standards also concern the Smart City:

- ISO 9001 - Implementation and monitoring of quality management systems
- ISO 50001 - Energy management system standard
- ISO 23045 - Energy efficiency assessment
- ISO/TC 242 - Energy management
- ISO/TC180 - Solar energy
- ISO/TC 59/SC 17 - Sustainability in buildings and civil engineering projects
- ISO/TC 205 - Building environment design

1.4 Smart Electrical Grid

1.4.1 Traditional Electrical system

1.4.1.1 Architecture

Electric power system is a network that includes electrical machines, lines and mechanism to generate electricity and supply to the customers. The Electrical Grid is composed of interconnected generators and small networks that generate, transport and distribute electricity to supply customers such as habitation, commercial buildings, industries, hospitals and other urban services such as public lighting and transportation.

The electrical power network is generally divided into three sectors: Generation, Transmission and Distribution. Figure 1.23 shows the organization of the French Electrical Power System; it includes 351 700 km of High Voltage lines (HV), 415 100 km of air Low Voltage lines (LV), 276 900 underground Low Voltage lines and 750 400 transformers from HV to LV.

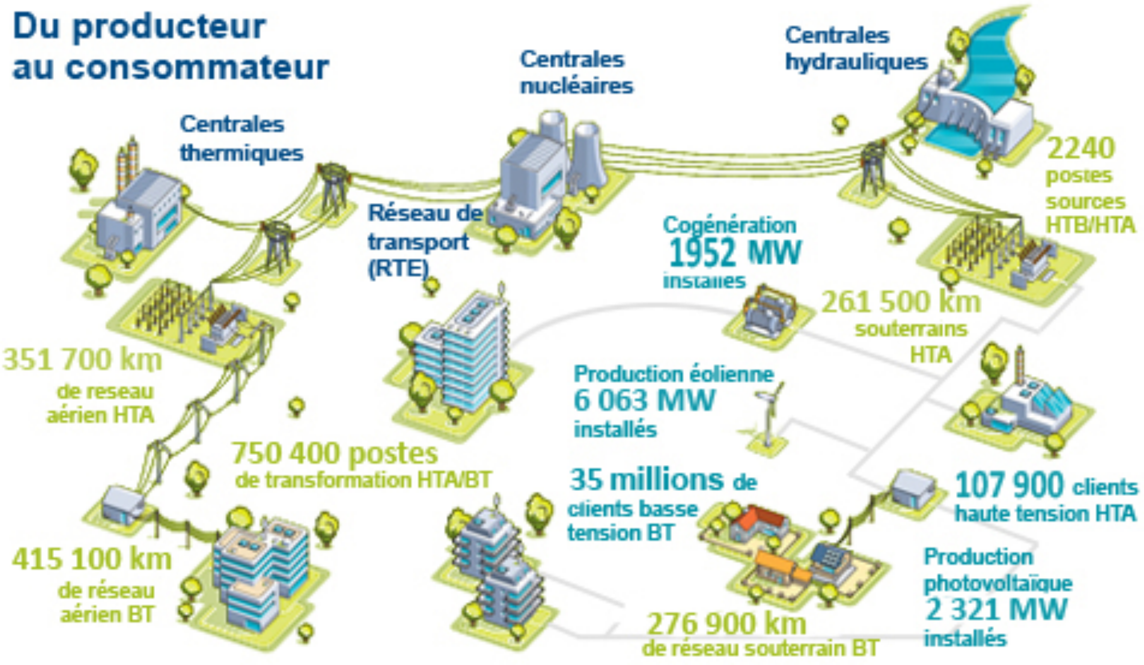

Figure 1.23 French Electrical Grid
(Source ENEDIS[30])

The generation section uses generators to convert the energy from various sources to electric power at a given voltage. Figure 1.24 shows the sources of electrical generation in France. Around 82% of the French electricity comes from nuclear sources, 8% from hydraulic and 6% from oil.

For economic dispatching, a control center collects the generators' output values and controls the generators to meet the demand at the lowest cost. AC electric power is generated at frequencies 50 or 60 Hz. In the case of a sudden change in the demand, the generator frequency could experience some variation.

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[30] http://www.enedis.fr/fonctionnement-du-reseau

The transmission section ensures the transmission of electricity to long distances through high-voltage (HV) overhead lines or HV underground cables. The transmission voltage could vary between 33 and 500 kV. The voltage levels are determined based on the amount of power needed and the distance it must traverse. Electrical transmission network is highly meshed to ensure the continuity of the power supply in case of any section loss in the network.

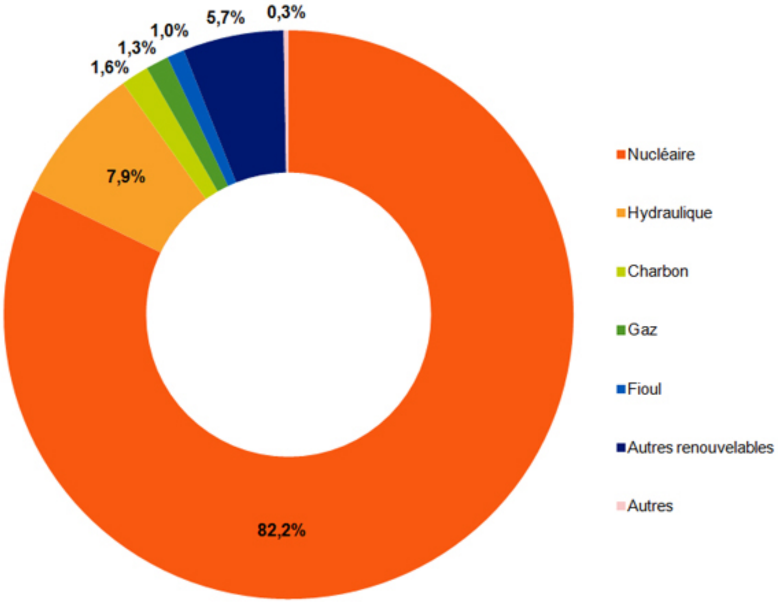

Figure 1.24: Electrical Energy Generation Sources in France (Source EDF[31])

In the meshed network system, the lines are generally loaded around 50 % to allow continuation of supply after outage of the load sharing lines or transformers. In addition to the supply reliability, the meshed network provides some benefits such as broad choices of generating plants, reduction in reserve capacity of generators, diversity of load demand (Islam et al. 2013).

Distribution section is ensured by supply lines between high-voltage substations and customers at lower voltage, which depends on countries (63 to 225 kV in France).

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[31] https://www.edf.fr/groupe-edf/information-sur-l-origine-de-l-electricite-fournie-par-edf)

Distribution transformers transform the electrical voltage to supply consumers at the required voltage (220 V, 440 V, or higher for commercial or industrial uses).

1.4.1.2 Electrical grid challenges

In the beginning, electricity was primarily utilized by lighting systems. As more industries shifted from oil and gas to electricity, there was an enormous increase in the demand for electricity. In addition, modern buildings, both residential and commercial, constitute a major portion of this demand. It is estimated that around 73% of electricity in the US is consumed by buildings (Conti & Holtberg, 2015).

Since electricity concerns vital issues of the daily life, the industry and services, reliability is one of the major challenges of the electrical system. It consists of the capacity of the electrical system to deliver continuous power to consumers within accepted standards. It is mainly related to loss of voltages (Kueck et al. 2004). It can be evaluated by frequency, and duration, of interruptions as well as magnitude of adverse effects on the electric supply. Power quality may be defined as the measures, analysis and improvement of bus voltage to maintain that voltage at rated voltage and frequency, to meet the requirements of the consumers' devices (Kueck et al. 2004).

Protective system is used in the electrical system to protect electrical generators, transformers, lines and equipment against faults, which could occur during operation process. The purpose of this system is to immediately isolate the fault part from the system so that the remaining part can continue the power supply. The relay operation should be selective and fast to trip the related circuit breaker. The protection system prevents personnel injuries and equipment damage. It also minimizes power interruptions, impacts of faults and fault-related disturbances on the system.

The electrical grid also faces the challenges of ageing infrastructure, continued growth in demand, integration of increasing renewable energy sources, the need to improve the security of supply and the need to reduce carbon emissions. Figure 1.25 shows major electrical outages in the United States from 1991 – 2005. We observe an important increase in these outages: The number of outages exceeding 100 MW increased from 65 in 91-95 to around 140 in 2001-2005, while the outages concerning impacting more than 50 000 customers increased from 40 in 1991-1995 to around 90 in 2001-2005. These huge outages are principally due to the aging electrical system in the United States.

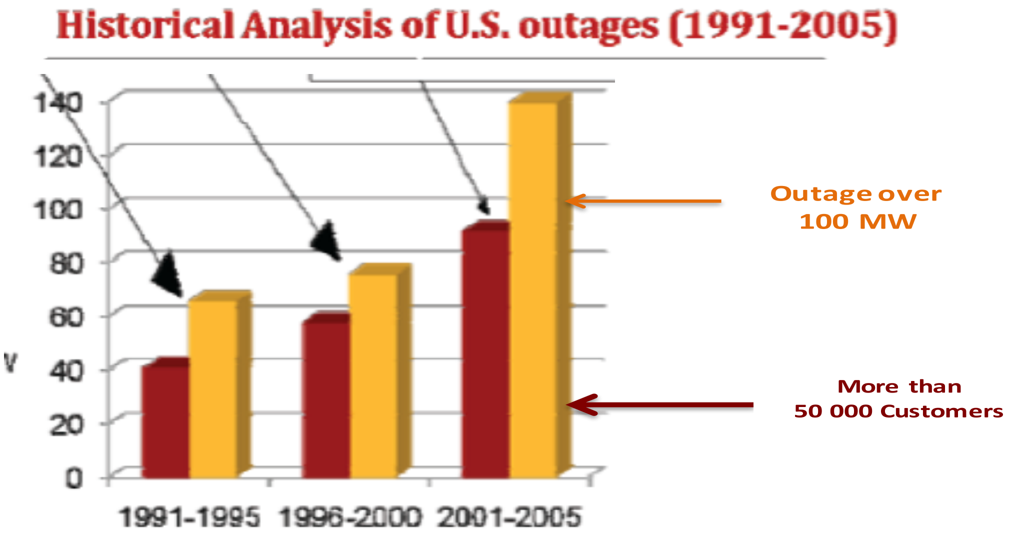

Figure 1.25: Major electrical outages in the United States (Source eia data[32])

Developing countries suffer from lack of electrical infrastructure. According to the International Energy Agency (iea)[33], around 1.3 billion people lack access to electricity: more than 600 million in sub-Saharan Africa, more than 300 million in India. Figure 1.26 shows the critical situation in Africa, where around 55% of the population does not have access to electricity. In some countries, the ratio of the population without electrical service exceeds 80%. Providing electric power to these un-serviced areas will cause a huge jump in demand in the coming decades

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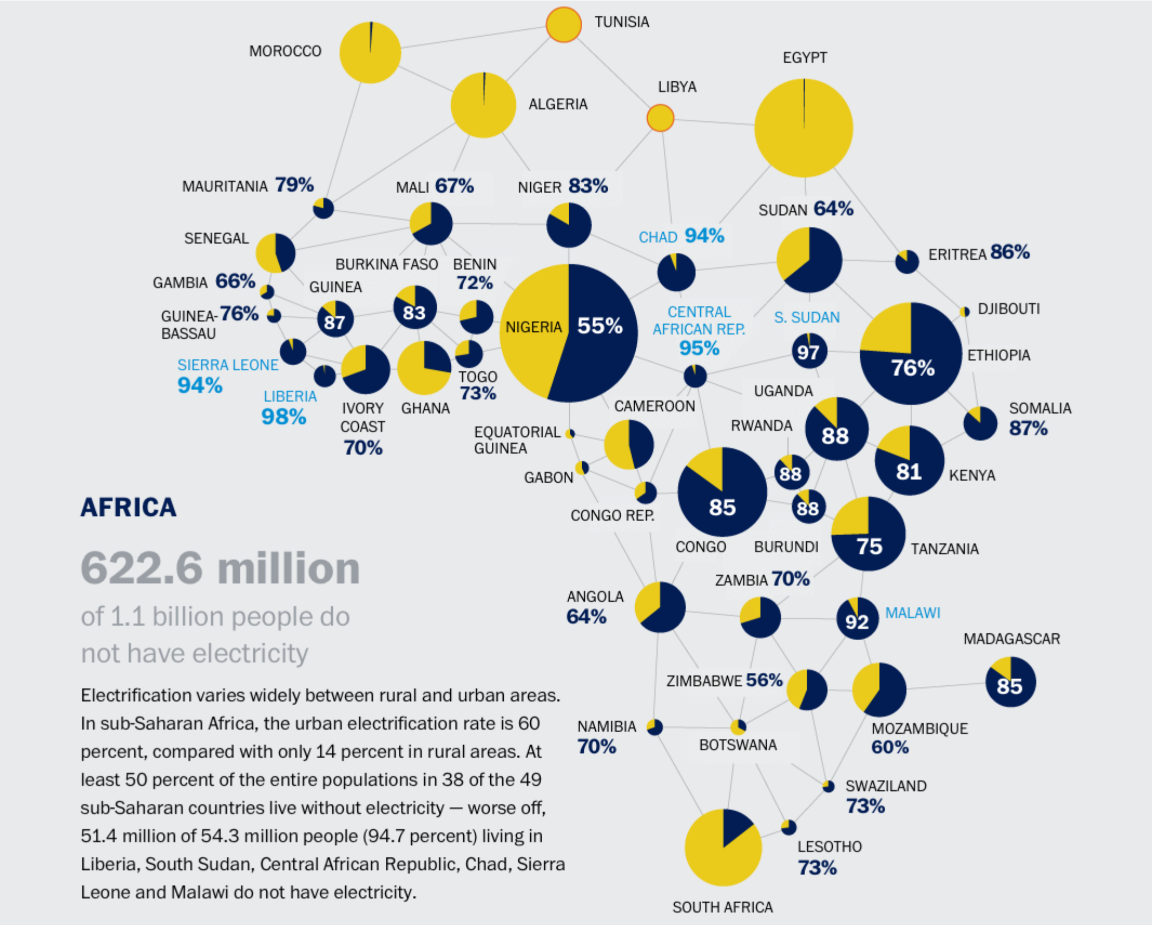
[32] http://www.greentechmedia.com/articles/read/turning-the-the-tide-on-outages

[33] http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/



Electrification varies widely between rural and urban areas. In sub-Saharan Africa, the urban electrification rate is 60 percent, compared with only 14 percent in rural areas. At least 50 percent of the entire populations in 38 of the 49 sub-Saharan countries live without electricity — worse off, 51.4 million of 54.3 million people (94.7 percent) living in Liberia, South Sudan, Central African Republic, Chad, Sierra Leone and Malawi do not have electricity.

Figure 1.26: Population access to electricity in Africa (Washington Post[34], source iea [27])

1.5 Smart Grid

1.5.1 History and Driver

The majority of the world's electricity system was built when the cost of energy was reasonably low and there was a near absent concern for the environmental protection. Since minor upgrading has been made to meet the rising demand, the grid still operates the way it did almost 100 years ago: energy flows over the grid from central power plants to consumers, and reliability is ensured by preserving surplus capacity (Frye 2008, Hossain et al. 2013). Consequently, today, most the electrical power systems are not eco-friendly. Because of their low energy efficiency and major dependence on energy generated from fossil fuels, they produce a high

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[34] https://www.washingtonpost.com/graphics/world/world-without-power/

amount of greenhouse gases. In addition, they are not adapted to the integration of renewable energy sources, and to meet the increase in the demand for energy.

The aging power grid faces new challenges such as higher demands, the lack of the grid's reliability with frequent outages in the recent years and a higher concern in the environment, particularly in the reduction of the greenhouse gas emissions. As a result, the electrical power system (generation, transmission and consumption) has been the focus of investigations to address the above challenges and to transform the power grid into a more efficient and reliable system. The digital revolution presents a great opportunity to achieve the goal of modernizing the conventional electrical system by transforming it into a "Smart Grid". The Smart Grid offers the possibility of greater monitoring and control of the power system and hence more effective, flexible, and lower-cost operation (Ekanayake et al. 2012).

1.5.2 Definition of the Smart Grid

Smart Grid does not have any single obvious definition. It combines several technologies, customer solutions and addresses several policy and regulatory drivers (Hossain et al. 2013).

The European Technology Platform[35] defines the Smart Grid as "An electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both—to efficiently deliver sustainable, economic and secure electricity supplies".

According to the U.S. Department of Energy[36], a "Smart Grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electrical system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources".

According to Hossain et al. (2013), the "Smart Grid can be described as the transparent, seamless, and instantaneous two-way delivery of energy information, enabling the electricity industry to better manage energy delivery and transmission

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[35] https://ec.europa.eu/research/energy/pdf/smartgrids_en.pdf

[36] https://www.smartgrid.gov/files/systems_report.pdf

and empowering consumers to have more control over energy decisions. A Smart Grid incorporates the benefits of advanced communications and information technologies to deliver real-time information and enable the near-instantaneous balance of supply and demand on the electrical grid".

1.5.3 Smart Grid Deployment

Figure 1.27 summarizes the digital layers, which should be implemented in the electrical power system for its transformation into a Smart Grid (Iea 2011[37]). It includes: Wide-area monitoring and control layer.

The Wide-area monitoring and control layer connects the generation, transmission and distribution components of the electrical system. It allows a real-time monitoring and display of power system components and performance across large geographic areas. It helps operators to understand and optimize power system components and performance. Thanks to advanced system operation tools, it prevents blackouts and facilitates the integration of variable renewable energy systems. It is also beneficial for data collection, decision-making, mitigating wide-area disturbances, and improving transmission capacity and reliability.

Information and communications technology integration layer

The Information and communications technology integration layer connects all the components of the electrical power system as well as all the customers (industrial, service and residential). It could include private utility communication networks (radio networks, meter mesh networks) or public networks (Internet, cellular, cable or telephone). It supports tow-way data transmission for deferred and real-time operation, and during outages. It allows the interaction with all the stakeholders for more efficient use and management of the grid.

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[37] https://www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf

Renewable and distributed generation integration layer

The renewable and distributed generation integration layer concerns all the components of the electrical power system as well as all the customers. It offers the possibility of an efficient integration of renewable and distributed energy resources.

Transmission enhancement applications layer

The transmission enhancement applications layer concerns mainly the transmission system. Flexible AC transmission systems are used to enhance the controllability of transmission networks and to maximize power transfer capability. It uses sensors to identify the current carrying capability of a section of network in real time; it can optimize utilization of existing transmission assets, without the risk of causing overloads. The use of high-temperature superconductors can significantly reduce transmission losses and enable economical fault-current limiting with higher performance.

Distribution grid management layer

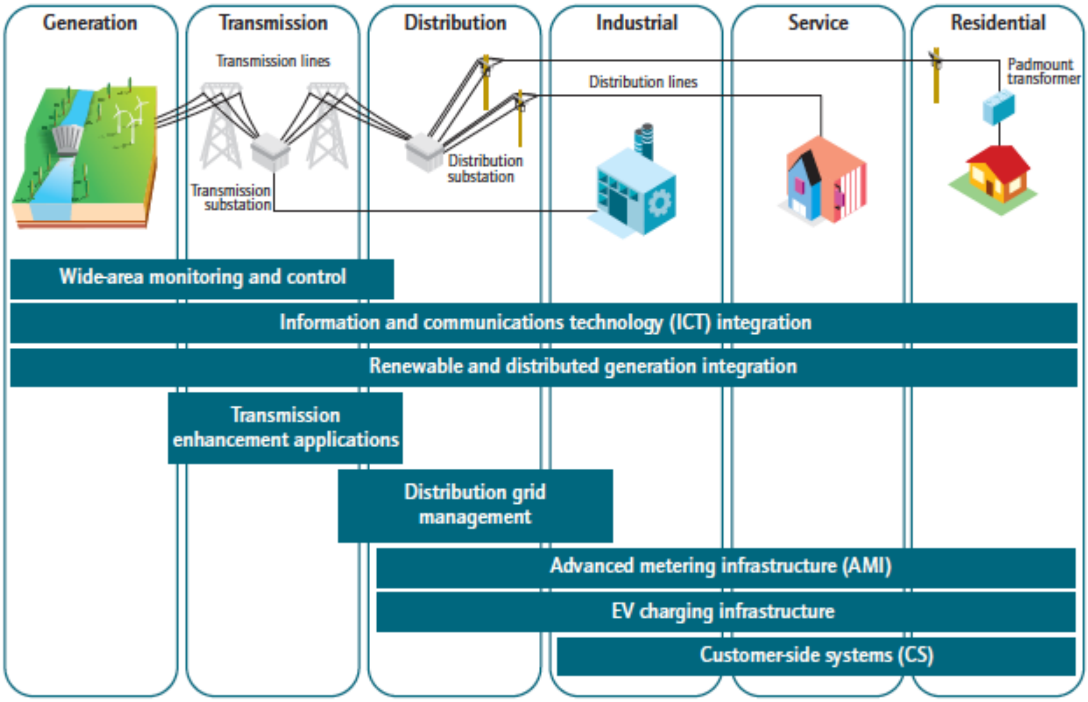
This layer uses distribution and sub-station sensing and automation to reduce outage and recovery time, maintain voltage level and improve asset management. Thanks to advanced distribution automation, the system processes real-time information from sensors and meters for fault location, automatic reconfiguration of feeders, voltage and reactive power optimization, or to control distributed generation.

Advanced metering infrastructure layer

This layer concerns the distribution component and the costumers. It includes the deployment of technologies that enable two-way flow of information, providing customers and utilities with data on electricity price and consumption, including the time and amount of electricity consumed. This layer can also provide (i) Remote consumer price signals, (ii) The possibility to collect, store and report customer energy consumption data for any required time intervals or near real time, (ii) Improved energy diagnostics from more detailed load profiles, (iv) Ability to identify location and extent of outages, (v) Remote connection and disconnection, and (vi) Losses and theft detection.

Customer-side systems layer

This layer concerns customers. This layer includes monitoring, smart appliance, software and platforms that enable customers to follow their consumption, to control their devices for an optimal management, and to beneficiate from incentive measurements such as dynamic prices, generation of renewable energy, energy storage.



Source: Technology categories and descriptions adapted from NETL, 2010 and NIST, 2010.

Figure 1.27: Smart Grid deployment (Source iea 2011)

1.6 Conclusion

This chapter included analysis of the literature concerning the Smart City and Smart Grids. Despite the recent development and application of these concepts, the literature concerning these issues is very rich and dense because it concerns large areas of today's major concerns (environment, quality of life, economic development, urban services, cities, governance) as well as large scientific areas (information and communication technology, engineering, social sciences).

The world challenge as to the population growth is of one of major pressure factor on the increase in the energy demand and greenhouse gas emission.

The environmental risks and challenges as well as the huge expected increase in the energy demand require a mutation in the way we are to deal with the energy. We must totally change the energy generation, transmission, distribution and consumption. This could be done through energy transition.

Cities are a principal concern in the world today. They host around 70% of the economic activity and are responsible of around 80% of the greenhouse gas emissions. With the vertiginous increase in the urban population, the roles played by cities in the environment, and our lives will yet expand. Since the city is a living complex system composed of multitude of complex sub-systems, the transformation of the city into a sustainable city (eco- and socio- friendly) requires edge- innovations that use both technology and social sciences. It requires a complete change in the way we manage the city to offer adequate and modern services for citizens and economic sector, in a world submitted to rapid changes and mutation.

The digital transformation through the revolution of the Internet, broadband data communication, social media, mobile, clouds computing and Big-Data offers today great opportunity to modernize the industry and services in building more efficient systems that optimize the design, the construction, the production, the maintenance and the relations with end-users.

The Smart City Concept is based on the application of the digital transformation in urban area. Since citizens are the focal point in the City, the Smart City concept combines the digital transformation with social issues such as governance and the implication of Citizens in the design and development of their City. This chapter presents a synthesis of works conducted in the Smart City; it explains the emergence of this concept, the methodology to be followed for its implementation and the standards related to the Smart City.

Finally, this chapter presents the Smart Grid concept, with a focus on how this concept transforms the traditional electric power system into a modern and efficient system. It also presents the digital layers to be developed for building a Smart City.

The literature survey shows that the Smart City and Smart Grids issues constitute today a great opportunity for the humanity to meet the environmental challenges and to build inclusive cities that focus on the quality of life of citizens. However, the Smart City and the Smart Grid concepts are complex and recent. Their implementation requires depth of knowledge gained from large experimentations and demonstrators.

The following chapters will present the construction of a large-scale demonstrator of the Smart City (SunRise Smart City) at the Scientific Campus of the University of Lille. After a brief presentation of the demonstrator SunRise, the Smart Grid side of this project is presented with details concerning the architecture of the grid as well as its monitoring properties, data collection and control. Analysis of the data consumption will be also presented as well as the recommendations for the improvement of the overall efficiency of the Grid.

Chapter 2

Presentation of the Scientific Campus Electrical Grid – Project SunRise

Table of contents

Chapter 2 Presentation of the Scientific Campus Electrical Grid – Project SunRise

This chapter describes the Electrical Grid of the Scientific Campus, which is used as a support for this research. As this research is conducted within a large scale demonstrator of the Smart and Sustainable City, project SunRise, which targets the construction of demonstrators of the urban networks (electricity, district heating, drinking water, sanitation, storm water and public lighting) at the Scientific Campus is presented; this campus stands for a town with around 25 000 inhabitants.

This is followed successively with the scientific campus, the electrical system of the campus, the management of the grid, and the data visualization.

2.1 SunRise Smart City project

The SunRise Smart City demonstrator was initiated in 2010 by a consortium of academic, industrial and local government partners to build a large-scale demonstrator of the Smart City, with a particular focus on urban infrastructures. Through this project, the SunRise consortium aimed to develop an international expertise, bringing together experts of governmental agencies, industry and academia, for the assessment of the environmental, economic and operational impact of the Smart City in improving the current state of practice and the city capacity building in the field of sustainability. The demonstrator was established at the Scientific Campus of the University of Lille, which stands for a town of about 25 000 inhabitants.

The originality of the SunRise project lies in the following:

- It concerns a large-scale experimentation conducted on a campus, which stands for a small town.
- It covers the totality of urban infrastructures as well as buildings.

- It is supported by a large partnership, including local government, urban services providers, industry and academia.
- It is used as a living lab for both research, education and PhD programs
- It is conducted within an international environment.

Figure 2.1 shows the platform of the SunRise Smart City Project. This summarizes the organization of this project and its management. The platform is based on a GIS-based urban information system, which includes the information concerning the campus networks asset (drinking water, sanitation, storm water, electrical grid and district heating) as well as all the buildings.

For each network, the information system includes all the components of the network, their attributes as well as the maintenance information. The data collected via the smart sensors is also stored in the information system.

The engineering and professional tools were established for the data analysis and their use for both the optimal management of the networks as well as their security. A webserver is used for the display of the data, using graphical tools. This webserver offers the possibility of displaying the networks and their interaction, the data concerning the consumption at different time and space scales, and the alert messages concerning the operating faults…etc.

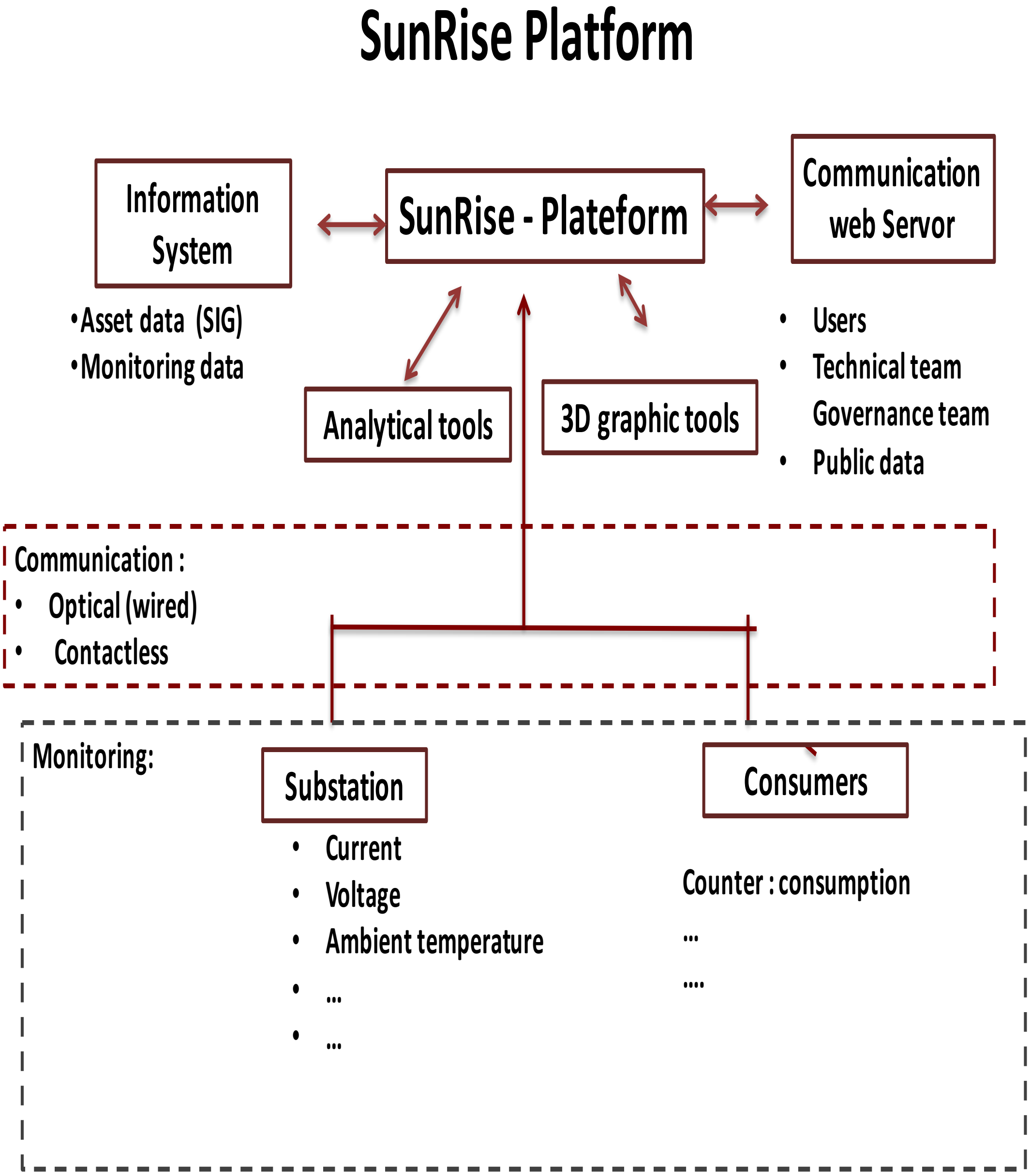


Figure 2.1 Platform of the SunRise Smart City project

2.2 Presentation of the Scientific Campus (SunRise Project)

The scientific campus of the University of Lille is located near the city of Lille, north of France. The campus stands for a small town of 110 Hectares and 25 000 users (Students, academic administrative and technical staffs) (Shahrour et aL, 2014; 2016, 2017). It was built between 1964 and 1966. Later, some buildings were renovated and others have been newly constructed.

Today the campus includes around 150 buildings (324,000 m²). Figure 2.2 shows the buildings of the campus. They can be classified according to their usage in the following categories:

- Administration and services (15%),
- Research (18%),
- Education (26%),
- Education & Research (22%),
- Student residence (15%)
- Restaurants (4%).

The age of the buildings varies between 1 and 50 years. However, the majority of these buildings are old with low energy performances.

Figure 2.2 Scientific Campus of the University of Lille, support of SunRise demonstrator (145 buildings, 325 000 m^2)

The campus includes important infrastructure with about 100 km of urban networks, which ensure urban services such as drinking water, storm water, sanitation, electricity, public lighting, district heating and transport (Figure 2.3).

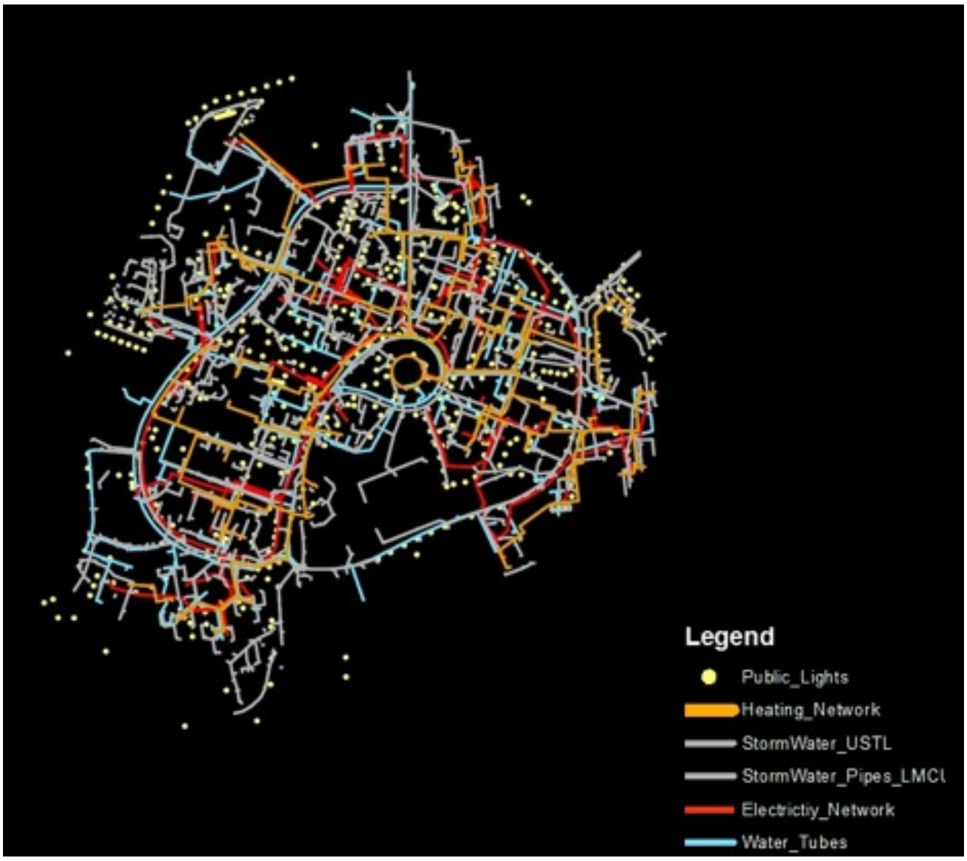


Figure 2.3 Urban networks of the Campus of Scientific City (100 km of urban networks ensuring the water, energy and transport services).

2.3 Presentation of the Electrical System of the Campus

2.3.1 General presentation

The electrical system ensures the distribution of the electricity for all the buildings and facilities of the campus. It is completely managed by the technical staff of the university. Figure 2.4 shows the architecture of the electrical system. It is composed of:

- A supply station
- A High Voltage grid (HV)

- Substations
- A Low Voltage Grid.
- Advanced Metering Infrastructure

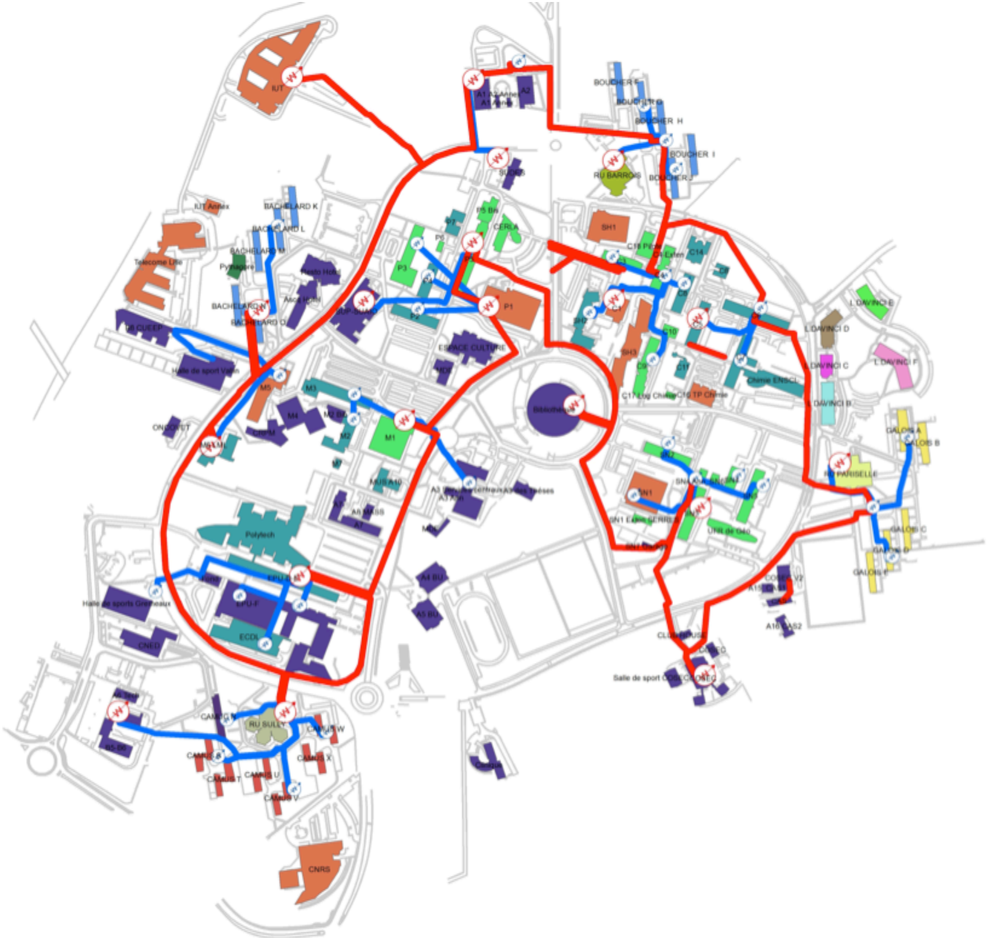


Figure 2.4 Electrical system of the campus

The supply station of the campus is located in building A2, north of the campus; the French Electrical Company supplies it with 20 kV. The High Voltage Grid at 20 kV then transmits the electrical power to the remaining substations. The substations include transformers, which transform the high voltage power to low voltage power (220 or 440 V) to supply the buildings and the facilities through the Low Voltage Grid (LV).

The High Voltage Grid, including the substations, was completely renovated in 2012. The Low Voltage Grid remained unchanged, with the same low performances.

All the data concerning the electrical system were collected, geo-localized and integrated into the SunRise GIS system, which also includes all the data concerning the campus infrastructure. Figure 2.5 shows the 3 layers of the GIS – System related to the electrical system: High Voltage Grid, Low Voltage Grid and Communication Network.

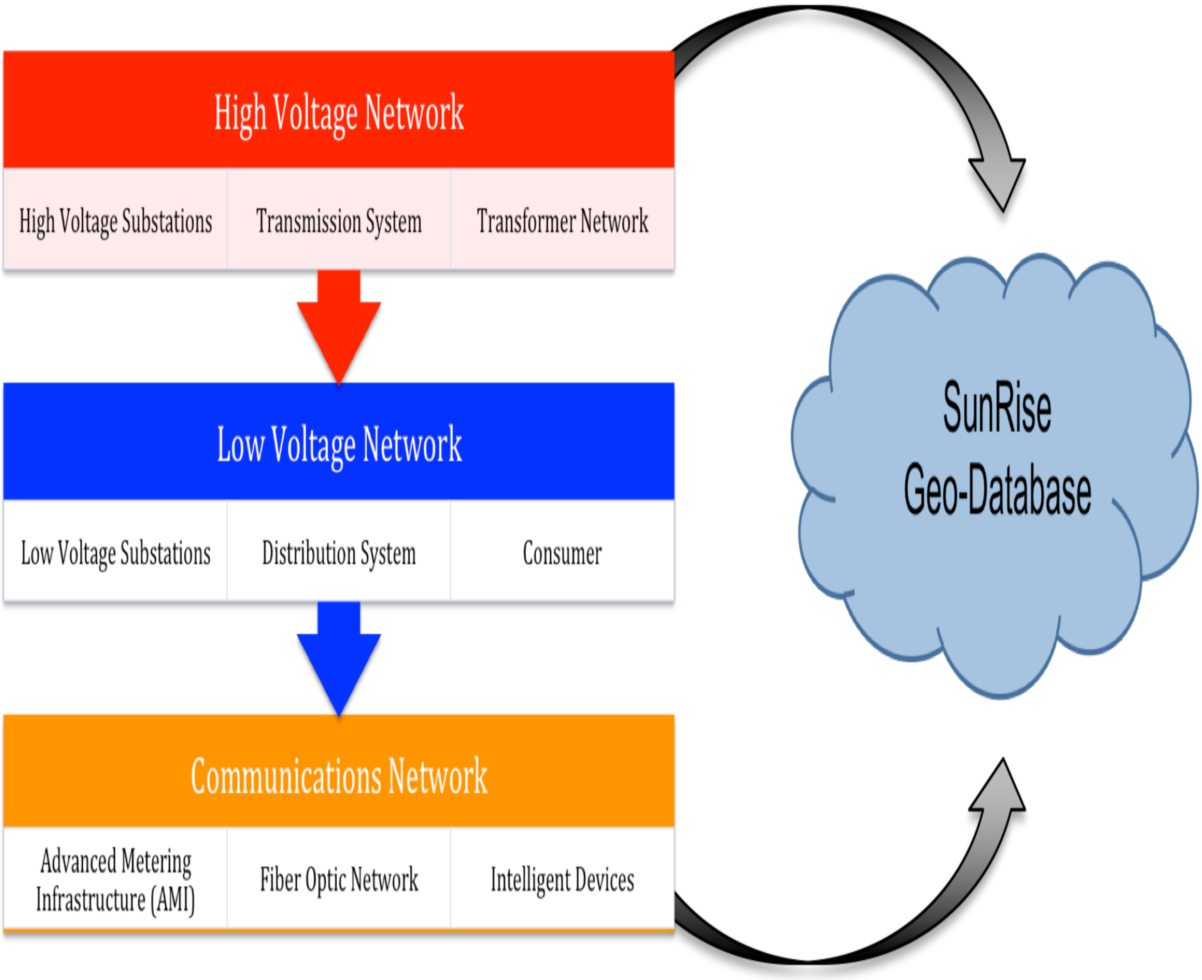
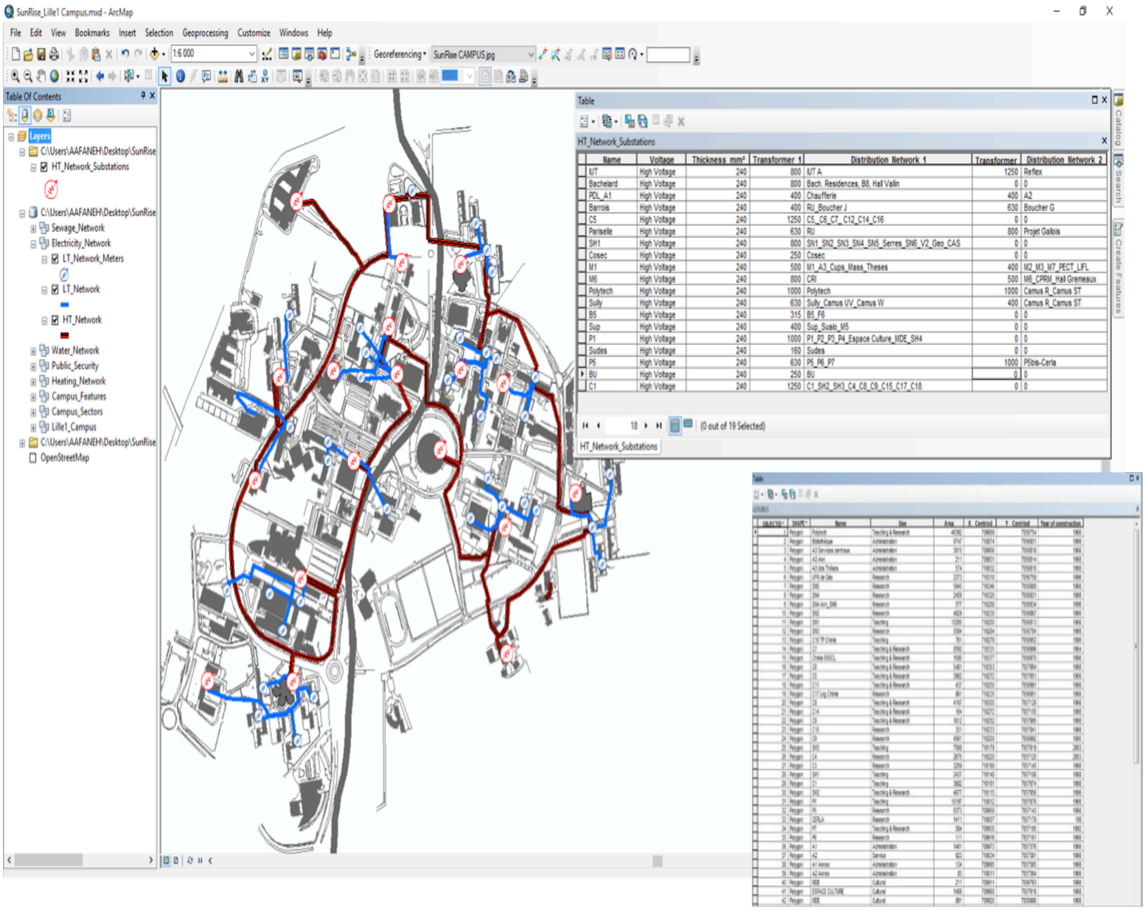


Figure 2.5 Layers of the Electrical system in SunRise GIS system

Each layer includes all the information (attributes) of all the components of the layer as well as their geo-localization.

Users can access all this information and benefit from all the facilities and tools of the GIS system for the data analysis and visualization. They can also cross-reference the information of the electrical grid with data concerning other networks or systems. Figure 2.6 shows an example of the data editing and visualization using the GIS system.



HT_Network_Substations

Name	Voltage	Thickness mm²	Transformer 1	Distribution Network 1	Transformer	Distribution Network 2
IUT	High Voltage	240	800	IUT A	1250	Reflex
Bachelard	High Voltage	240	800	Bach. Residences, B8, Hall Valin	0	0
PDL_A1	High Voltage	240	400	Chaufferie	400	A2
Barrois	High Voltage	240	400	RU_Boucher J	630	Boucher G
C5	High Voltage	240	1250	C5_C6_C7_C12_C14_C16	0	0
Pariselle	High Voltage	240	630	RU	800	Projet Gallois
SH1	High Voltage	240	800	SN1_SN2_SN3_SN4_SN5_Serres_SN6_V2_Geo_CAS	0	0
Cosec	High Voltage	240	250	Cosec	0	0
M1	High Voltage	240	500	M1_A3_Cups_Mass_Theses	400	M2_M3_M7_PECT_LIFL
M6	High Voltage	240	800	CRI	500	M6_CPRM_Hall Gremeaux
Polytech	High Voltage	240	1000	Polytech	1000	Camus R_Camus ST
Sully	High Voltage	240	630	Sully_Camus UV_Camus W	400	Camus R_Camus ST
B5	High Voltage	240	315	B5_F6	0	0
Sup	High Voltage	240	400	Sup_Suaio_M5	0	0
P1	High Voltage	240	1000	P1_P2_P3_P4_Espace Culture_MDE_SH4	0	0
Sudes	High Voltage	240	160	Sudes	0	0
P5	High Voltage	240	630	P5_P6_P7	1000	P5bis-Cerla
BU	High Voltage	240	250	BU	0	0
C1	High Voltage	240	1250	C1_SH2_SH3_C4_C8_C9_C15_C17_C18	0	0

18 (0 out of 19 Selected)

HT_Network_Substations

Figure 2.6 Example of data visualization using the GIS electrical system

2.3.2 Electricity tariff

The French Company of Electricity (EDF) supplies electricity. The electricity tariff includes 5 rates, which depend on the month and the hour of consumption. Figure 2.7 shows the time intervals for the 5 rates. The tariff could be summarized as follows:

Peak hours (tariff 10.893 c€/kwh):

- December to February (8:00 -10:00 and 17:00- 19:00)

Winter high-rate hours (tariff 6.635 c€/kwh):

- December to February (6:00-8:00 10:00-17:00, 19:00 – 22:00)
- March and November (6:00-22:00)

Winter low-rate hours (tariff 4.474 c€/kwh):

- November to March (22:00-6:00)

Summer high-rate hours (tariff 4.125 c€/kwh):

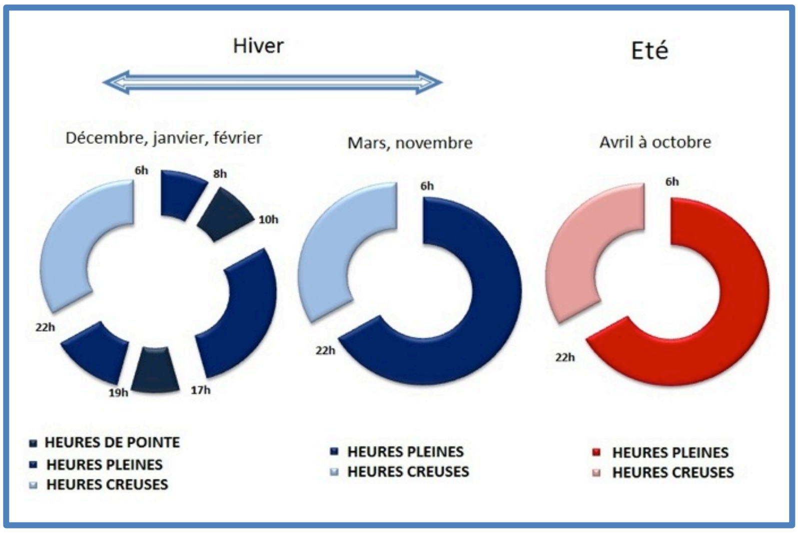
- April to October (6:00-22:00)

Summer low-rate hours (tariff 2.580 c€/kwh):

- April to October (22:00-6:00)

It can be noticed that the tariff rate varies considerably during the day. In winter, it varies from 4.474 c€/kwh to 10.893 c€/kwh; while in summer, it varies from 2.580 c€/kwh to 4.125 c€/kwh. This high variation shows the necessity to explore the possibility of the use of high-consumption facilities during the low-rate time intervals.

Figure 2.7 Electricity tariff rates for the campus (5 rates)



2.3.3 High Voltage Network

Figure 2.8 shows the high voltage network. It includes the high voltage liners, which transport the electric power at 20 kV. The liners connect all the substations to the supply station. It is composed of two loops. The first one starts from the supply station (Building A2) and supplies all the substations in the east and the south sections of the Campus. The second supplies the substations in the Northwest up to the substation M6, where it meets the first loop.

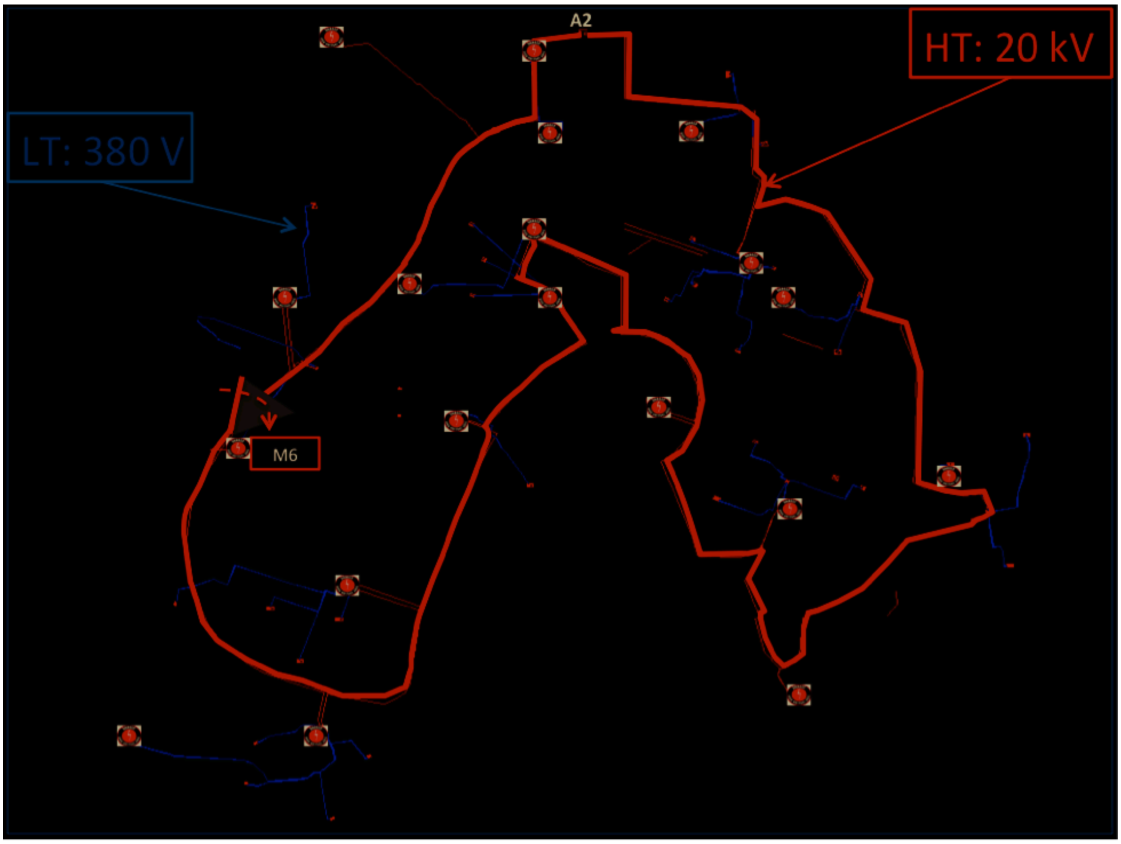


Figure 2.8 High Voltage network of the Scientific Campus

2.3.4 Substations

The High Voltage Grid includes a main substation (building A2-supply station) and 19 other substations, which are installed in the following buildings:

- Administrative buildings: SUDES, SUAIO, A, COSEC
- Restaurants: Barrois, Pariselle, Sully
- Residence: Bachelard
- Academic buildings: M1, M6, P1, P5, C5, BU, SN3, Polytech, B5, IUT.

Figure 2.8 shows the location of these stations at the Scientific Campus. Each substation includes a high-voltage component (Figure 2.9) and a low-voltage component (Figure 2.10), as well as the digital devices needed to execute the necessary tasks.

The high-voltage component has two roles. The first role is to receive the 20kV electrical power, and transmit it to the next substation on the loop, thereby continuing the flow of the HV-loop network. The second role is to receive the 20kV and to step-down the voltage to 380V via the substation's transformer, and then distributes the stepped-down voltage to its neighboring buildings via the Low Voltage (LV) network. A substation might have one, or two transformers depending on its load; some substations deliver power to a single neighboring building, while others deliver the load to up to 10 buildings.

Reaching the TGBT, the stepped-down 380V voltage makes its way to the buildings in its distribution network; the thicknesses of the wires can vary throughout the campus between 90mm^2 and 300mm^2.

The transformers do not function at 100% capacity, but at around 80%. The motive behind this is to avoid problems, such as overheating. The transformers function with losses of about 10%.

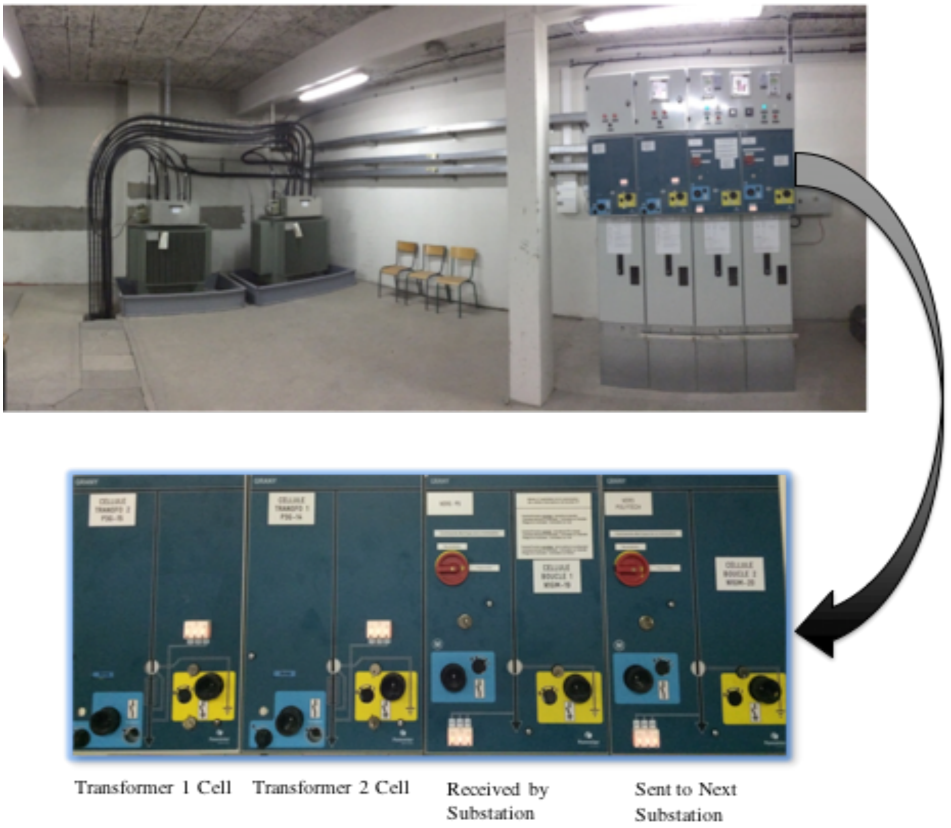


Figure 2.9 : The High Voltage component of the Substation

Figure 2.10 : The Low Voltage component of the Substation

2.3.5 Low Voltage Network

The Low Voltage network refers to the distribution network (secondary network) that supplies the buildings after the transformation of the electric power from High Voltage to Low Voltage takes place at the substations.

The campus is organized into sectors. Each substation is responsible for delivering electricity to its neighboring buildings (depending on the load of the building). Therefore, each building on the Low Voltage Network is connected, and is able to communicate with the main control unit that operates the grid.

Similar to the High Voltage Network, all the parameters of the low voltage network are geo-referenced and integrated into the SunRise database. Figure 2.11 shows this network. Lines in blue indicate the Low Voltage Network that connects the campus buildings and facilities, to the substations.

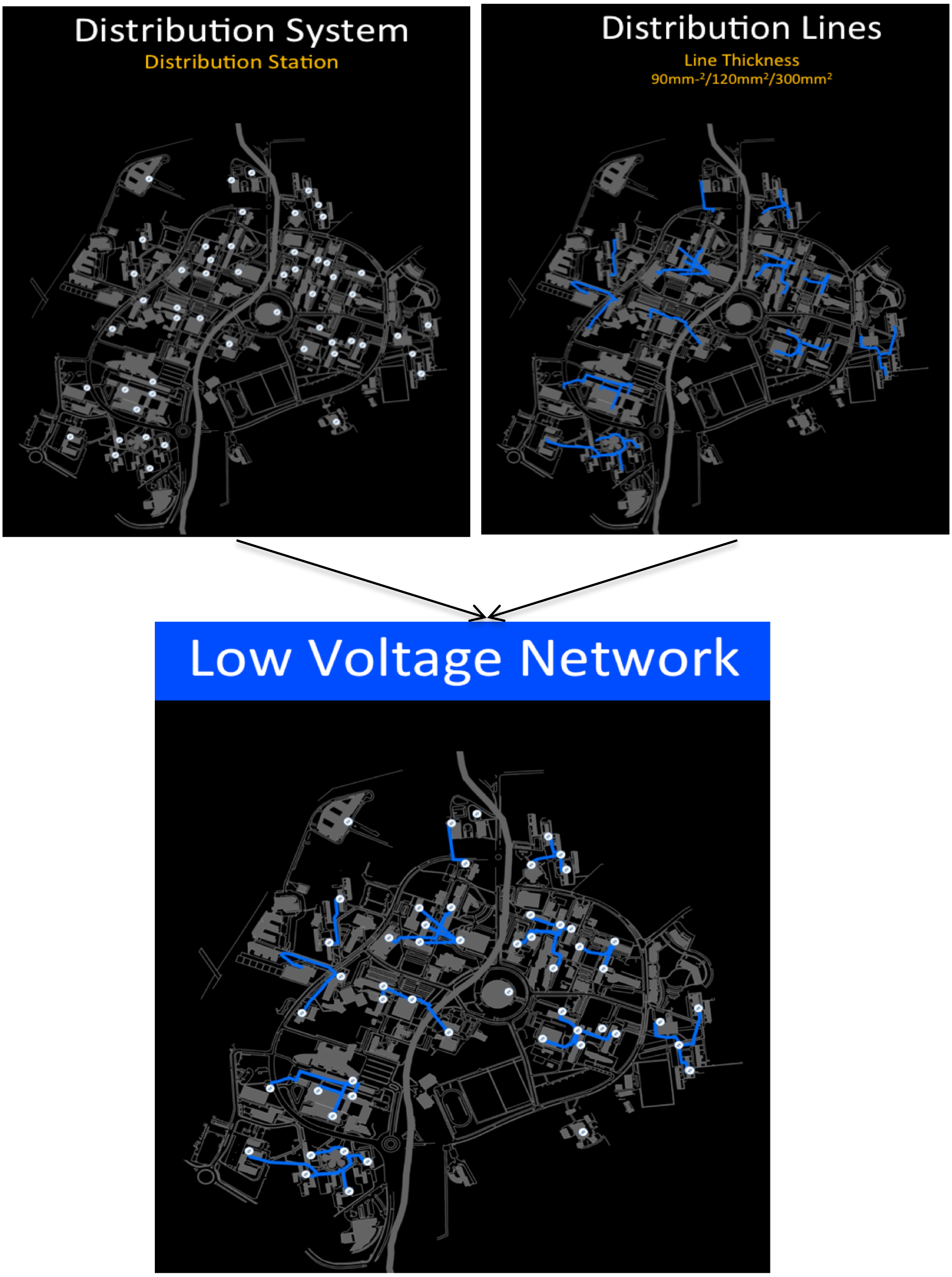


Figure 2.11 Low voltage network of the Scientific Campus

2.3.6 Data communication

Figure 2.12 shows the entire electrical grid as well as the fiber optic communications network, which is responsible for data transmission. The two-way fiber optic communications network gives the central server access to the totality of the smart sensors and switches in the substations. The electronic switches can be automatically controlled (open/closed) by the server, as well as by the network manager (remotely/on-site), who can configure, monitor and manage the network remotely.

The fiber optic network is the basis for the two-way communication between the control system and the smart meters located in substations as well as in the buildings. The fiber optic network lines move in parallel with the High Voltage Network, passing through each of the H.V substation. Fiber-optic communication is what is used for communication between the H.V substations, distribution stations and the buildings (end-users).

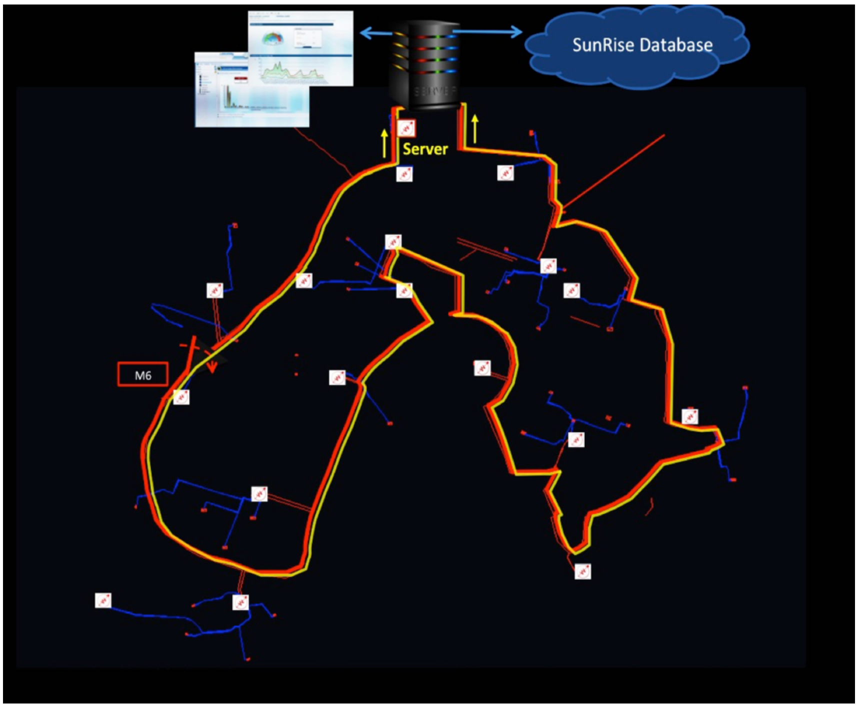


Figure 2.12 The electrical system of the Scientific Campus (red: High voltage network, blue: Low Voltage network, Yellow: Fiber optic communications network).

This allows the main server to communicate with all the buildings located on the campus. The fiber optic network is connected to the output of the smart meters (located in the low voltage distribution panel), through the use of the Lynx-110 and EWD-100 devices. The EWD-100 device is a serial-to-Ethernet switch, which enables communication to and from serial devices over a wired, or wireless Ethernet network (serial to TCP/IP conversion).

The smart meters monitor the electrical consumption, along with the following parameters, which are used for the supervision and the control of the electrical grid:

- Consumption
- Voltage
- Current
- Power (P, Q)
- pf
- Frequency

2.4 Management of the Electrical Grid

2.4.1 Management System

The Electrical Gird is managed using the MicroEner's S.I.R.A.C.U.S system for the automatic reconfiguration of the High Voltage Grid. This system restores operation to the high voltage 'loop' network, by identifying and locating the fault, as well as isolating the affected area and re-routing transmission, thereby healing the system quickly and efficiently.

The grid is equipped with motorized breakers that can be controlled remotely by the SIRACUS II, which includes:

- **Grid Manager**: Isolates the grid, by default, and then reconfigures it upon request.
- **IM30/AP** Protective Relays: They serve to protect from phase errors.

- **MC20 Indicators:** They only indicate fore mentioned phase errors.
- **MX14/5 Connection Managers**: They serve to connect two breaking elements with a single connection.
- **Transformers:** used to step-down the voltage for the relays and indicators.
- **EDW100 & LYNX110:** These devices are responsible for converting the electrical signals from the sensors (smart meters), and relays, in to the needed fiber protocol to be transmitted through the fiber-optic communications network. They all communicate together using MODBUS RTU protocol with the grid manager being 'master' and the rest of the devices being 'slaves', only transmitting data when asked to do so. The data then makes its way through the fiber optic communications network to the data management system.

The system could be controlled manually or automatically. In the manual control, the system indicates the location of the error and vital measurements is taken constantly, but no action is taken unless the controller (person in charge of the network) enforces it.

In the automatic control, the system detects the error, isolates it, redistributes power to effected sector and reconfigures the system to fix the fault; if successful, it powers it back on.

This mode has 3 states:

a. **Normal**: when an error is detected, a command is sent to the IM30/AP to close that substation and the MC20, in accordance with their respective MX14/5, relays that error back to the manager, which in turn cuts off the relay before and after said substation, killing all power running through it. The system then resets the faulted substation.

b. **Degraded:** it's the same process as with the Normal mode, but instead of isolating the substation immediately the system kills the whole site and then searches through it, substation by substation to find the error and fix it.

c. **Surveillance:** this mode is triggered when an error is detected but the breaker corresponding to that substation was not triggered. The substation will then be put under surveillance until further action takes place.

During these proceedings, the network manager(s) are made aware of the situation. Once the fault is located, two actions simultaneously take place. First, the server commands the electronic switches in the substation to open, thereby isolating it from the rest of the grid. Then, the network's principle switch is closed, thereby re-routing power to the damaged area via the unaffected side of the H.V loop-network, thus giving the system self-healing, safe, smart, efficient and reliable characteristics.

2.4.2 Grid Security

In the normal operating mode, the principle switch between the two loops of the grid, which is located in building M6, is normally open (Figure 2.13). The substations are supplied by one of the two loops.

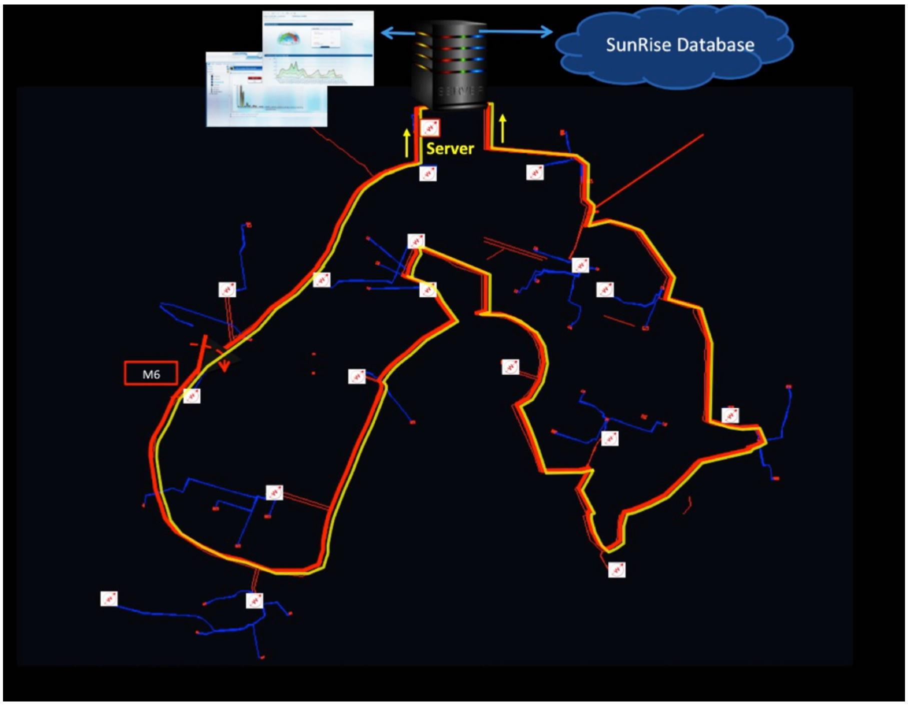


Figure 2.13 Normal operation mode of the Electrical Grid.

If a fault occurs at any substation, the following operations are automatically conducted:

- The concerned substation is identified and located;
- This substation is isolated from the grid using the local switches; and,
- The switch of the substation M6 is closed in order to supply the substations located between the substation M6 and the isolated substation.

Figure 2.14 summarizes the operations conducted automatically by the system, immediately after the occurrence of a fault.

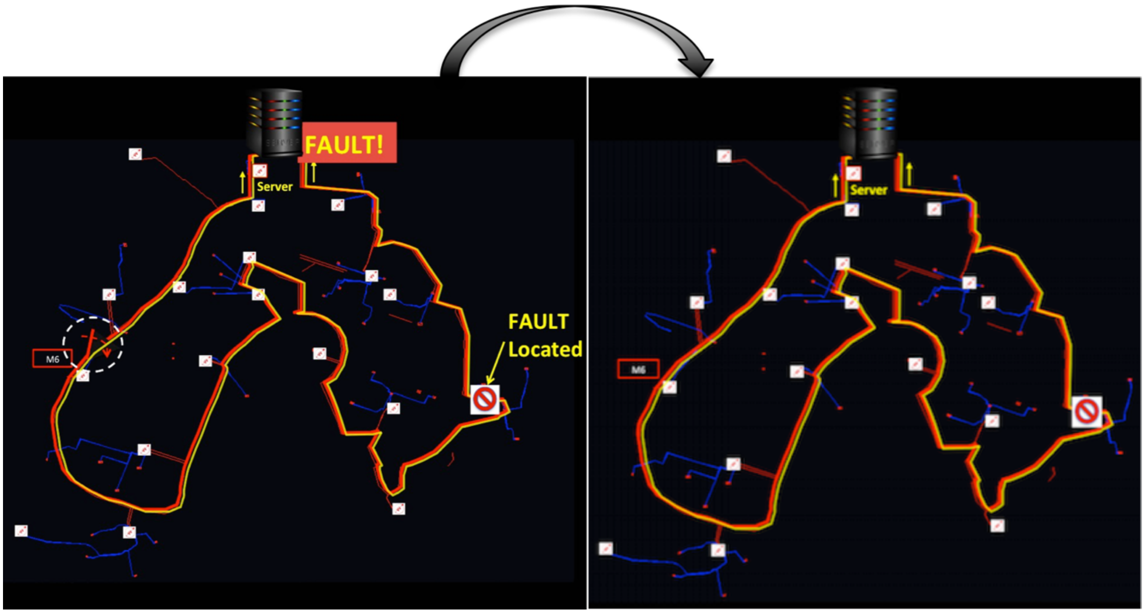


Figure 2.14 Operations conducted by the system immediately after the occurrence of a fault

2.5 Data visualization

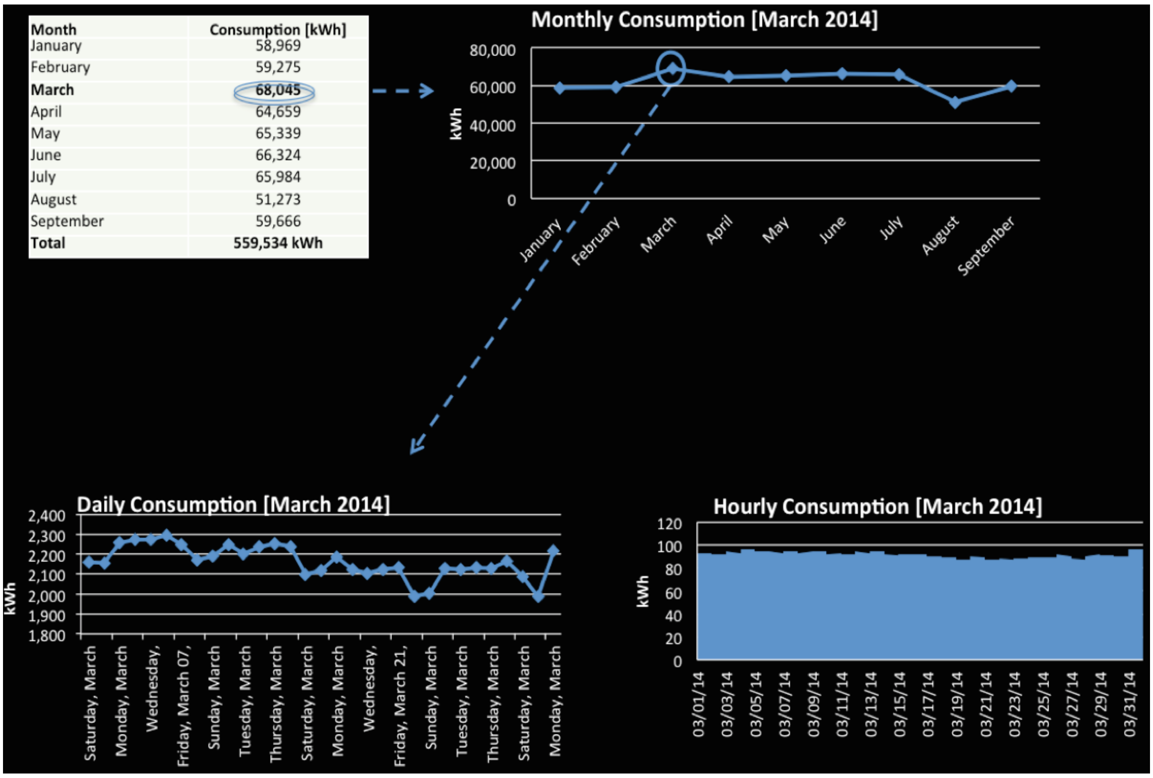
The data concerning the electrical system is accessible via a Webviewer using any standard Internet browser on any terminal. It provides the campus's consumption data

(HV & LV networks) at different times intervals (yearly, monthly, weekly, daily or hourly).

The Vertelis Webviewer ensures the real-time monitoring of the electrical grid by the Socomec devices through:

- Historical measurements
- Configuration of network's main parameters
- Configuration of the HV-Loop network (ex: configuration of the principle switch)
- Statistical data (min, max, average, etc.)
- Monitoring electrical values (voltage, current…etc.)
- Events related to energy quality
- Status of the system
- Managing Alarms
- Viewing and extraction of load curves
- Export of reports (xls, pdf…etc.)
- Analysis and Extraction of quality data
- Fault current monitoring (residual current monitoring)
- Consumptions that cannot be measured can be deducted through calculations (virtual counters)

Figure 2.15 shows an example of visualization of the electrical consumption at 3 time-intervals: hourly, daily and monthly. These curves could be established for any building or group of buildings at any time.



Month	Consumption [kWh]
January	58,969
February	59,275
March	**68,045**
April	64,659
May	65,339
June	66,324
July	65,984
August	51,273
September	59,666
Total	**559,534 kWh**

Figure 2.15 : Illustration of the data (daily: Maximum, Minimum and Min) concerning the electrical consumption (March 2014)

Figure 2.16 illustrates another example of data illustration. It concerns the variation of the electrical current in the period from September to November 2014. For each day, it shows the maximum, minimum and the mean value of the current. Figure 2.17 shows the electrical consumption of a group of buildings ranked according to the value of their consumption.

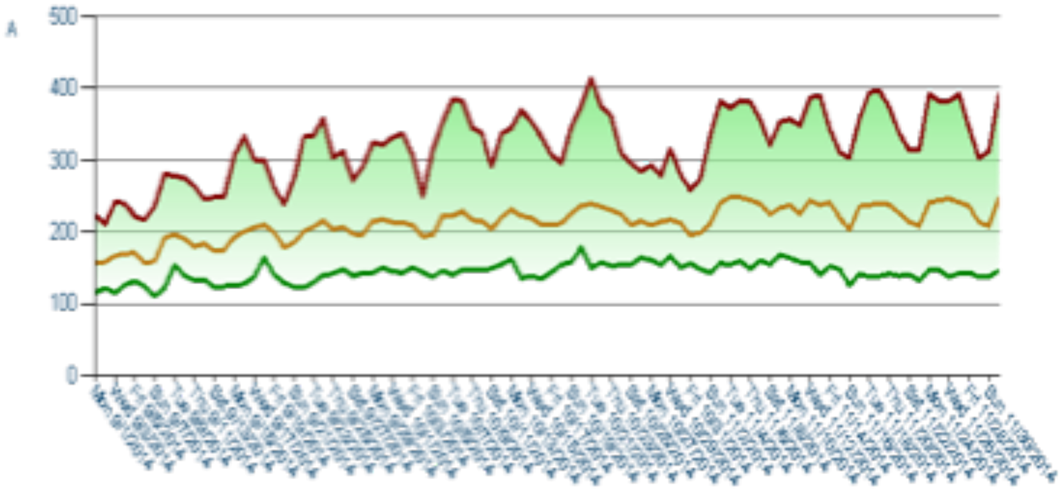


Figure 2.16: Illustration of the data (daily: Maximum, Minimum and Min) concerning the electrical current (September – November 2014)

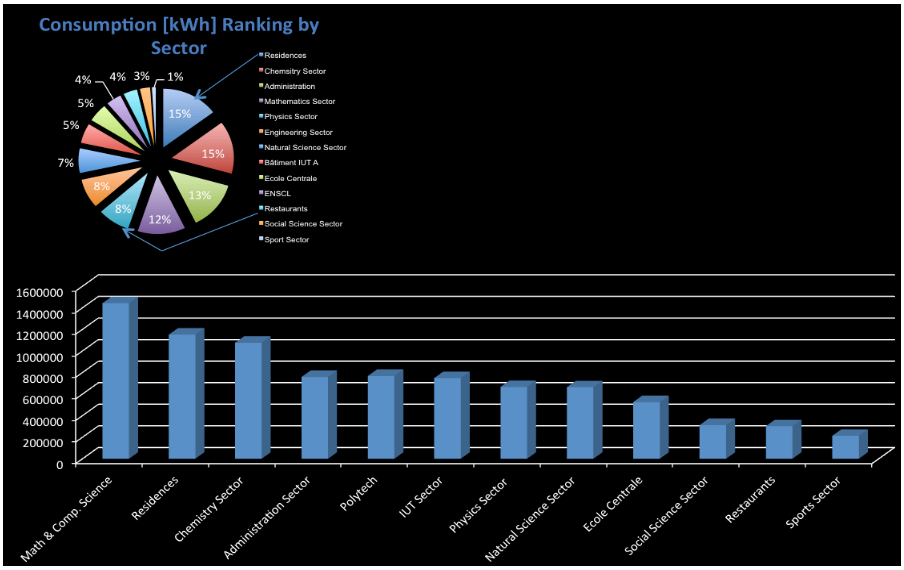


Figure 2.16 : Ranking of the buildings according to their electrical consumption

2.6 Conclusion

This chapter included a presentation of the electrical grid of the Scientific Campus of the University of Lille, which is used as a support for this research; it is conducted within the project SunRise, which aims at the transformation of the Scientific Campus into a large-scale demonstrator of the Smart and Sustainable City. The originality of the project

SunRise lies in the smart monitoring of all the urban networks and the collection and analysis of all the data in the same platform.

The Scientific Campus stands for a town of around 25 000 inhabitants. The electrical system supplies around 150 buildings and facilities, which ensure a variety of services such as research, learning, administration, catering (restaurants), sports and residences. It includes a High-Voltage Network, substations, transformers, a Low-Voltage Network as well as smart sensors and switches that allow an automatic control of the Grid.

The High Voltage Grid was renovated in 2012. It resulted in smart substations that allow, in the case of a local fault, the isolation of this fault and the reconfiguration of the grid in order to ensure the supply continues to the unaffected areas of the grid. The grid is controlled via a management system that allows a manual or automatic control procedure.

A great amount of data concerning the electrical system has been presented; in the following chapter, this data as well as their analysis are delineated in order to understand the electrical system operating process.

The electrical consumption constitutes an important issue for the University; we will analyze this consumption in order to explore the sources of energy saving as well as the sources of reduction of energy losses.

Chapter 3

Analysis of the Electrical Consumption of the Scientific Campus

Table of contents

Chapter 3: Analysis of the Electrical Consumption of the Scientific Campus

The application of the Smart Technology to the electrical grid aims to improve the safety and efficiency of the grid as well as reducing the energy consumption. The electrical grid of the scientific campus offers great opportunity to apply this technology at a large-scale test site, and to develop new tools, knowledge and expertise in this area.

Since the electrical grid of the university supplies all the buildings of the campus and sensitive research tools, the SunRise team did not deal with the operating security of the grid. The work focused on the performances of the grid through analysis of the consumption to explore the possibilities of reducing this consumption and improving the global performances of the electrical system.

This chapter presents first the methodology developed for the data analysis including all the steps of this methodology: (i) record of the electrical consumption and transmission to the electrical grid server, (ii) Data transmission to SunRise server, (iii) data cleaning and storage, and (iv) construction of buildings' consumption profiles and analysis of the consumption.

This methodology is applied to the analysis of the global consumption of the campus and buildings.

3.1 Introduction

Analysis of the electrical consumption constitutes a major concern in the management of the scientific campus. It aims at studying the consumption of each building of the campus in order to establish its consumption profile and then to analyze this profile regarding both the physical characteristics of this building, and its usage. This analysis will enable the technical team of the campus to detect any anomaly in the consumption, to explore the possibility of reducing this consumption and then to track in real-time any abnormal event related to the electrical consumption. This work could be conducted on any group of buildings, such as the main sectors of the campus: social sciences, natural science, mathematics and computer science, physics, chemistry, engineering schools, administration, restaurants and residences (Fig. 3.1).

This chapter presents the methodology established for the consumption analysis, including data collection, storage and data analysis. Then it presents the application of this methodology to the analysis of the global consumption of the campus as well as the consumption of some typical buildings, and finally some recommendation for the reduction of the campus' consumption.

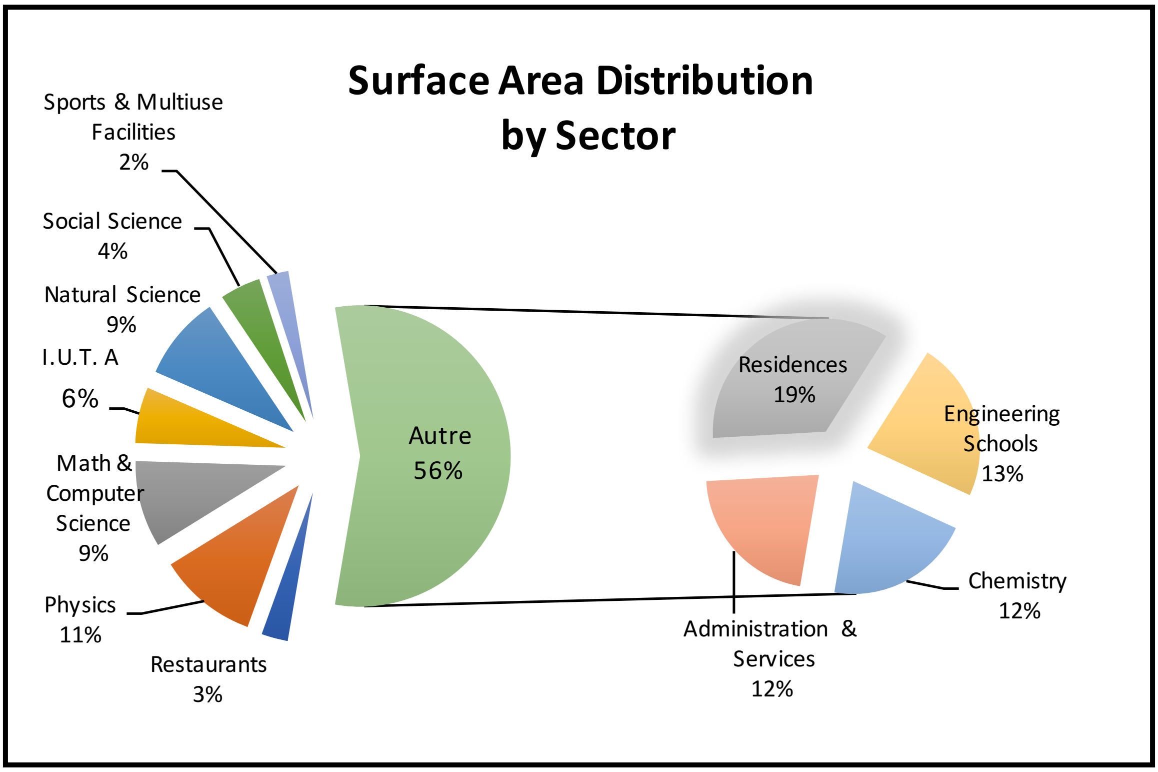


Figure 3.1. Main Sectors of the Scientific campus

3.2 Methodology of consumption analysis

The methodology established for the consumption analysis is based on the collection of data from the electrical consumption meters integrated in High Voltage and Low Voltage substations, followed by the analysis and display of the data. Figure 3.2 shows the methodology established for the analysis of the electrical consumption of the scientific campus. It includes the following three steps:

- Record of electrical consumption and transmission to the electrical grid server.
- Data transmission SunRise information system.
- Construction of the consumption profile and analysis.

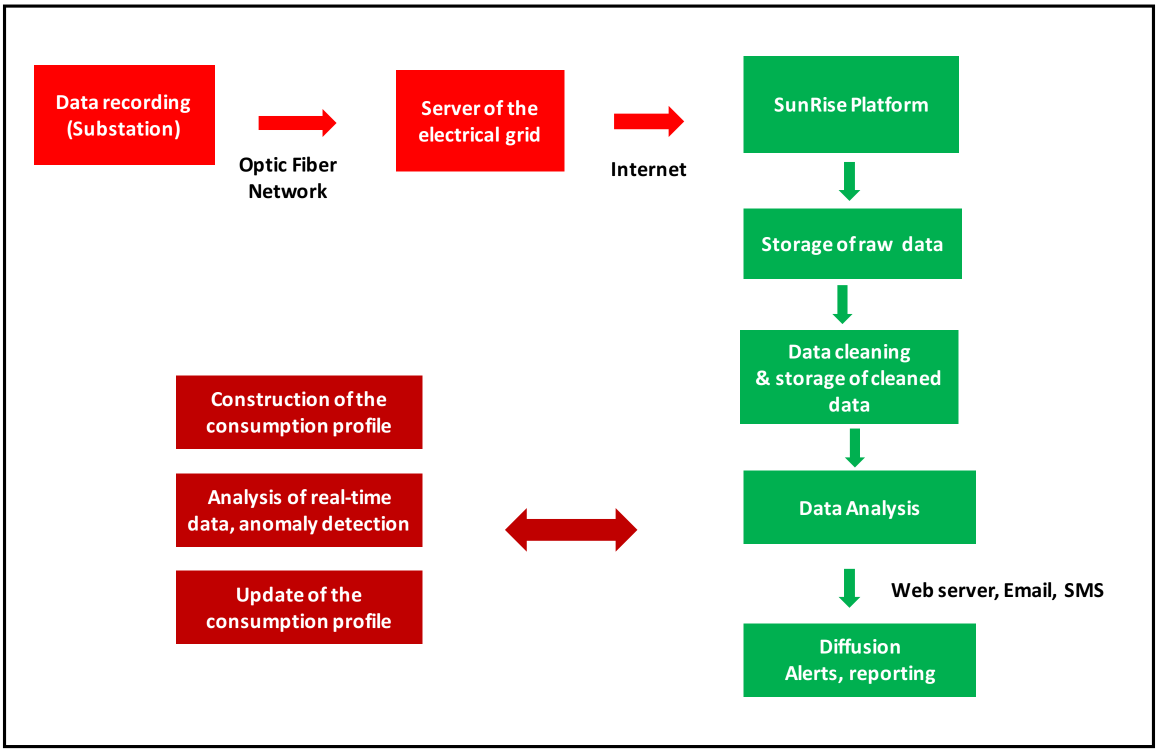


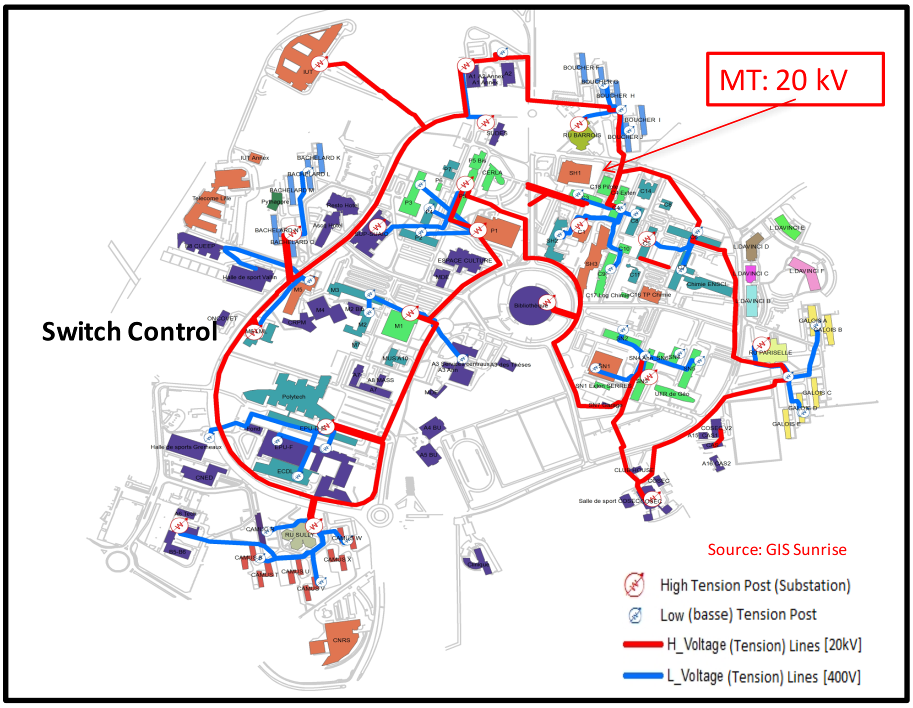
Figure 3.2. The methodology established for the analysis of the electrical consumption

The following sections present and discuss these steps.

3.2.1 Record of the electrical consumption and transmission to the electrical grid server

The first step concerns the measurement of the electrical consumption by the electrical meters installed in the substations and buildings. Figure 3.3 shows the localization of the substations on the campus. Each substation also records other parameters related to the electrical grid such as the current, voltage, frequency and temperature.

The substation also ensures the control of the electrical grid through switches. It can isolate the substation from the electrical grid in case of any local fault. The frequency of which the data is recorded is by 10-minute intervals; moreover, the grid is constantly being monitored. This high frequency is necessary to ensure the safety of the electrical grid: immediately detect any local fault and confine it before its extension to the grid.



Source: GIS Sunrise

Figure 3.3. Localization of the electrical substations, which record the electrical consumption as well as as other paremters related to the management of the grid.

Recorded data are transmitted to the server using the fiber-optic capabilities of the electrical grid. The server ensures the management of the electrical grid, particularly the supervision of the grid and rapid intervention in the occurrence of any irregular event, or fault, which could disturb the stable functioning of the grid as well as cause an electrical outage. Since this part of the is very sensitive, and it controls the electrical supply of the campus buildings, infrastructures and research devices, SunRise team did not work on the server.

3.2.2 Data transmission to SunRise server and storage in the SunRise Information System

Data recorded in the electrical grid server are transmitted to SunRise server, using the Internet. Data is pushed from the server of the electrical grid to SunRise server. The platform stores the raw data in SunRise information system by updating the historical data in the platform.

Since data could include some imperfections, which could result from measurement, recording and transmission errors, we proceed to the data-cleaning phase as follows (Figure 3.4):

(i) Verification of all data over the observed period. In the case of absent of data, the term “lost data” is added to the file. The determination of the “lost data” could be carried out using provisional models, based on advanced methods such as the Artificial Neural Network, trained on historical data or using statistical methods. However, since the absence of data for the consumption analysis is not critical, this method was not developed for this work.

(ii) Verification of data value. This verification could be easily conducted using the building consumption profile, which will be presented here. If the data does not match the consumption profile, the technical staff of the university is informed through email and SMS. The mention “out of range data” is added in the data base, which means that it requires additional analysis.

The “cleaned” data is stored in the information system of SunRise. It could be updated with the arrival of new data to replace the “lost data” or “out of range data”.

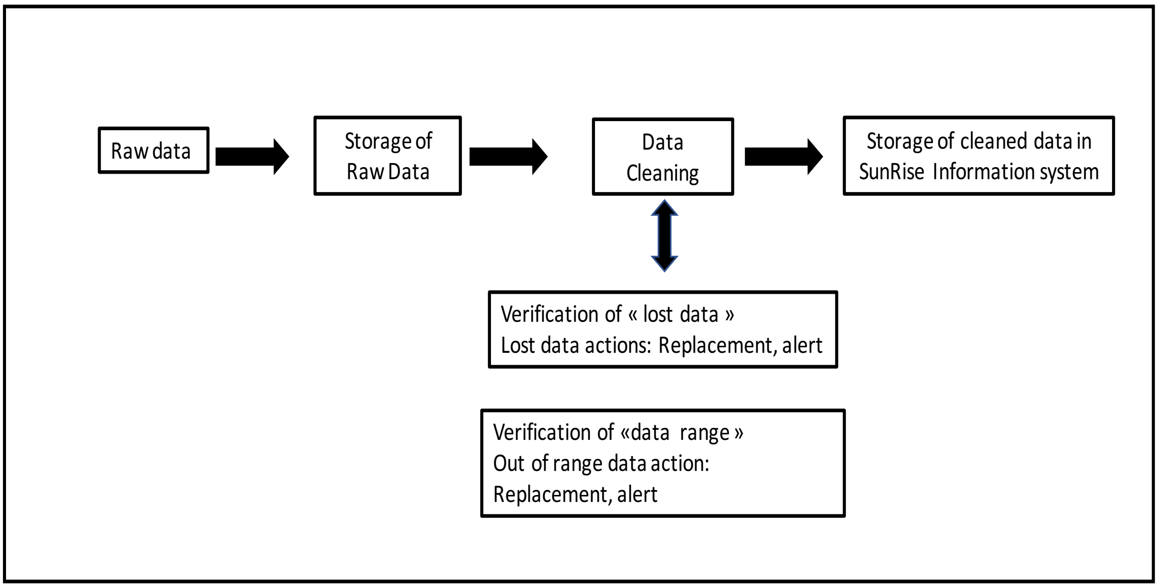


Figure 3.4. Data processing and storage in the SunRise platform

3.2.3 Construction of the consumption profile

The construction of the consumption profile constitutes an important step in the analysis of the consumption of any building or group of buildings. It allows the campus managers to understand the consumption of the building, to detect any anomalies in consumption, and to conduct performances actions.

This construction is based on the analysis of historical data. It should be established at different scales: hourly, daily, weekly and monthly.

Considering the usage of the campus, which is mainly related to academic activity, the daily scale seems to be the most pertinent. In fact, the consumptions during the weekend and working days could vary significantly. During holidays, the campus activity slows down; therefore a reduction in the electrical consumption is expected. The consumption in summer is also different from that in winter.

The construction of the daily consumption profile is conducted as follows (Figure 3.5):

- Identification of the "categories" of days, which have a specific consumption profile (week end, working day, summer day, winter day, vacation day, specific event day…etc.).
- For each category and for each hour:
    - Determination of the mean value (V_m), as well as the standard deviation (V_{sd}).
    - Construction of two expected intervals:
        - Interval 1: $[V_m-2V_{sd}, V_m+2V_{sd}]$, which should include 75% of random values
        - Interval 2: $[V_m-3V_{sd}, V_m+3V_{sd}]$, which should include 90% of random values

This step is then conducted for the weekly and monthly scales.

The intervals for each category are stored in the information system and then used for the verification of the real-time consumption. They could also be used for the replacement of "lost data" and the rectification of "out of range data".

The consumption profile is conducted for each substation, which supply one, or a group of buildings, and for any combination of substations or groups of buildings.

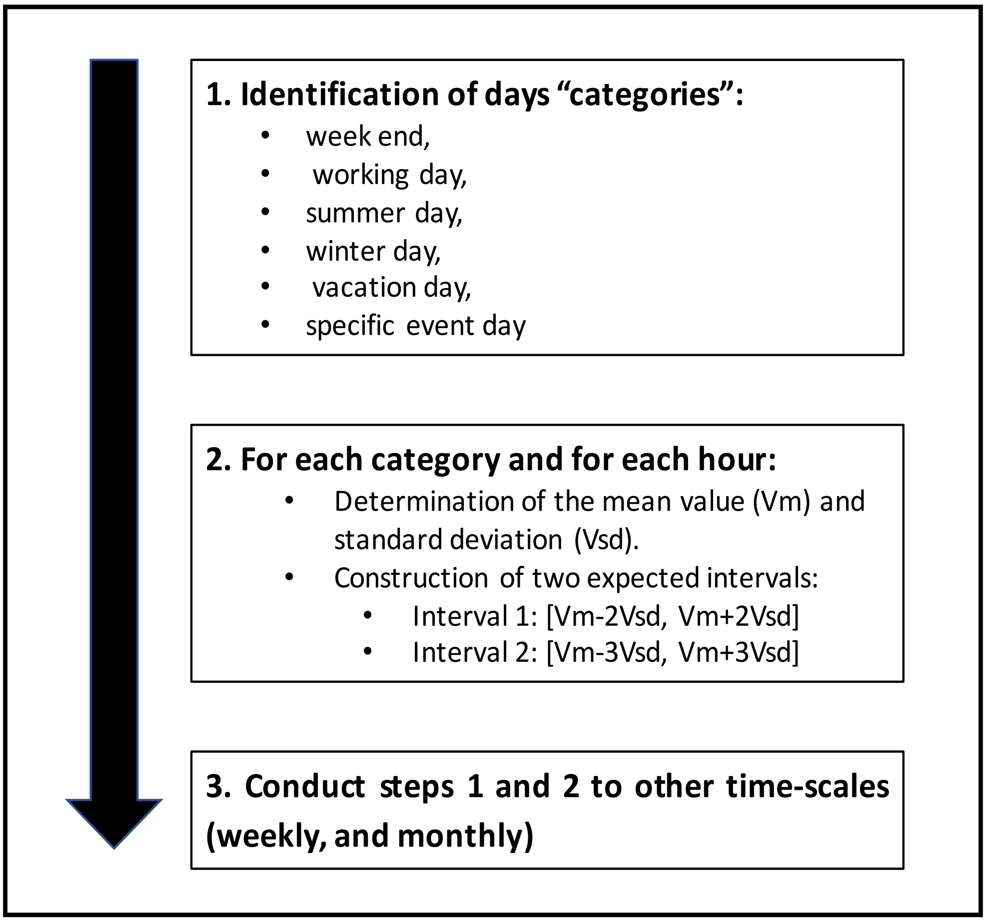


Figure 3.5. Construction of the consumption profile

3.3 Analysis of the global consumption of the campus

Analysis presented in this section concerns the period from 1st March 2013 to 28 February 2014 (over one year). It will be conducted according to the methodology presented in the previous section— first at the daily scale, then at the weekly, monthly and hourly scales.

3.3.1 Daily scale analysis

3.3.1.1 Data cleaning

Figure 3.6 displays the daily consumption according to raw data. Table 1 summarizes the statistical analysis of these data. The daily average consumption is equal to 51.8 MWh with a standard deviation = 15.7 MWh. The maximum consumption is equal to 79.77 MWh, while the minimum consumption is equal to 0 MWh. The latter value is not acceptable because the campus devices and building are not expected to stop. Figure 3.6 shows three periods with irregularly low consumption:

- From 19 to 21 July 2013: The consumption is around 3.2 MWh, which is very low regarding the campus consumption during summer (around 30 MWh)
- From 7 to 13 November 2013: The consumption is equal to 0
- 18 July (Friday) and 21 July (Monday): The consumption is around 20 MWh, which is low as measured against the consumption of working days in summer (around 30 MWh).

Table 1 Statistical analysis of the daily consumption (Raw data)

Average (MWh)	51,80
Max ((MWh))	79,77
Min (MWh)	0,00
Standard deviatin (MW	15,70
Sdev/mean	0,30

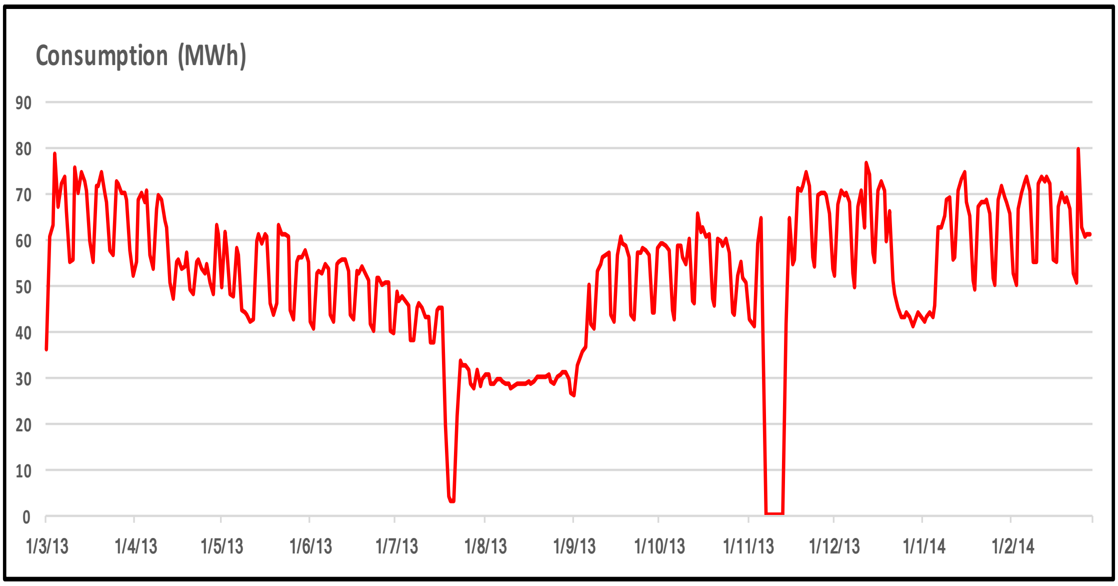


Figure 3.6. Daily consumption of the campus – Raw Data (Period 1/3/2013 – 28/2/2014)

According to the methodology presented in the previous section, the "unaccepted data" were deleted. Figure 3.7 displays the cleaned data. We note more regular data than that observed with the raw data. Table 2 summarizes the statistical analysis of this data. The daily average consumption is equal to 53.4 MWh with a standard deviation = 13.17 MWh. The maximum consumption is equal to 79.77 MWh, while the minimum consumption is equal to 26.14 MWh.

Figure 3.7 shows low consumption for the following periods:

- Summer vacation (23july to 5 September) with a daily consumption of around 30 MWh.
- Toussaint vacation (Beginning of November), with a daily consumption of around 40 MWh.
- Christmas Vacation, with a daily consumption around 40 MWh.
- Weekends, the consumption is around 20% to 25% lower than that of the working days.

Average (MWh)	53,42
Max ((MWh))	79,77
Min (MWh)	26,14
Standard deviatin (MWh)	13,17

Table 2 Statistical analysis of the daily consumption – Cleaned data

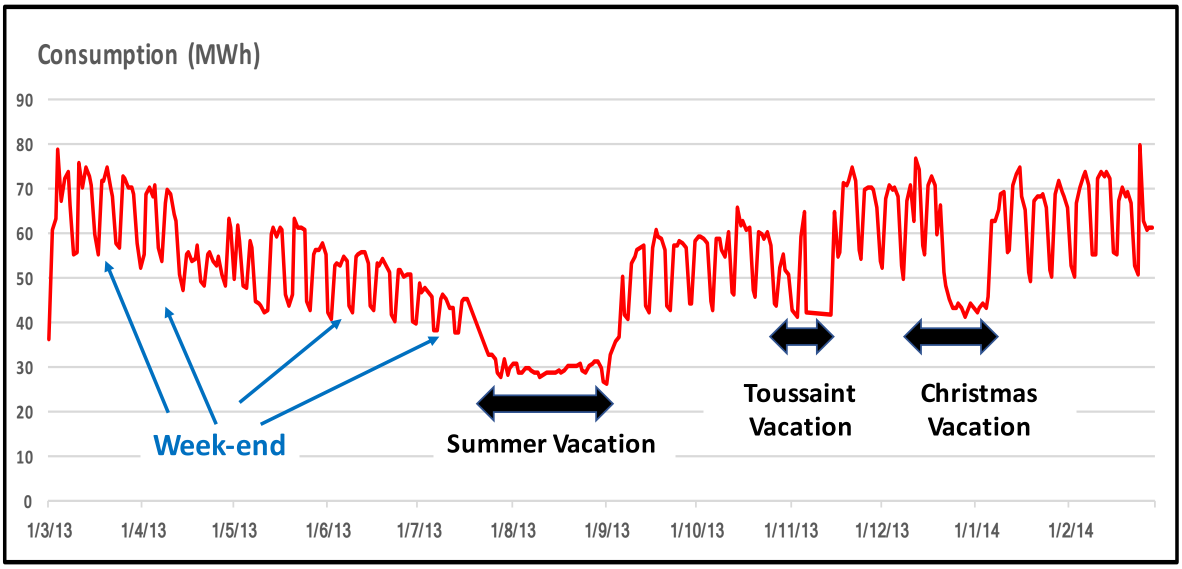


Figure 3.7. Daily consumption of the campus – Cleaned Data (Period 1/3/2013 – 28/2/2014)

3.3.1.2 Classification of the data consumption (consumption categories)

The variation of the daily consumption permits the establishment of the following categories of electrical consumption (Figure 3.8):

- **Class 1** "Summer Vacation": consumption is equal to around 30 MWh/day. This value is about 56% of the average consumption. It is high if we consider that the main part of the campus activities is not active. This consumption at the building level is to be explored in details in order to identify the sources of these consumption levels, so as to reduce it.
- **Class 2** "Christmas and Toussaint vacations": consumption is equal to 40 MWh/day.
- **Class 3** "10 April to 22 July and 6 September to November 6": consumption varies between 40 MWh/day (weekend) and 65 MWh/day (working days).
- **Class 4** "5 November to 9 April (Christmas vacation not included)": Daily consumption varies between 50 MWh/day (weekend) and 80 MWh/day (working days).

From these classes, we can roughly identify the following five levels of consumption, which are summarized in Table 3.

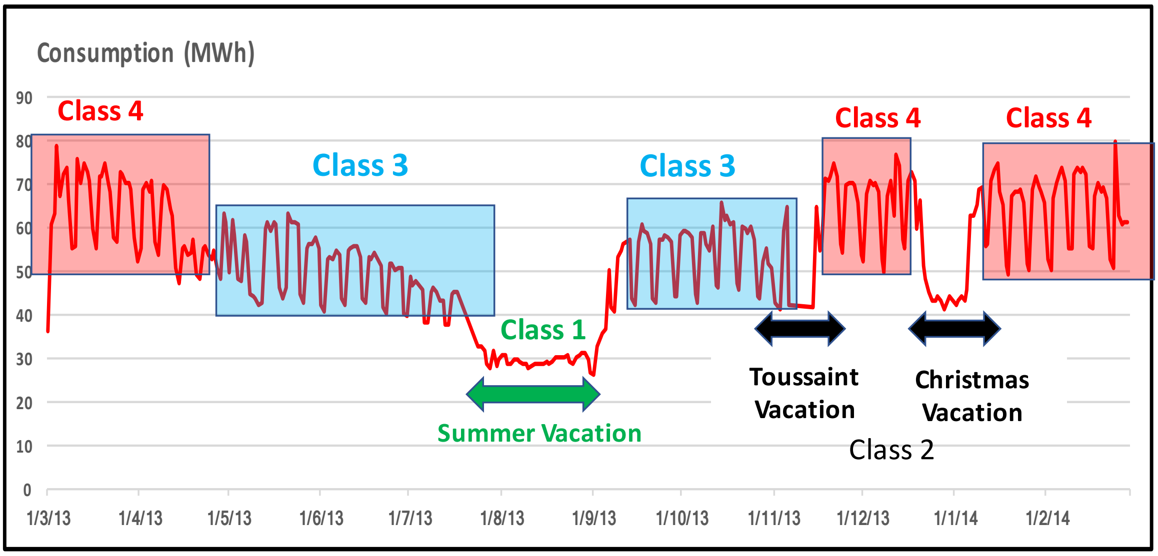


Figure 3.8. Level of the campus consumption

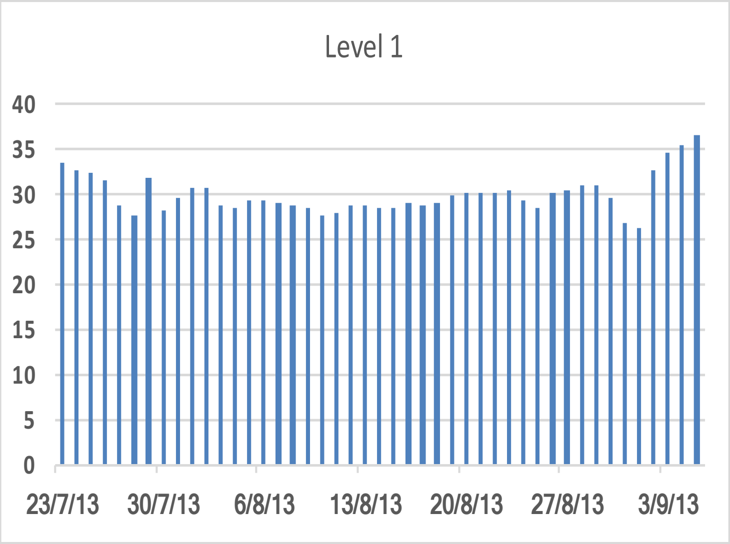
Table 3 Levels of the daily consumption of the campus

Level	Consumption	Period
1	30 (MWh/day)	Summer vacation
2	40 (MWh/day)	Class 2 and Week-end of class 3
3	50 (MWh/day)	Week-end of class 4
4	65 (MWh/day)	Working days of Class 3
5	80(MWh/day)	Working days of Class 4

Figure 3.9 details the consumption of level 1. We observe a homogeneous class with a mean value close to 30 MWh/day, and a standard deviation of 2.16 MWh. The standard deviation is equal to 7% of the mean value, which confirms the pertinence of this class.

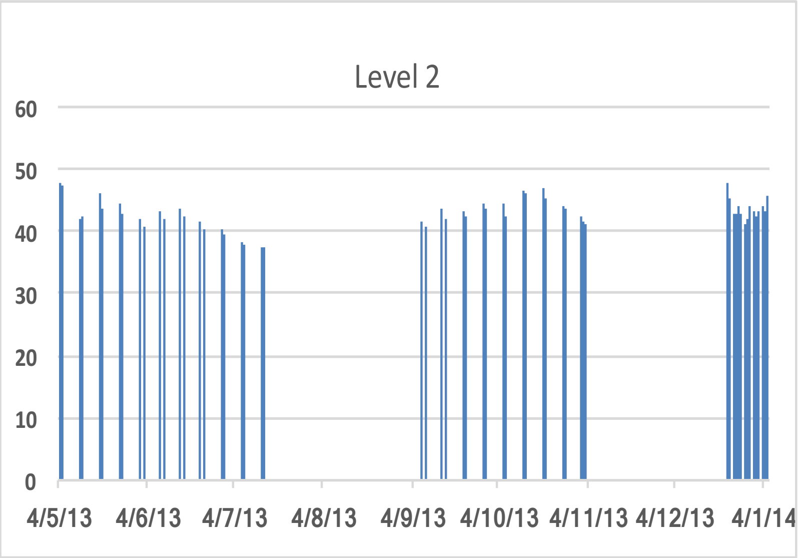
Figure 3.10 details the consumption of level 2. We observe also a homogeneous class with a mean value close to 43 MWh/day, and a standard deviation = 2.39 MWh. The standard deviation is equal to 5.6 % of the mean value, which confirms the pertinence of this class.

Figure 3.11 details the consumption of level 3. We observe a homogeneous class with a mean value = 53.6 MWh/day, and a standard deviation = 3.5 MWh. The standard deviation is equal to 6.5 % of the mean value, which confirms the pertinence of this class.



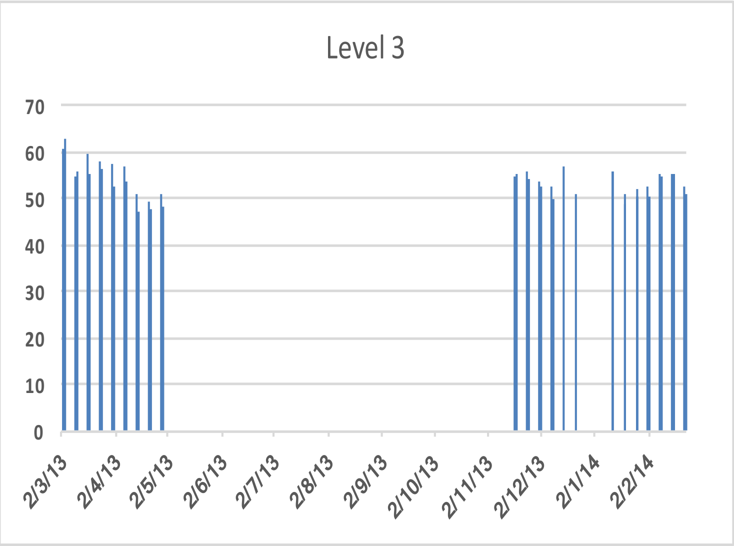
Mean	29,97
Min	26,14
Max	36,59
St_Dev.	2,16
St_Dev/Mean (%)	7,22

Figure 3.9. Data concerning consumption level 1



Mean	42,99
Min	37,43
Max	48,00
St_Dev.	2,39
St_Dev/Mea	5,56

Figure 3.10. Data concerning consumption level 2

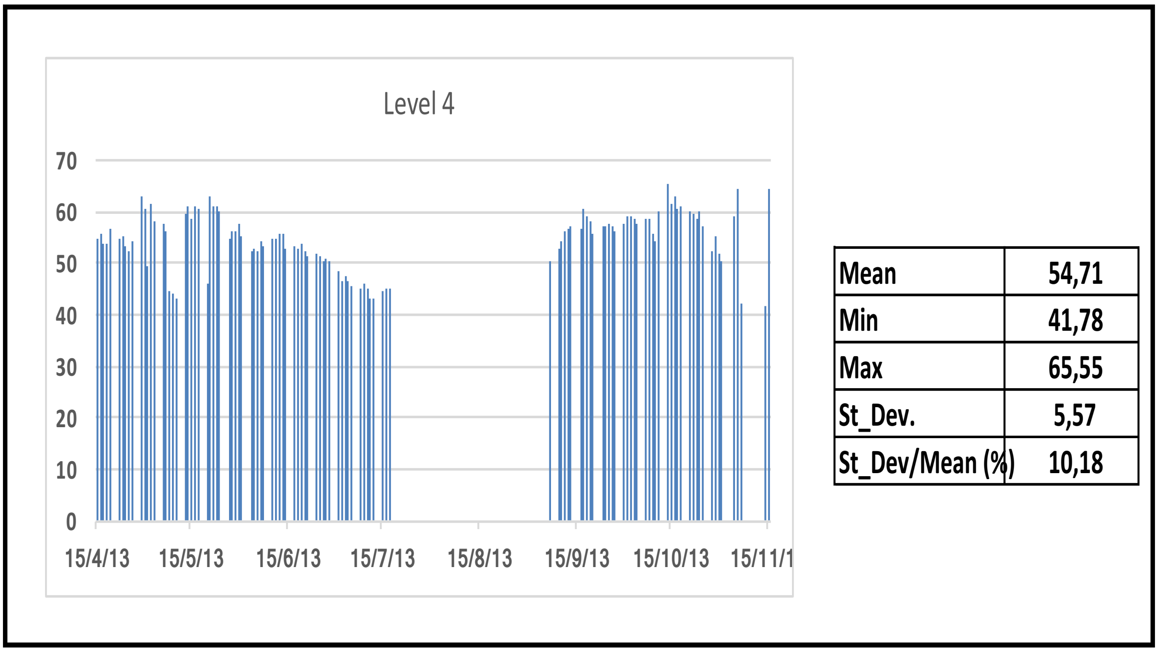


Mean	53,61
Min	46,97
Max	62,86
St_Dev.	3,50
St_Dev/Mean (%)	6,53

Figure 3.11. Data concerning consumption level 3

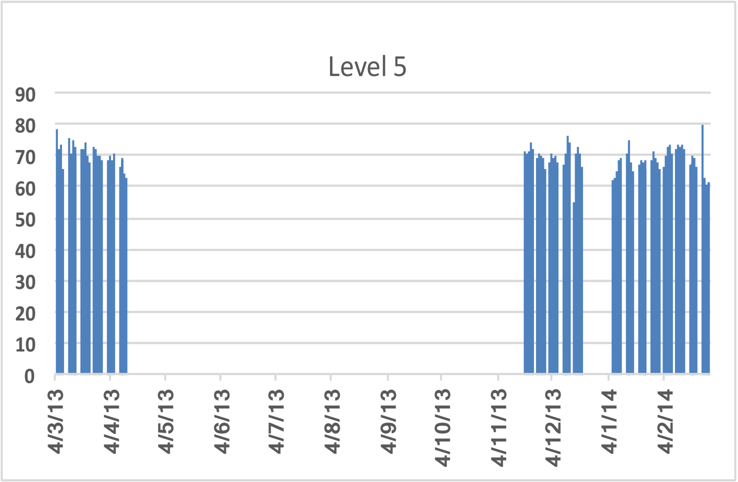
Figure 3.12 details the consumption of level 4. The daily consumption varies between 41.78 and 65.55 MWh/day with a mean value = 54.71 MWh/day and standard deviation = 5.57 MWh (10.18 % of the mean value). This class is still large and could be subdivided to improve its quality.

Figure 3.13 details the consumption of level 5. We observe a homogeneous class with a mean value close to 69 MWh/day, and a standard deviation = 4.3 MWh. The standard deviation is equal to 6.23 % of the mean value, which confirms the pertinence of this class.



Mean	54,71
Min	41,78
Max	65,55
St_Dev.	5,57
St_Dev/Mean (%)	10,18

Figure 3.12. Data concerning consumption level 4



Mean	69,06
Min	55,03
Max	79,77
St_Dev.	4,30
St_Dev/Mean (%)	6,23

Figure 3.13. Data concerning consumption level 4

3.3.2 Weekly scale analysis

3.3.2.1 Data cleaning

Figure 3.14 displays data concerning the weekly consumption according to raw data. For each week, it provides the mean daily consumption, the maximum daily consumption and the minimum daily consumption. It shows anomalies discussed earlier for weeks 21, 22 and 37.

After data cleaning, we obtain the weekly consumption presented in Figure 3.15, which is more regular than that presented in Figure 3.14. The great change in the weekly consumption is due to the important variation in the consumption between working and weekend days.

Figure 3.16 displays the variation of the total weekly consumption. It varies between 199 and 473 MWh, with a mean value = 373 MWh, and a standard deviation = 80 MWh, which is about 21% of the mean consumption. Since the weekly consumption includes important variation, which is due to the difference in consumptions between working days, weekends, holidays, its use for the control of the management of the electrical grid is not recommended.

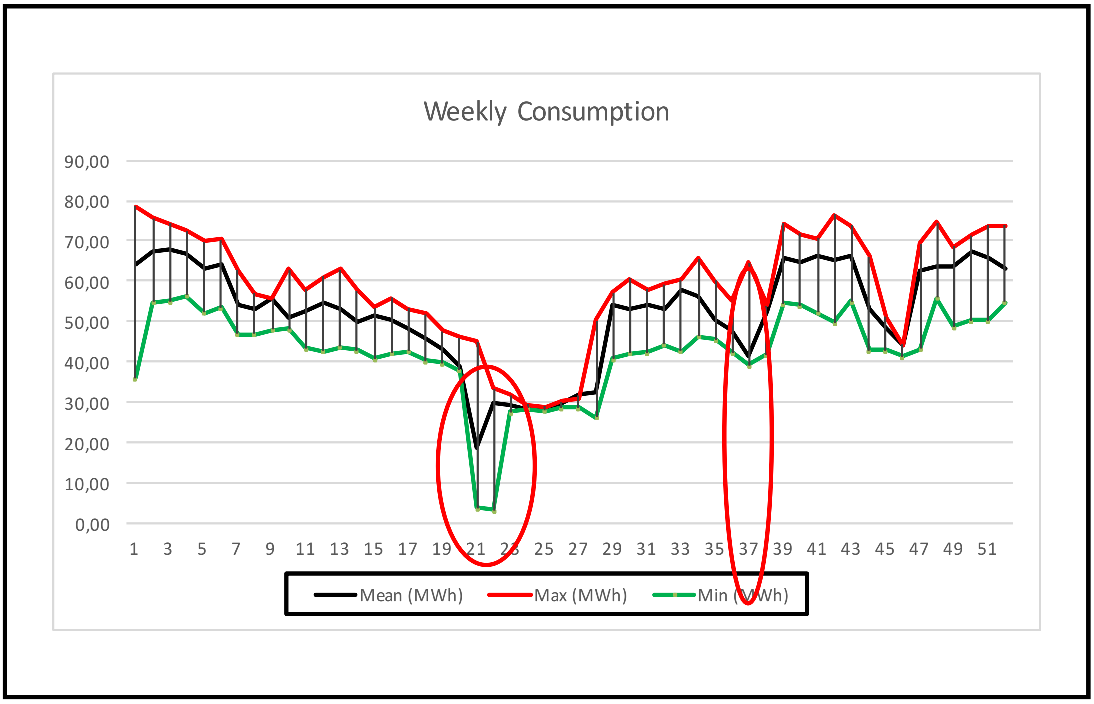


Figure 3.14. Weekly consumption of the campus – Raw Data (Period 1/3/2013 – 28/2/2014)

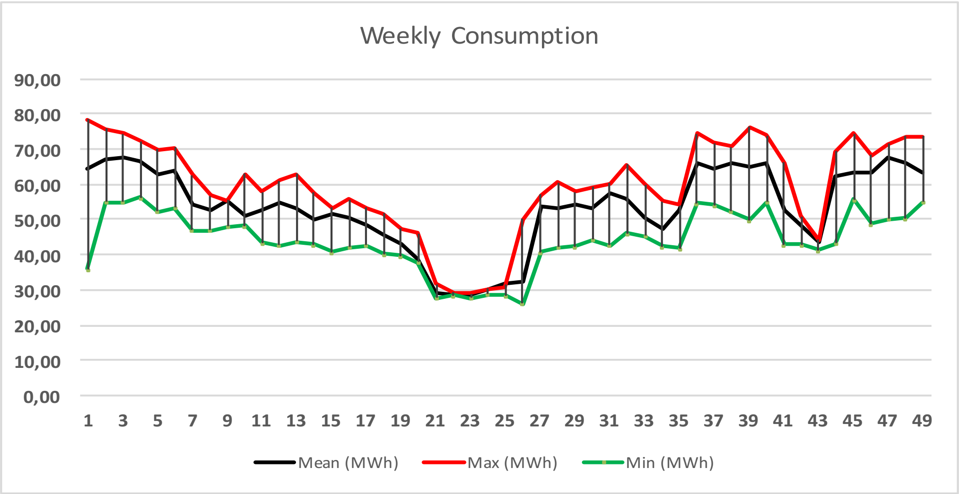
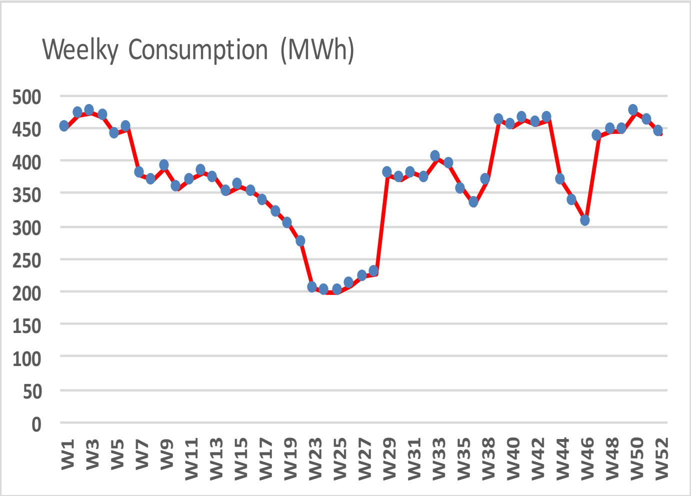


Figure 3.15. Weekly consumption of the campus – cleaned Data (Period 1/3/2013 – 28/2/2014)



Mean	373,10
Max	473,39
Min	198,79
St_Dev	80,06
St_Dev/mean (%)	21,46

Figure 3.16. Total weekly consumption of the campus – cleaned Data (Period 1/3/2013 – 28/2/2014)

3.3.3 Monthly scale analysis

Figure 3.17 displays data concerning the monthly consumption according to the cleaned data. For each month, it provides the mean daily consumption, maximum daily consumption and minimum daily consumption. The mean consumption per month varies between 29200 MWh and 66740 MWh, with a mean value = 53150 MWh and a standard deviation = 11385 MWh (21 % of the mean value).

Figure 3.18 displays the total consumption per month. This consumption varies between 907 and 2038 GWh with a mean value = 1606 GW and a standard deviation = 330 GWh, which is equal to 21% of the mean value. Since the monthly consumption shows an important change, due to difference in consumption between working days, weekends and holidays, it could not be used for management of the electrical grid.

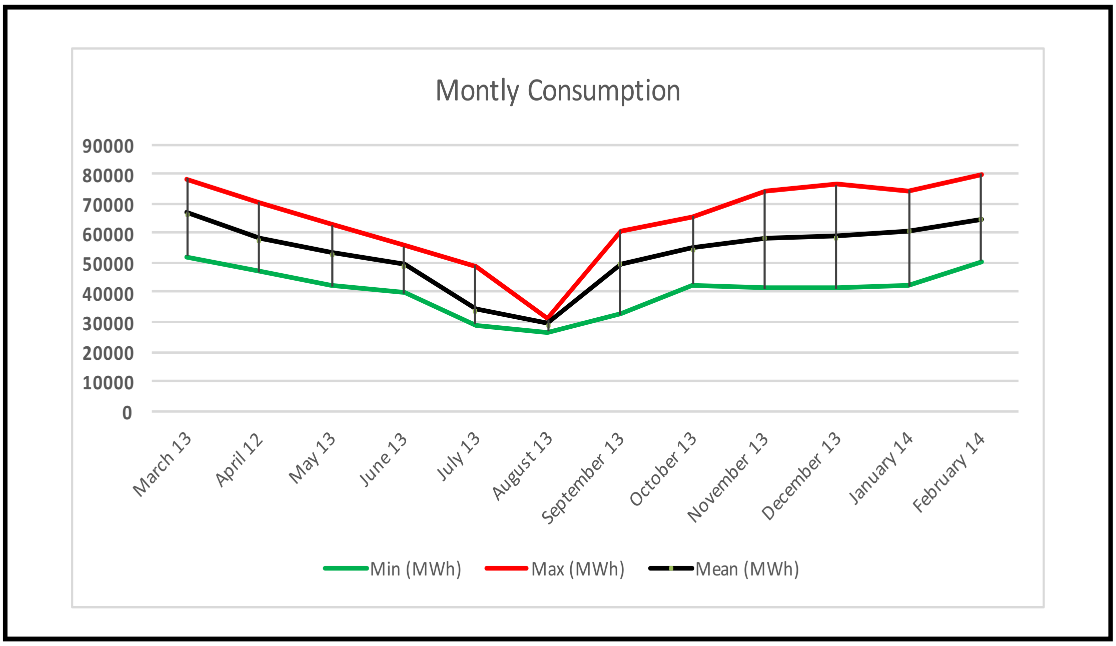
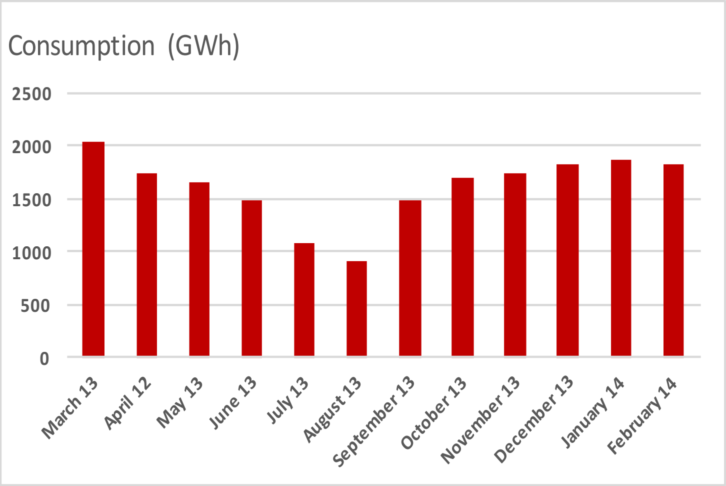


Figure 3.17. Mothly consumption of the campus – (Period 1/3/2013 – 28/2/2014)



Mean (GWh)	1606
Min (GWh)	907
Max (GWh)	2038
St_Dev. (GWh)	330
St_Dev/Mean (%)	21

Figure 3.18. Total Mothly consumption of the campus – (Period 1/3/2013 – 28/2/2014)

3.3.4 Hourly scale analysis

This section presents analysis of the consumption at hourly scale. It aims at exploring the variation of the consumption during the day to understand how and when the electrical energy is consumed, and to detect anomalies in this consumption. Analysis is conducted for two periods: Winter and Summer. For each period, we compare the working day consumption to the weekend consumption.

Figure 3.19 displays the consumption on a working day (Tuesday, 17 December 2013) and a comparison with the consumption on a weekend day (Saturday, 14 December 2013). These days represent of the consumption days in winter. The statistical analysis of these consumptions is summarized in Table 4.

The working day consumption is equal to 60.45 MWh. The hourly consumption varies between 1961 kW and 3404 kW, with a mean value = 2628 kW and a standard deviation = 559 kW (21% of the mean value). Between 2:00 and 8:00 am, the hourly consumption is near constant (around 1900 kW); it increases gradually from 8:00 am and attains the maximum (3400 kW) at 11:00 am. It then decreases gradually to 2900 kW at 6:00 pm. At 8:00 pm it is equal to 2100 kW, then it increases up to 3300 kW at 10:00 pm. This increase could be related to the activity of students in their residences.

The weekend day total consumption is equal 47.76 MWh. This value is equal to 80% of the working day consumption. It could be considered high because the majority of the University activity is stopped during the weekend. The hourly consumption varies between 1915 kW and 2582 kW, with a mean value = 2077 kW and a standard deviation = 151 kW (7% of the mean value). This consumption is near constant over the major part of the day and night except for an increase between 1:00 and 2:00 pm. The low variation in the consumption during the weekend at its utmost (80% of the working day) is not normal. It could be attributed to buildings' lighting and devices' functioning. It requires a deep analysis at the building level to understand the origin of this consumption.

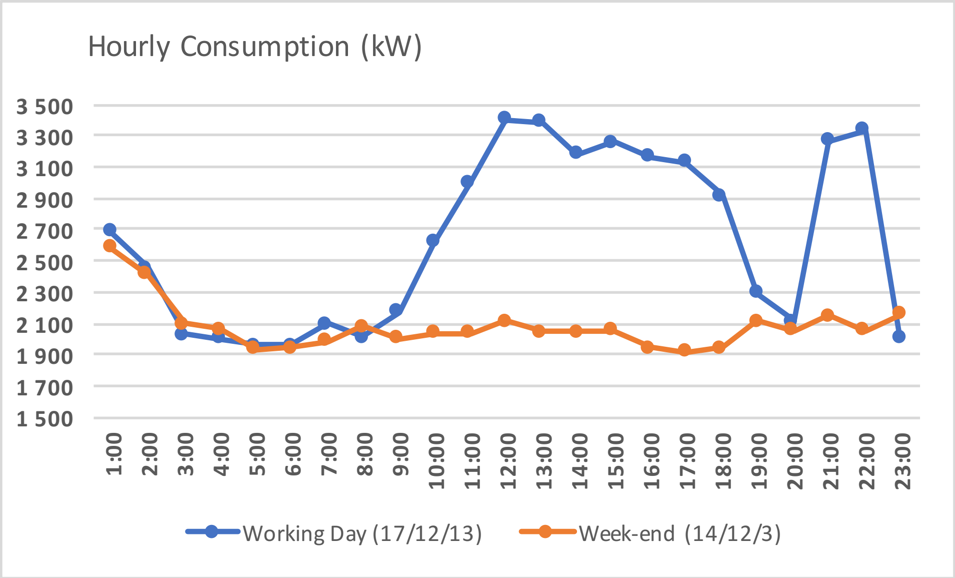


Figure 3.19. Analysis of the hourly consumption – Comparison of Working day (17/12/13) and Weekend (14/12/13)

Table 4 – Consumption data for a working day and a weekend day – December 2013

Consumption (kWh)	**(Tuesday, 17 December 2013)**	**(Saturday, 14 December 2013)**
Total	60 454	47 764
Mean	2 628	2 077
Max	3 404	2 582
Min	1 961	1 915
St-Dev	559	151
St-Dev/Mean (%)	21,27	7,27

Figure 3.20 displays the consumption on a working day (Tuesday, 4 June 2013) and a weekend day (Sunday, 2 June 2013). These days are representative of the consumption in summer. The statistical analysis of the consumption is summarized in Table 5.

The working day total consumption is equal to 43.17 MWh (around 70% of the winter working day). The hourly consumption varies between 1445 kW and 2087 kW, with a mean value = 1877 kW and a standard deviation = 383 kW (20% of the mean value). Between 1:00 and 7:00 am, the hourly consumption is almost constant (around 1400 kW), and then it increases gradually and attains a maximum at 11:00 am (2487 kW). After 11:00 am, it decreases gradually to 2200 kW at 5:00 pm, and then it decreases rapidly to 1600 kW at 9:00 pm.

The weekend day total consumption is equal 33.23 MWh MWh (around 70% of the winter weekend day). This value is equal to 77% of the working day consumption. The hourly consumption varies between 1362 kW and 1520 kW, with a mean value = 1445 kW and a standard deviation = 39 kW (2.7% of the mean value). This consumption is almost constant over day and night. It confirms the comments of the previous paragraph.

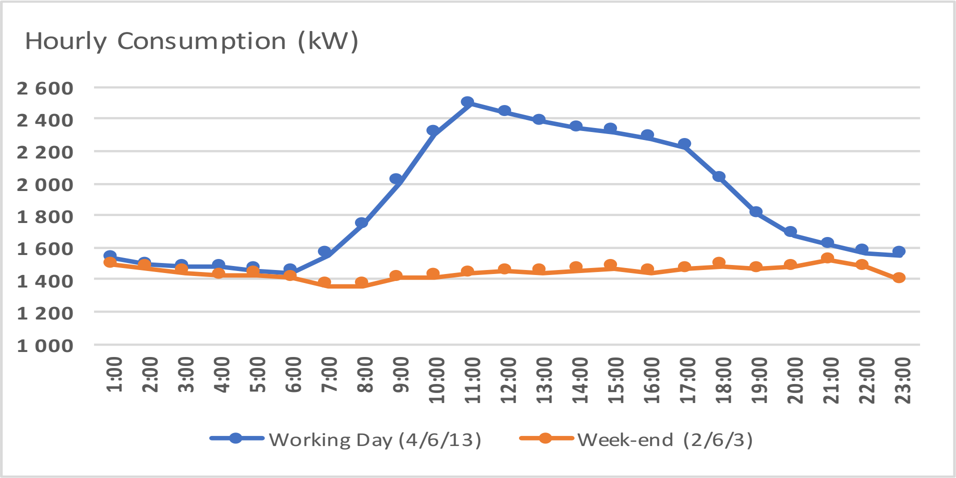


Figure 3.20. Analysis of the hourly consumption – Comparison of Working day (4/6/13) and Weekend (2/6/13)

Table 5 – Consumption data for a working day and a weekend day – June 2013

Consumption (kWh)	**(Tuesday, 4 June 2013)**	**(Sundy, 2 June 2013)**
Total	43 171	33 227
Mean	1 877	1 445
Max	2 487	1 520
Min	**1 445**	1 362
St-Dev	**383**	**39**
St-Dev/Mean (%)	20,43	2,71

3.3.5 Analysis of the power demand

Analysis of the power demand constitutes an important issue. It allows the understanding of the peak power demand and its comparison to the subscription contract to check if we can reduce the power subscription, which could result in important savings.

Figure 3.21 shows the 10 highest peaks of the power demand per month for the period between March 2013 and February 2014, as well as the power subscription, which is equal to 5250 kW (Red line in the figure). We observe that over the 120 peaks, only 2 peaks exceed the power subscription in March; the first peak is equal to 6258 kW, while the second is equal to 5932 kW. These 2 peaks are isolated. We must explore their origin for their elimination.

Other peaks are sensibly lower than the subscription power. Generally, they are lower than 4100 kW, which means that the subscription could be reduced by about 20%, which allows important saving in the electrical expenses.

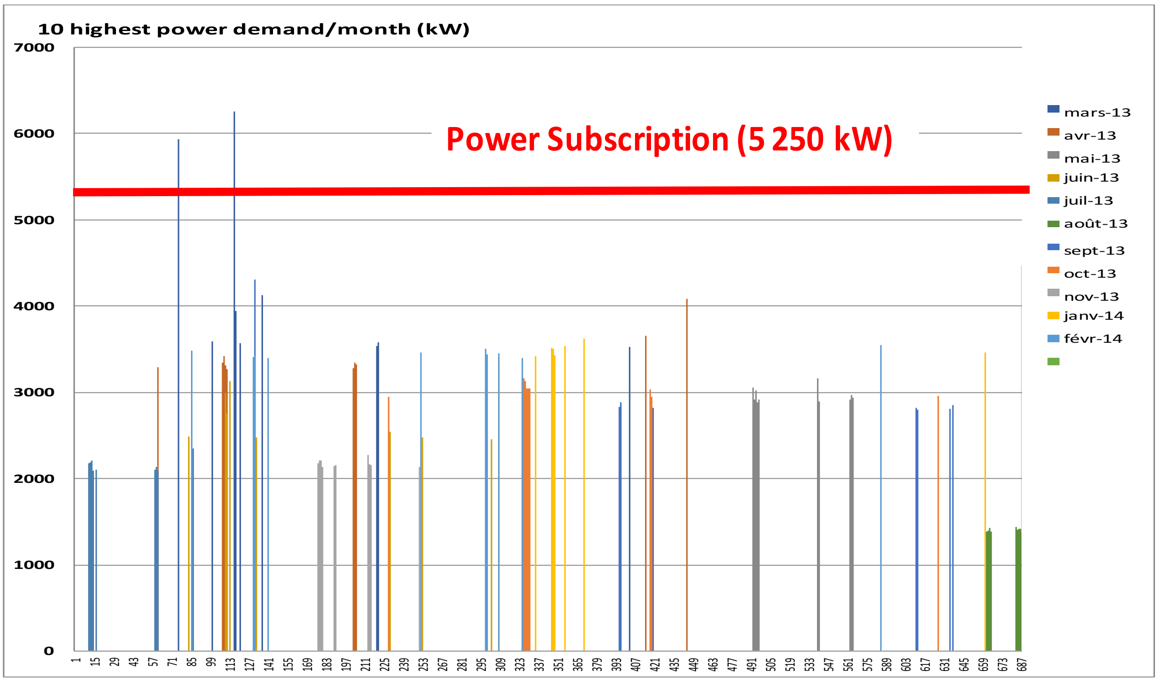


Figure 3.21. The 10 highest peaks of power demand per month (March 2013 - February 2014)

3.4 Analysis of the Consumption of Building P2

3.4.1 Presentation of the building

The Building P2 is a part of the sector of Physics (Figure 3.22). It was constructed in 1966. P2 is composed of five levels (floors), with a global surface of 4800 m^2. It is used for both teaching and research. The district-heating network of the campus ensures the heating of the building. Electrical power is used mainly for lighting and for the supply devices used in teaching and research purposes. The building does not host high power research equipment. The electrical consumption is recorded as described above and transmitted to the SunRise platform.

In the following sections, an analysis of the consumption of this building in 2015 (From 01/01/2015 to 31/12/2015) is presented. According to the results of the global consumption analysis (Section 3.3), analysis of Building P2 consumption will be conducted at the pertinent scales: daily and hourly.

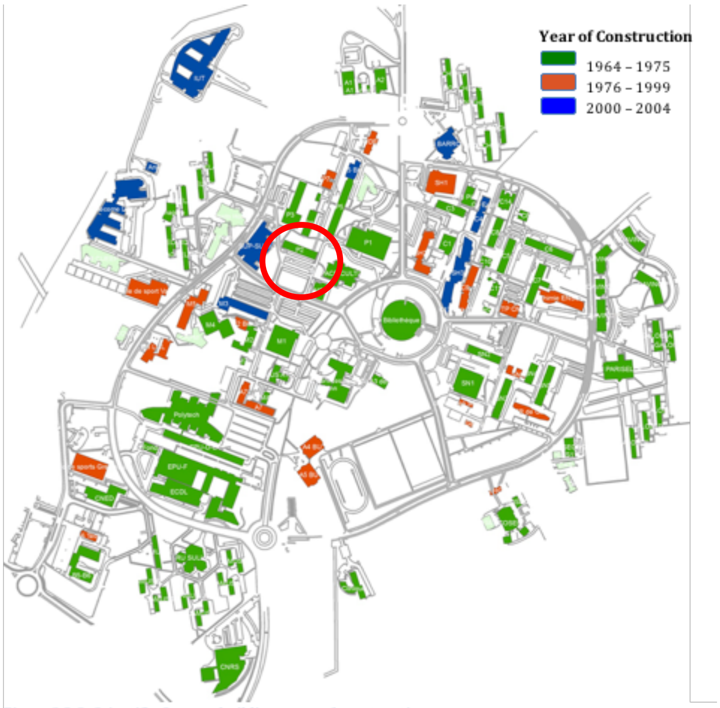


Figure 3.2-2: Scientific Campus buildings year of construction

Building P2
Sector : Physics
Construction : 1966
Surface : 4800 m^2
Usage : Teaching & Research
5 levels

Figure 3.22. Location and characteristics of building P2.

3.4.2 Daily scale analysis

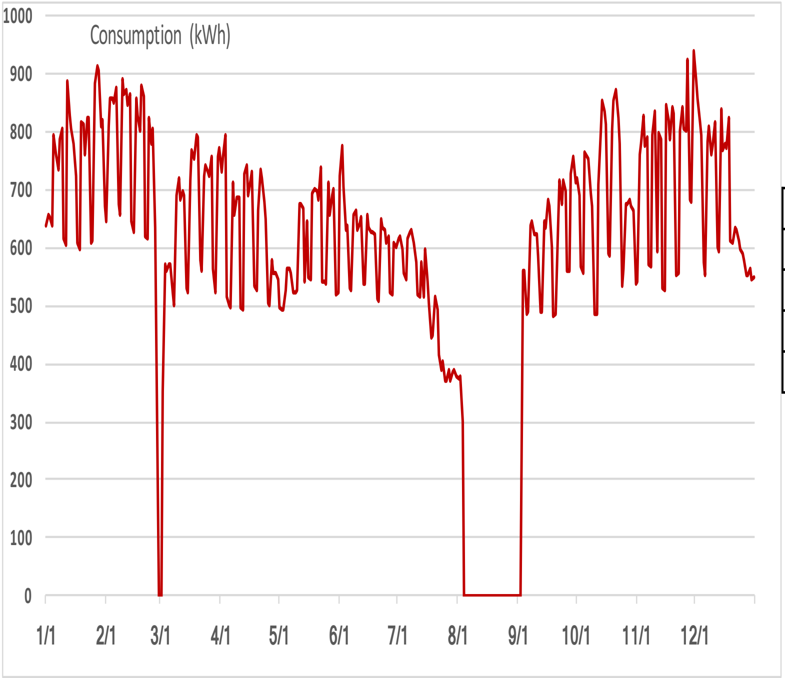
3.4.2.1 Data cleaning

Figure 3.23 displays the daily consumption according to raw data. The daily average consumption is equal to 597 kWh with a standard deviation = 223 kWh. The maximum consumption is equal to 938 kWh, while the minimum consumption is equal to 0. The latter value is not acceptable because the building functioning is not expected to stop.

Figure 3.23 shows two periods with abnormal low consumptions:

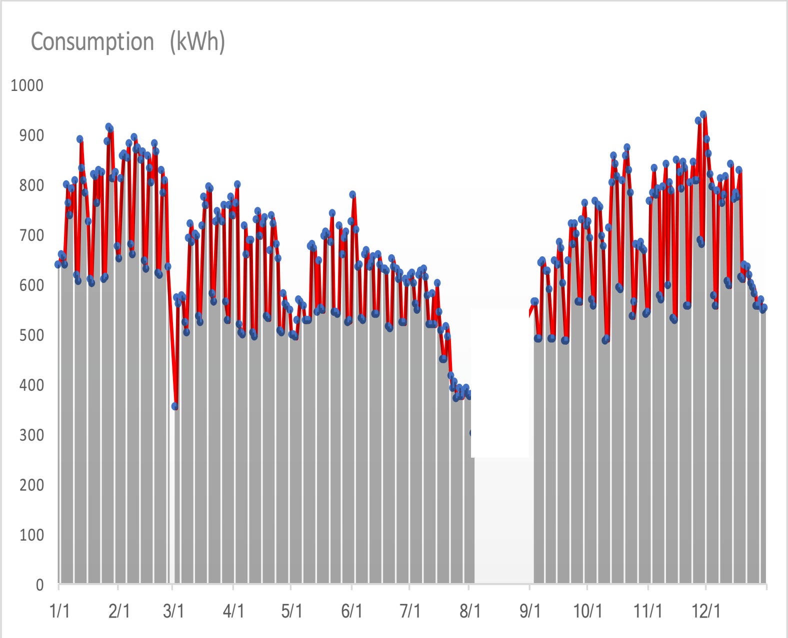
- From 27 February to 1st March: consumptions are equal to 0.
- From 4 August to 2 September: consumptions are equal to 0.

According to the methodology presented in the previous section, the “unaccepted data” were deleted. Figure 3.24 displays the cleaned data. We note more regular variation than that observed with raw data. The daily average consumption is equal to 655 kWh with a standard deviation = 128 kWh. The maximum consumption is equal to 938 kWh, while the minimum consumption is equal to 300 kWh.



Mean (kWh)	597
Min (kWh)	0
Max (kWh)	938
St_Dev. (kWh)	223
St_Dev/Mean (%)	37

Figure 3.23. Daily consumption of building P2– Raw Data (Period 1/1/2015 – 31/12/2015)



Mean (kWh)	655
Min (kWh)	300
Max (Wh)	938
St_Dev. (kWh)	128
St_Dev/Mean (%)	20

Figure 3.24. Daily consumption of building P2– cleaned Data (Period 1/1/2015 – 31/12/2015)

The consumption of Building P2 can be classified in the following four categories (Figure 3.25):

- Class 1 "summer vacation": For this period, the consumption is expected to be very low, because the building is closed; unfortunately, data is missing for this period.
- Class 2 "Christmas, Winter (2-8 march), May vacations (1-10), June-July, September": The daily consumption varies between 500 and 650 kWh.
- Class 3 "March, April, May (11 – 30), October): The daily consumption varies between 500 and 800 kWh.
- Class 4 "January, February, October (20 – 30), November, December (1 – 20): The daily consumption varies between 600 kWh and 900 kWh.

From these classes, we can identify five levels of consumption, which are summarized in Table 6

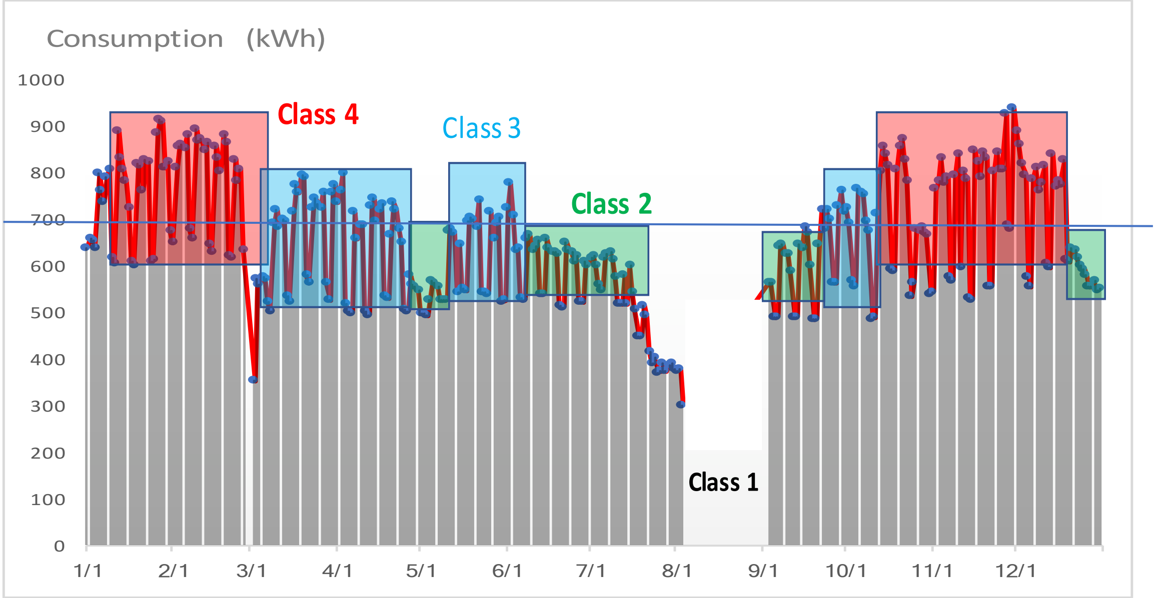


Figure 3.25. Daily consumption of building P2– cleaned Data (Period 1/1/2015 – 31/12/2015)

Table 6 – Level of consumption of building P2

Level	Consumption	Period
1	Missed	Summer vacation
2	500 kWh	Week-end of class 2 and 3 and vacations
3	600 kWh	Working days of class 2 and week-end of class 4
4	750 kWh	Working days of Class 3
5	850 -900 kWh	Working sdays of Class 4

3.4.3 Hourly scale analysis

Figure 3.26 displays the consumption on a working day (Tuesday, 15 December 2015) and a weekend day (Saturday, 12 December 2013). These days are representative of the consumption in winter. The statistical analysis of these consumptions is summarized in Table 7.

The total working day consumption is equal to 741 kWh. The hourly consumption varies between 22 kW and 47 kW, with a mean value = 32 kW and a standard deviation = 5 kW (16% of the mean value). Between 9:00 pm and 8:00 am, the hourly consumption is almost constant (around 30 kW). After 8:00 am, it increases gradually and attains 35 kWh at 12:00 am. Then it decreases between 12:00 am and 2:00 pm (lunch time). After 2:00 pm, it increases to reach a peak value (47 kW) at 6:00 pm. After 6:00 pm, it decreases to 30 kW at 9:00 pm. This variation of the consumption is expected in winter for a working day. The peak consumption around 6:00 pm could be related to the intensive activity and the use of lighting.

The weekend day total consumption is equal 573 kWh. This value is equal to 77% of the working day consumption. It is high because most the building activity is expected to be inactive during the weekend. The hourly consumption varies between 15 kW and 31 kW, with a mean value = 25 kW and a standard deviation = 15 kW (25% of the mean value). This consumption is close-to constant between 6:00 pm and 8:00 am (30 kW) and between 9:00 am and 5:00 pm (around 17 kW).

We observe that the night consumption on the weekend day is equal to that of the working day. This consumption could be related to water-heating during the off-peak hours (11:00pm- 5:00 am).

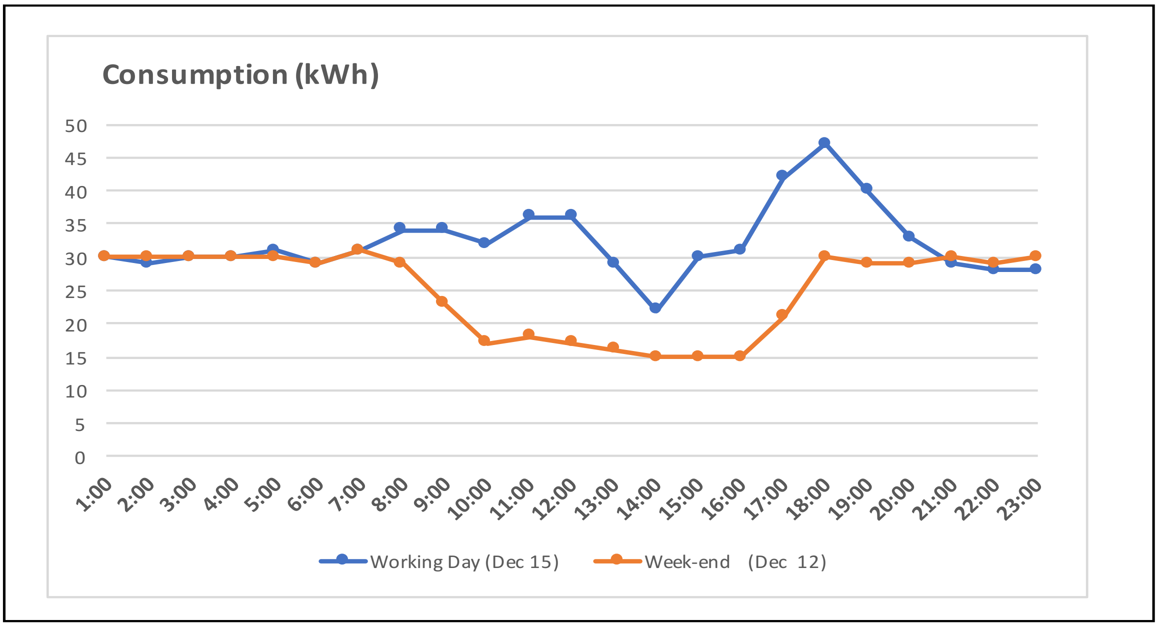


Figure 3.26. Analysis of the hourly consumption of P2 – Comparison Working day (15/12/15) and Weekend (12/12/13)

Table 7 – Consumption data of P2 for a working day and a weekend day – December 2013

Consumption (kWh)	Working Day (Dec 15)	Week-end (Dec 12)
Total	741	573
Mean	32	25
Max	47	31
Min	**22**	**15**
St-Dev	**5**	**6**
-Dev/Mean (%)	16,42	25,59

Figure 3.27 displays the consumption on a working day (Tuesday, 9 June 2015) as compared with that of a weekend day (Sunday, 7 June 2015) in summer. The statistical analysis of these consumptions is summarized in Table 8.

The total working day consumption is equal to 631 kWh (85% of the winter working day). The hourly consumption varies between 18 kW and 33 kW, with a mean value = 27 kW and a standard deviation = 5 kW (19% of the mean value). Between 11:00 pm and 5:00 am, the hourly consumption is almost constant (around 33 kW). After 5:00 am, it increases gradually and attains 17 kW at 7:00 am. Then, it increases during the day and attains a peak at 5:00 pm (32 kW). After 5:00 pm, it decreases to 17 kW at 10:00 pm.

The weekend day total consumption is equal 495 kWh. This value is equal to 78% of the working day consumption. As described for winter days, the night, weekend and working days' consumption are equal. The hourly weekend consumption during the day is constant (around 17 kW). It is equal to that in winter.

Analysis of winter and summer consumptions shows the existence of a “latent” power demand, which is around 17 kW. This latent demand is responsible of a daily energy consumption of 408 kWh, which is equal to 82% (resp. 64%) of the weekend consumption (resp. working day) in summer and to 71% (resp. 55%) of the weekend consumption (resp. working day) in winter. Consequently, this latent consumption is important and should be tracked to explore the possibility of its reduction.

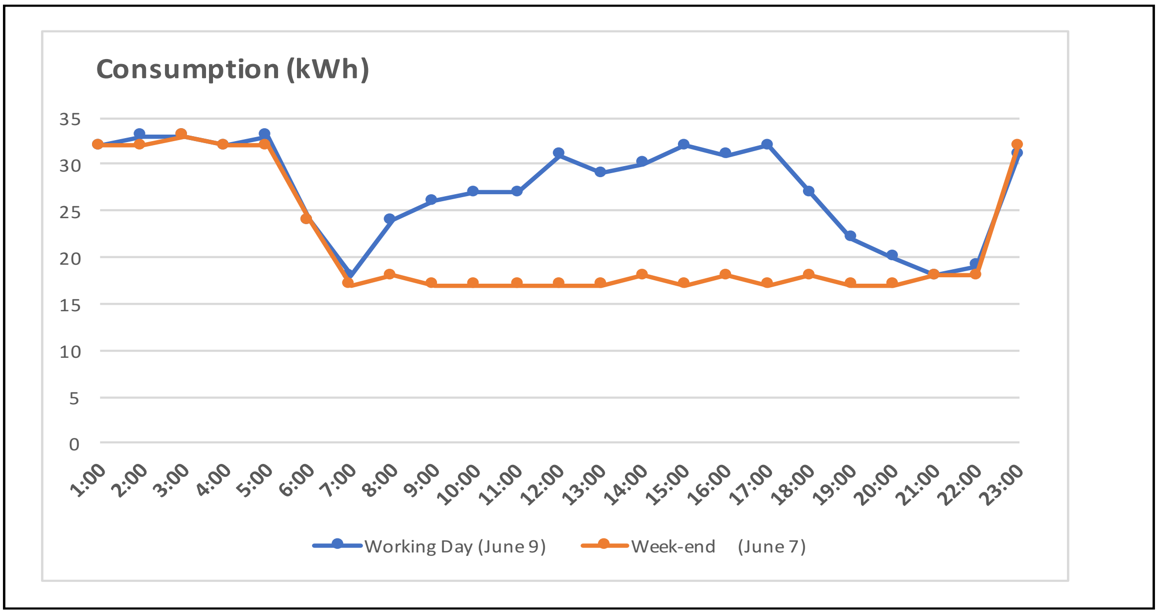


Figure 3.27. Analysis of the hourly consumption of P2 – Comparison Working day (9/6/15) and Weekend (7/6/15)

Table 8 – Consumption data of P2 for a working day and a weekend day – June 2015

Consumption (kWh)	Working Day (June 9)	Week-end (June 7)
Total	631	495
Mean	27	22
Max	33	33
Min	**18**	**17**
St-Dev	**5**	**7**
-Dev/Mean (%)	18,77	30,79

3.5 Conclusion

This chapter presented analysis of the electrical consumption of the Scientific Campus of the University of Lille. First, it included a presentation of the methodology developed within project SunRise used for data analysis. This methodology covers the following steps:

- Measurement of the electrical consumption using Smart electrical meters and transmission of the recorded data to the electrical grid server.
- Transmission of raw data from the electrical grid server to the SunRise server.
- Data cleaning, and storage in SunRise's information system.
- Construction of the consumption profile of buildings and groups of buildings and analysis of these profiles to identify energy losses.
- Analysis of real-time data, and use of consumption profiles, to detect any unusual consumption.
- Analysis of the source of anomalies and recommendation for the improvement of the electrical system.

This methodology was applied on the analysis of the global consumption of the campus at different scales: daily, weekly, monthly and hourly. Analysis of the electrical consumption at the daily scale resulted in the identification of five levels of consumption. Each level is related to a specific period. For each level, the mean consumption and standard deviation were determined. They are used to manage the electrical consumption according to the methodology presented above.

Analysis of consumption data showed some anomalies, particularly high values during the weekend and holidays as well as at night. The sources of these consumptions should be analyzed to undertake rapid improvement actions, such as shutting down of buildings' lighting and stopping some devices and appliances during night and non-working days.

The proposed methodology was also applied to Building P2, which is used for both teaching and research. Analysis of the consumption of this building resulted in the identification of five levels of electrical consumption, which combine the different building usages: weekend, working day, vacations, night activity, day activity, summer and winter. For each level, the expected consumption and the corresponding periods were established. The resultant data can be used to manage the real-time data consumption of this building and to track energy loss.

Analysis of the Building P2 consumption showed a “latent” energy demand of 17 kW, which generates important daily consumption: around 82% (resp. 64%) of the weekend consumption (resp. working day) in summer, and 71% (resp. 55%) of the weekend consumption (resp. working day) in winter. This “latent” demand is important and should be tracked to explore the possibility of its reduction.

General Summary

Thesis concern

My thesis is based on a strategic issue faced by the City, as well as our planet, and the development, deployment and use of digital innovation towards the modernization of urban infrastructures, in order to meet the increasing challenges of both the City, and in return our planet. It included a review of the City challenges, the digital innovations and their application to the transformation of the urban infrastructures into smart infrastructures, with a primary focus on electrical grids. It also included an overview of the implementation of the Smart Grid technologies in a large-scale demonstrator of the Smart City (project SunRise), following the use of this technology for a comprehensive analysis of the electrical consumption at the scientific campus of Lille University.

City challenges

Cities are a principal concern in the world today. They host around 70% of the economic activity and are responsible of around 80% of the greenhouse gas emissions. With the vertiginous increase in the urban population, the roles played by cities in the environment, and our lives will yet expand. Today, the City is submitted to a huge pressure, due to the acceleration of urban population growth, increasing demand of energy and natural resources, such as water, increase in air pollution and greenhouse gas emissions and their consequences on global warming, climate change and public health. The City is a living complex system composed of a multitude of complex sub-systems. It must face the critical problem of ageing infrastructures. Undeniably, urban infrastructures particularly in developed countries, suffer today because of their

incapacity to meet the rising challenges, that of sustainability, legitimate demand of citizens to a decent quality of life, and cuts in both investment and maintenance funding. Considering these challenges, the City stakeholders must develop new strategies, based on scientific and technological development, and innovation, to transform the "old" urban infrastructures into modern and efficient infrastructures that ensure optimal and safe functioning of the city, while meeting the expectation of citizens and the requirement of sustainability.

Using Smart technology to meet city challenges

The digital transformation through the revolution of the internet, broadband data communication, social media, smart mobiles, cloud computing and Big-Data, offers a great opportunity to modernize urban infrastructures by building more efficient systems that optimize design, construction, maintenance and management in relation to end-users and environmental requirements. The Smart City Concept is based on the application of the digital transformation in urban areas. Since citizens are a focal point in the City, the Smart City concept combines the digital transformation with social issues such as governance and the implication of Citizens in the design and development of their City. The Smart Grid concerns the application of the digital technology towards the transformation of the "conventional" electrical system used today, into a more modern and "intelligent" system.

Literature survey showed that Smart City and Smart Grid issues constitute a great opportunity for humanity to meet the environmental challenges of today, and to build inclusive cities and energy systems that focus on the quality of life of citizens. However, these concepts are complex and recent. Their implementation requires learning from large-scale experimentations and demonstrators, before implementing into existing cities. A testing phase vital to a smooth smart city transition. This work aims to contribute to this issue through the analysis of the smart grid implementation, as well as the use of the smart electrical grid in an existing large-scale demonstrator of the Smart City, project “SunRise.”

SunRise Smart Grid

SunRise project aims to transform the Scientific Campus of Lille University into a large-scale demonstrator of the Smart and Sustainable City. The originality of this project lies in the smart monitoring of the urban utility networks, along with the collection and analysis of the data, all in the same platform. The Scientific Campus stands for a town of around 25 000 inhabitants. The electrical system supplies around 150 buildings and facilities, which involve a variety of different services such as research, learning, administration, catering, sports and residences. It includes a High-Voltage network, substations, transformers, a Low-Voltage network as well as smart sensors and electronic switches that allow an automatic control of the entire Grid. The High Voltage Grid was renovated in 2012. It resulted in smart substations, which allow, in the case of a local fault, the isolation of this fault and the automatic reconfiguration of the grid, ensuring a reliable supply to all the unaffected sectors. The Grid is controlled via a management system that allows a manual or automatic control of the Grid.

Use of the Smart system to analyze the campus electrical consumption

The thesis research focused on studying the use of the smart grid for the analysis of the electrical consumption of the scientific campus at Lille University. To achieve this goal, we developed a methodology for data processing, which includes the following steps: (i) measurement of the electrical consumption using Smart electrical meters and transmission of the recorded data to the electrical grid server, (ii) transmission of raw data from the electrical grid server to SunRise server and storing the data in SunRise information system, (iii) data cleaning; (iv) construction of the consumption profiles of buildings and groups of buildings and the analysis of these profiles to identify energy losses, (v) analysis of real-time data, and using the consumption profiles to detect any abnormal consumption and (vi) the analysis of the source of irregularities, providing recommendation for the further improvement of the electrical system.

This methodology was applied for analysis of the global consumption of the campus at different scales: daily, weekly, monthly and hourly. Analysis of the electrical consumption at the daily scale resulted in the identification of 5 levels of consumption. Each level is related to a specific period. For each level, the mean consumption and standard deviation were determined. Today, they are used to control the electrical consumption according to the methodology presented above.

Analysis of consumption data showed some anomalies, particularly high values during the weekend, holidays as well as at night. The sources of these irregular consumptions should be analyzed to rapidly commence improvement actions, such as shutting down building lighting, HVACs…etc., in addition to stopping non-essential devices and appliances during the night and non-working days. Analysis showed the possibility of reducing the campus power subscription by about 20%, which will result in attractive savings.

The proposed methodology was also applied to some buildings of the campus.

- Building P2, which is used for both teaching and research purposes. Analysis of the consumption of this building resulted in the identification of 5 levels of electrical consumption, which combine the different building usages: weekend, working day, holiday, night and day activity as well as summer and winter. For each level, we established the expected consumption and the corresponding periods. They can be used to control the real-time data consumption of this building and to track energy losses. Analysis of the consumption showed a "latent" energy demand of 17 kW, which generates significant daily consumption: around 82% (resp. 64%) of the weekend consumption (resp. working day) in the summer and 71% (resp. 55%) of the weekend consumption (resp. working day) in the winter. This "latent" demand is an important factor and should be tracked to explore the possibility of its reduction.

Thesis output

The output of the thesis includes an enhanced literature review of the city challenges and smart technology, analysis and presentation of the implementation and operational ability of the Smart Grid technology at the Scientific Campus of Lille University, a town-like environment of 25 000 inhabitants, and the application of this technology for the analysis of the electrical consumption of the campus at different time-scales (hourly, daily, weekly and monthly). The consumption analysis resulted in (i) an enhanced understanding of the electrical demand of the whole campus and some representative buildings of the campus, (ii) construction of consumption profiles of the campus and representative buildings, which allows a real-time control of the electrical consumption (iii) some recommendations to reduce the electrical energy loss through improvement of the lighting and devices control considering the main use of the buildings.

Future work

The following phase of this work should focus on the operating safety. Data concerning this issue are available. They constitute a valuable base for the future research.

The future work should also focus on the construction of a social network concerning the energy issues at the campus. The platform role is to inform users about energy consumption throughout the campus, sources of energy loss and recommendations for energy savings. It should also reinforce the involvement of users in the development of a sustainable campus.

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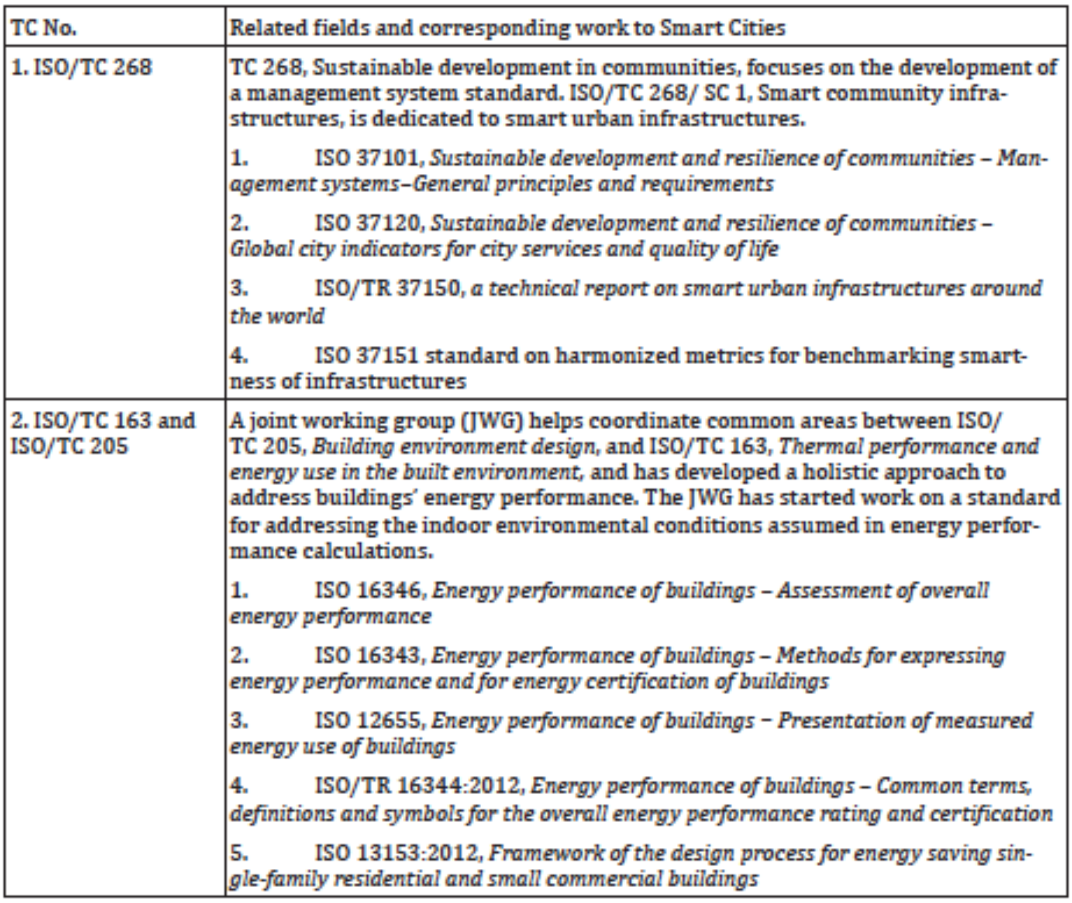
Appendix: ISO Standardization Work on Smart Cities

Source – ISO Smart Cities preliminary report 2014[38]



TC No.	Related fields and corresponding work to Smart Cities
1. ISO/TC 268	TC 268, Sustainable development in communities, focuses on the development of a management system standard. ISO/TC 268/ SC 1, Smart community infrastructures, is dedicated to smart urban infrastructures. 1. ISO 37101, *Sustainable development and resilience of communities – Management systems–General principles and requirements* 2. ISO 37120, *Sustainable development and resilience of communities – Global city indicators for city services and quality of life* 3. ISO/TR 37150, *a technical report on smart urban infrastructures around the world* 4. ISO 37151 standard on harmonized metrics for benchmarking smartness of infrastructures
2. ISO/TC 163 and ISO/TC 205	A joint working group (JWG) helps coordinate common areas between ISO/TC 205, *Building environment design*, and ISO/TC 163, *Thermal performance and energy use in the built environment*, and has developed a holistic approach to address buildings' energy performance. The JWG has started work on a standard for addressing the indoor environmental conditions assumed in energy performance calculations. 1. ISO 16346, *Energy performance of buildings – Assessment of overall energy performance* 2. ISO 16343, *Energy performance of buildings – Methods for expressing energy performance and for energy certification of buildings* 3. ISO 12655, *Energy performance of buildings – Presentation of measured energy use of buildings* 4. ISO/TR 16344:2012, *Energy performance of buildings – Common terms, definitions and symbols for the overall energy performance rating and certification* 5. ISO 13153:2012, *Framework of the design process for energy saving single-family residential and small commercial buildings*

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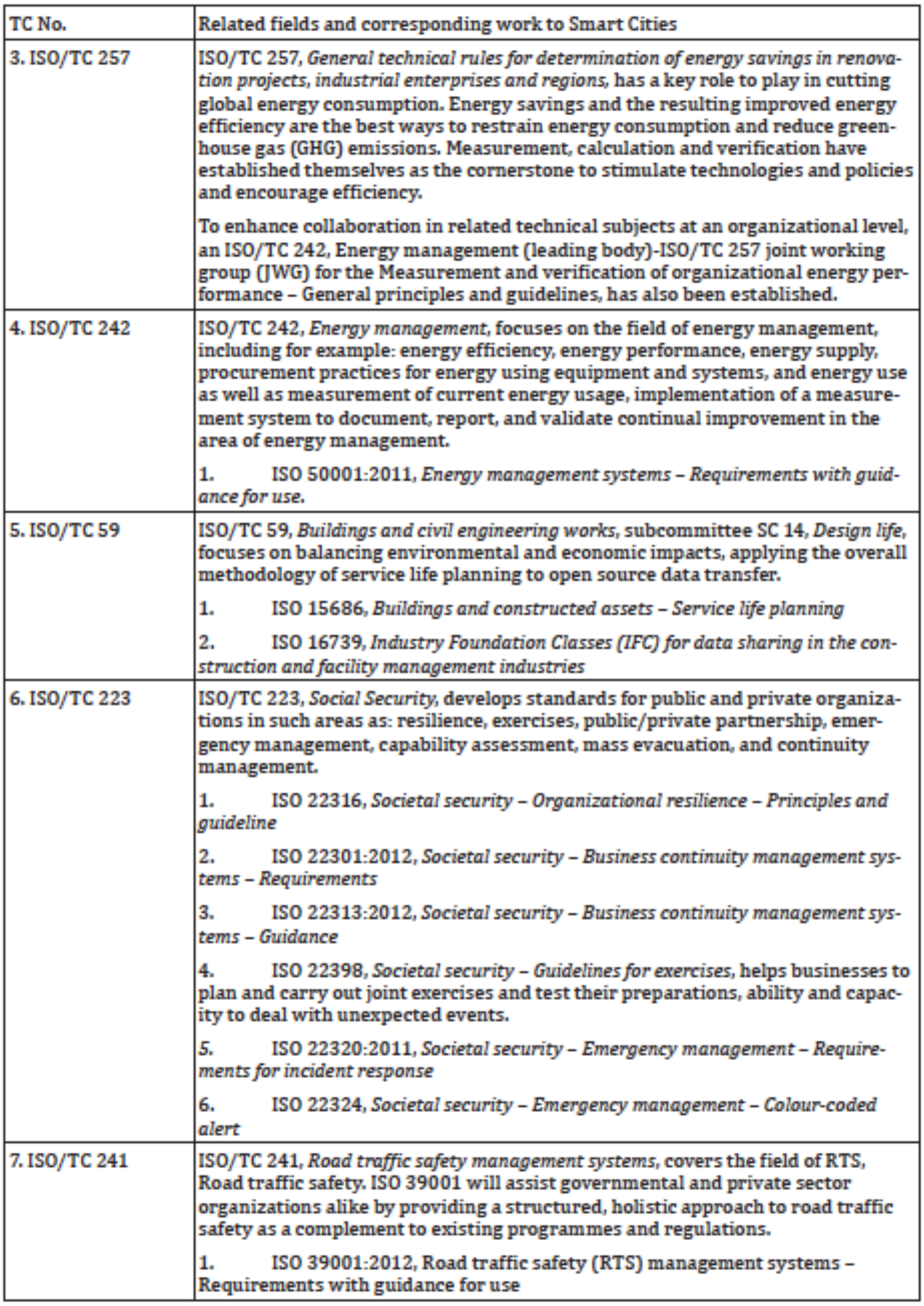
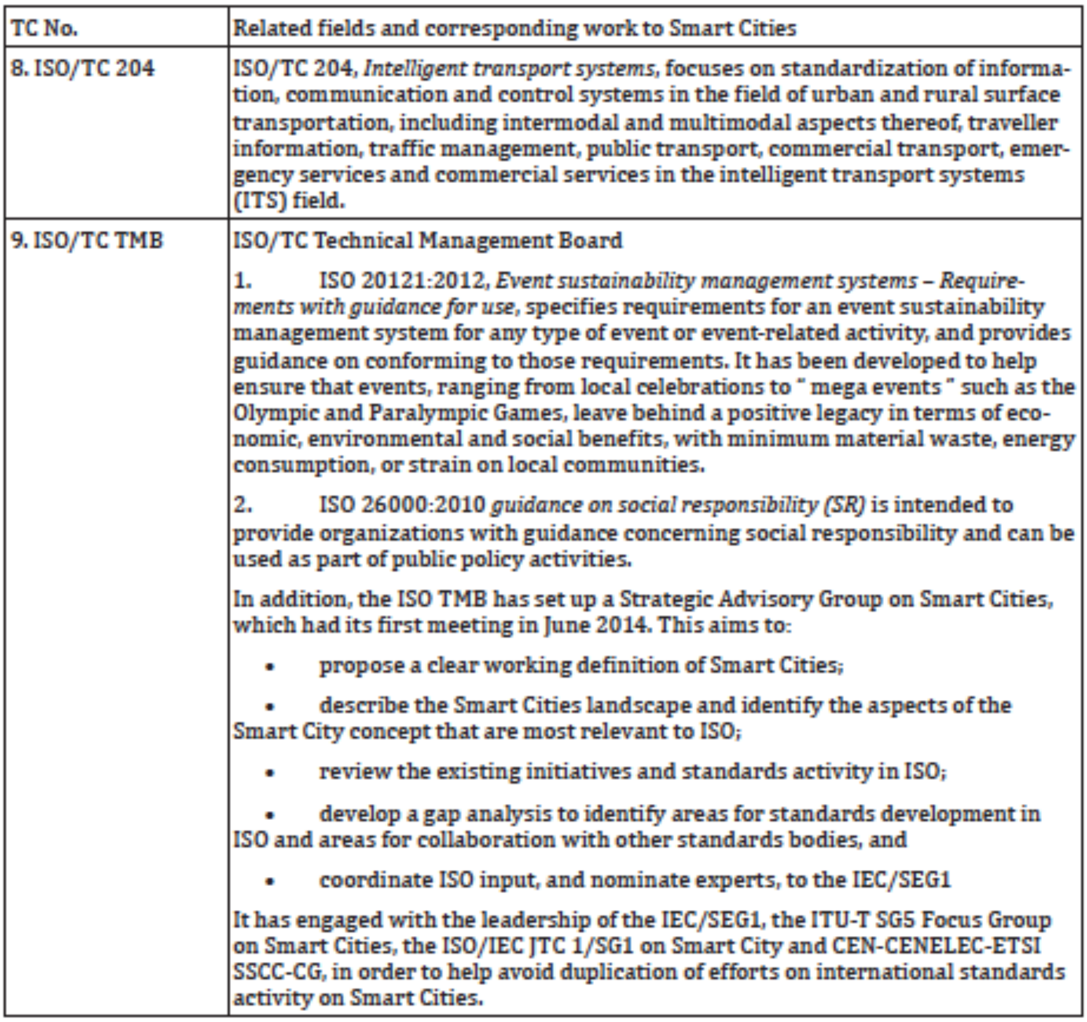
[38] http://www.iso.org/iso/smart_cities_report-jtc1.pdf)

Appendix



TC No.	Related fields and corresponding work to Smart Cities
3. ISO/TC 257	ISO/TC 257, *General technical rules for determination of energy savings in renovation projects, industrial enterprises and regions,* has a key role to play in cutting global energy consumption. Energy savings and the resulting improved energy efficiency are the best ways to restrain energy consumption and reduce greenhouse gas (GHG) emissions. Measurement, calculation and verification have established themselves as the cornerstone to stimulate technologies and policies and encourage efficiency. To enhance collaboration in related technical subjects at an organizational level, an ISO/TC 242, Energy management (leading body)-ISO/TC 257 joint working group (JWG) for the Measurement and verification of organizational energy performance – General principles and guidelines, has also been established.
4. ISO/TC 242	ISO/TC 242, *Energy management*, focuses on the field of energy management, including for example: energy efficiency, energy performance, energy supply, procurement practices for energy using equipment and systems, and energy use as well as measurement of current energy usage, implementation of a measurement system to document, report, and validate continual improvement in the area of energy management. 1. ISO 50001:2011, *Energy management systems – Requirements with guidance for use.*
5. ISO/TC 59	ISO/TC 59, *Buildings and civil engineering works*, subcommittee SC 14, *Design life*, focuses on balancing environmental and economic impacts, applying the overall methodology of service life planning to open source data transfer. 1. ISO 15686, *Buildings and constructed assets – Service life planning* 2. ISO 16739, *Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries*
6. ISO/TC 223	ISO/TC 223, *Social Security*, develops standards for public and private organizations in such areas as: resilience, exercises, public/private partnership, emergency management, capability assessment, mass evacuation, and continuity management. 1. ISO 22316, *Societal security – Organizational resilience – Principles and guideline* 2. ISO 22301:2012, *Societal security – Business continuity management systems – Requirements* 3. ISO 22313:2012, *Societal security – Business continuity management systems – Guidance* 4. ISO 22398, *Societal security – Guidelines for exercises*, helps businesses to plan and carry out joint exercises and test their preparations, ability and capacity to deal with unexpected events. 5. ISO 22320:2011, *Societal security – Emergency management – Requirements for incident response* 6. ISO 22324, *Societal security – Emergency management – Colour-coded alert*
7. ISO/TC 241	ISO/TC 241, *Road traffic safety management systems*, covers the field of RTS, Road traffic safety. ISO 39001 will assist governmental and private sector organizations alike by providing a structured, holistic approach to road traffic safety as a complement to existing programmes and regulations. 1. ISO 39001:2012, Road traffic safety (RTS) management systems – Requirements with guidance for use



TC No.	Related fields and corresponding work to Smart Cities
8. ISO/TC 204	ISO/TC 204, *Intelligent transport systems*, focuses on standardization of information, communication and control systems in the field of urban and rural surface transportation, including intermodal and multimodal aspects thereof, traveller information, traffic management, public transport, commercial transport, emergency services and commercial services in the intelligent transport systems (ITS) field.
9. ISO/TC TMB	ISO/TC Technical Management Board 1. ISO 20121:2012, *Event sustainability management systems – Requirements with guidance for use*, specifies requirements for an event sustainability management system for any type of event or event-related activity, and provides guidance on conforming to those requirements. It has been developed to help ensure that events, ranging from local celebrations to " mega events " such as the Olympic and Paralympic Games, leave behind a positive legacy in terms of economic, environmental and social benefits, with minimum material waste, energy consumption, or strain on local communities. 2. ISO 26000:2010 *guidance on social responsibility (SR)* is intended to provide organizations with guidance concerning social responsibility and can be used as part of public policy activities. In addition, the ISO TMB has set up a Strategic Advisory Group on Smart Cities, which had its first meeting in June 2014. This aims to: • propose a clear working definition of Smart Cities; • describe the Smart Cities landscape and identify the aspects of the Smart City concept that are most relevant to ISO; • review the existing initiatives and standards activity in ISO; • develop a gap analysis to identify areas for standards development in ISO and areas for collaboration with other standards bodies, and • coordinate ISO input, and nominate experts, to the IEC/SEG1 It has engaged with the leadership of the IEC/SEG1, the ITU-T SG5 Focus Group on Smart Cities, the ISO/IEC JTC 1/SG1 on Smart City and CEN-CENELEC-ETSI SSCC-CG, in order to help avoid duplication of efforts on international standards activity on Smart Cities.