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MEASUREMENT OF ENERGY CONSUMPTION OF ICT SOLUTIONS APPLIED FOR IMPROVING ENERGY EFFICIENCY IN TRANSPORT SECTOR

Master of Science thesis

Examiner: Dr. Josè Martinez Lastra

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ABSTRACT

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In the recent times, energy efficiency is an important field in manufacturing and transport sector, mainly due to ecological concerns and ever rising energy prices. Rapid increase in population is causing an energy overload and rise in level of Green House Gases (GHG), which should be dealt in an energy efficient and smart way. We are living in the information age, where broadband, internet and data center saturates the world of information. Information is available through all possible mediums, wired as well as wireless. Data transmission and data storing capacities of Information and Communication Technologies (ICT) infrastructures are growing very fast and continuously, which are helpful in developing effectual Intelligent Transport System (ITS) and will reduce various social and environmental problems caused by modern transportation.

This thesis is based on evaluating the share of energy consumed by ICT in a smart city for the transportation domain. The use of ICT in the transport sector has been increased for the last few decades where ICT is helping on developing more energy efficient systems. Due to extensive ICT equipment used, it is necessary to calculate the energy consumption of the ICT equipment itself to identify, how much energy has been reduced in the consumption. Consecutively, calculating the energy consumption and estimating how much energy efficiency is achieved with ICT equipment in the infrastructure. However, there is not a single widely approved methodology that can be implemented for appropriately estimating the energy consumption of the ICT infrastructure, which can yield correct and fruitful results. Apart from the methodologies followed for the work conducted, this thesis will also look into a number of other energy measurement methodologies.

All the entities involved in power consumption for ICT solutions in transportation are calculated and justified with visualizing the data collected. These results will help in evaluating the energy expenditure of the implemented systems and it will be possible to compare these values with the energy savings that are obtained. Finally, a JAVA based energy calculator is developed to accompany the test results collected.

PREFACE

The research work for this Master's thesis is conducted at Factory Automation and System Technology (FAST) Laboratory, for the department of Factory Automation and Industrial Informatics, Tampere University of Technology, Tampere, Finland. The work presented is a part of the MoveUS project: *ICT cloud-based platform and mobility services available, universal and safe for all users,* Tampere University of Technology is a key partner of the project. The research work was funded by European Union's Seventh Framework Programme for research and technological development.

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I would like to dedicate my thesis to my father, Zia Ul Islam and my mother.

Tampere, November 2016

Ahsan Zia

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ACRONYMS

AI	Artificial Intelligence
API	Application Programming Interface
ATMS	Advanced Traffic Management System
BPMN	Business Process Model and Notation
EE	Energy Efficiency
EEFF	Energy Efficient Factory of the Future
EM	Energy Management
EMS	Energy Management System
EPA	Environmental Protection Agency
ERP	Enterprise Resource Planning
EU	European Union
FASTory	Factory Automation and System Technology Laboratory
GHG	Green House Gases
GUI	Graphic User Interface
HMI	Human Machine Interface
HTTP	Hyper –Text Transfer Protocol
ICT	Information and Communication Technology
IDE	Integrated Development Environment
ISO	International Organization for Standards
ITS	Intelligent Transportation System
ITU	International Telecommunication Union
JEM	JouleX Energy Manager
JRE	JAVA Runtime Environment
MES	Manufacturing Execution System
UI	User Interface
UML	Universal Modeling Language

1. INTRODUCTION

In this age of information, energy is the main driving force behind the progress of human race. As energy is being produce and consumed in various forms, such as electric, mechanical, nuclear etc. The primary consumers of energy are transportation sector, manufacturing sector and residential sector. Transport domain consumes 28% of the global energy, while the consumption of industrial domain is around 51% [1].

Information and Communication Technology (ICT)[1] is a more extensive term and broader in scope than Information Technology (IT). It focuses on unified communication and telecommunications, computers and necessary software, middleware, audio–visual systems and storage. It enables users to access, transmit, store and manipulate information. In the modern time, more than three billion people have access to internet and almost in every ten internet users eight of them own a smart phone, which is expected to increase eight to ten percent per year from 2016 onwards.

There are numerous on-going studies of ICT energy consumption, and many of them are related to ICT-induced energy efficiency. ICT is only responsible for very small amount of global Green House Gase (GHG) emissions, an estimated 2% of man-made global emissions. But the rapid increase in ICT sector is also causing growth in emissions, which is the key motivation behind rising concerns about the environmental effects of ICTs [1].

ICT can reduce the environmental impacts of the other sectors, by increasing the energy efficiency. It is currently helping with energy reductions in the ample energy consuming sectors like, transport and manufacturing. ICT sector will increase the energy efficiency and will help to decrease carbon emissions to an enormous level until 2020, up to 15% [2]. Considering the amount of energy utilized by the industry and transport sector, the final energy dissipation related to ICT is quite negligible. The total electric power utilization by consumer electronics (televisions and hi-fi systems) in EU-27 is about 4.5%. Which are about 120 terawatt-hours (TWh) per year, and 97 TWh per year (3.5%) for ICT equipment including, communication infrastructure and data centers. The energy consumption of ICT is growing much rapidly than the total energy demand and its consumption is expected to increase to 15.5%, 400 TWh annually, which is due to the reason such as higher speed broadband access and higher capacity data centers [3].

Cities differ to each other with respect to population density, age distribution, development level, ICT solutions awareness among inhabitants, availability of ICT, geographic

[1] More detail about ICT can be accessed through:
https://en.wikipedia.org/wiki/Information_and_communications_technology

conditions and authority setup. City authorities are concerned in understanding the impact from a particular ICT solutions/service or project applied at a city level, or past ideas implemented in other cities. Some of the city authorities have already gained experiences from the use of ICT solutions and their impact on energy consumption and GHG emissions. Thus, it is valuable if experiences gained by one reference city could be used to help another city for better estimation of its possible gains from adopting the similar or parallel set of services. The Methodology, Recommendation ITU-T L. 1440, emphasis on evaluating the impact of ICT solutions in cities, it suggest the impact of ICT in relation to the overall impact of ICT solutions. Furthermore, it recommends methods explaining the various implementations the ICT should be used to reduce the rate of Green House Gases (GHG) emissions in the environment and increasing the energy efficiency of the systems [52].

1.1 Background

The potential of ICT for energy efficiency is a crucial task. ICT cannot induce energy efficiency by itself except for few cases in which embedded ICT directly controls energy flows. For bigger applications like smart cities, smart grids and transportation, ICT allows the possibilities to persuade users for improvement in energy efficiency. The concept of “Smart City” is a developing concept of the information age; *“Smart”* usually implies the use of ICT solutions in the city, a very commonly used term these days. A city is labeled as “Smart City” when it has ICT services in use, basic ICT structure and knowledge of operation of ICT solutions. The smart cities may include various smart functions and services, such as smart transport, smart housing and smart education system [3]. According to concepts given by various scientific publications and researches, the formal definition of “Smart City” that is used in this article is the following:

“A smart city is a city that meets its challenges through the strategic application of ICT goods, network and services to provide services to citizens or to manage its infrastructure” [4].

A standard smart infrastructure consists of a wide range of equipment ranging from small devices i.e. sensors, actuators, to big equipment i.e. server banks and data-centers, coordinating among each other to produce and operate the required system. These resources consume a definite quantity of power to perform the desired operations. An important effect of ICT is the power expenditure of all sort of ICT equipments during their operational life-time. The foremost significant factor of ICT equipment is the power consumption of devices during active mode. The second important factor is the devices in use, from servers to all other devices; sometimes, the standby consumption is even greater than the active time consumption. ICT equipment in use can be divided into different main categories, data centers, personal computers (PC), televisions, network equipment, and other ICT equipment such as printer, fax and audio devices [6].

According to a research, conducted by IBM[2] it has been found that almost 28 % of every dollar spent on energy bills were actually used by the IT equipment. The rest was spent on air-conditioning and other infrastructure, not generating productive outcomes of IT for the organization.

The estimated total energy consumption of data centers worldwide including cooling has an annual average consumption of about 58 GW [6]. This evaluation of PC power consumption is based on the number of PCs used worldwide. The average worldwide power utilization of different desktops and laptops, in "active" or "standby" or "off" mode is dissimilar and it is estimated at about 60 GW [6]. There are wide ranges of network equipment such as, routers, switches and modems. A recent evaluation of network equipment power consumption is about 50 GW yearly [6]. The average power consumption of TVs used worldwide is about 88GW yearly. Other ICT equipment including, printer and copiers etc. consumes about 80 GW. The total of all the above mentioned ICT equipment consume up to 336 GW yearly, which is about 8 % of the global electricity consumption, not including ICT used in manufacturing sectors. According to the observed trend, the increase in ICT energy consumption, the total power requirement for ICT equipment alone will be 430 GW in 2020, which will be more than 15% of the total global power consumption [6].

1.2 Problem Definition

1.2.1 Justification of Work

According to current studies, transport and logistics are contributing to about 40% of the global air pollution [5]. Improvement in transport generates a wide range of benefits for the whole global mobility system, which includes: reduction in air pollution, improved health conditions, the sustainability of the environment and energy savings in terms of cost and precious natural resources.

Most of the issues in transportation, such as traffic, share the same origin, population growth, which indicates the demand for personal or household vehicles. There is a breakthrough in ICT in the transportation sector, improving the efficiency of operations by being able to embed in business processes. With the recent advancements in cloud computing increased the use of mobile devices and cheap sensors. It has been decades that ICT is applied to the road network and transport sector to improve safety and efficiency. Therefore, it is essential to measure the energy consumption of the ICT solutions applied to the field.

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[2] More information available: Green ICT: Sustainable Computing, Media, e-Devices www.vertatique.com

1.2.2 Problem Statement

This thesis attempts to address, *"To identify the ICT solutions applied, the evaluation of ICT energy consumption of equipments and systems implemented for energy efficiency in the transportation sector of smart cities"*.

1.3 Work Description

1.3.1 Objectives

The primary objective of this work is to measure the power consumption of an ICT solution for improving energy efficiency in the transportation sector. A major part of this thesis will cover Intelligent Transportation Systems (ITS) and ICT concepts that are applied to the transport domain. Most of the presented details are based upon the current up-to-date available literature. Besides, calculating the total energy consumption of ICT solution in the smart cities for the transport domain, the thesis will also take a look at different methodologies that are used or that can be handy for this sort of evaluation of ICT solutions, mainly focusing on ITU L.1440 methodology for environmental impact assessment of Information and Communication Technology. The future extension of this work will be the comparison of energy efficiency that is attained as the result of successful implementation of ICT solutions applied to smart cities.

1.3.2 Methodology

In order to complete the objectives of this thesis, the subsequent steps were followed:

1. Up-to date literature review in the field of energy management in a generic prospective. It includes a study of established Energy Management Systems (EMS or EnMS). Study of ICT in transport domain along with its well-known example, Intelligent Transport System (ITS). Energy efficiency in manufacturing systems with a brief discussion on Smart Manufacturing systems and service oriented manufacturing systems.
2. Apart from the data collection done for the context of this thesis, there is a detailed review and analysis of possible approaches and techniques for measurement of energy consumption of ICT solutions, which also include a discussion on methodology for assessment of ICT energy consumption at a city level.
3. The evaluation of the infrastructures of the pilot cities i.e. Madrid, Genoa and Tampere of MoveUS platform. Technologies and tools used for data collection and visualization, implementation of those tools and methods.
4. Implementation of JAVA based "ICT Energy Calculator" developed using NetBeans, developed specifically for the thesis to accompany the test results.

1.3.3 Thesis Outline

The thesis is an organized work that is concluded in seven chapters. Chapter 2 presents literature review related to the context of the thesis. It includes broad discussion and concepts of Information Communication Technology (ICT) in transportation with a broad discussion about Intelligent Transport Systems (ITS), along with its different implementations, the concept of energy efficiency of ICTs in manufacturing systems with an insight on smart manufacturing, technologies for analyzing data, tools and methods for data visualization. Chapter 3 presents the methodologies to measure ICT energy consumption. The methodologies selected here are Continuous measurements of ICT infrastructure, "*Recommendation"* ITU-T L.1440 and Energy Star[3] "Energy Calculator Interface". Chapter 4 presents the methodology for assessment of ICT energy consumption at a city level, tools and techniques to analyze data and presents the research approach followed for this study. Chapter 5 documents the architecture of the pilot cities, along with their technical details, tools and methods to analyze and visualize the data. Chapter 6 shows the outcomes of the study, visualization of results and presents the implementation of JAVA based "ICT Energy Calculator" developed for the thesis. Finally, thesis conclusions, and further recommendations are presented in Chapter 7.

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[3] Description available at: http://energy.gov/eere/femp/energy-and-cost-savings-calculators-energy-efficient-products

2. LITERATURE REVIEW

We are living in the information age, where broadband, Internet and data center saturates the world of information. Information is available through all possible mediums, wired as well as wireless. Data transmission and data storing capacities of ICT infrastructures are growing very fast and continuously. According to European commission, the significance of ICTs is found limited in the technology than rather its ability to generate better access to information and communication in unreached population. Countries around the world have established organizations for the promotion of ICTs. It is expected that less technological developed regions have an opportunity to discover new ideas. The increasing technological advancement in advance countries will only just serve to intensify the effectively existing economical gap between technological "have" and "have not" regions [2][3].

ICT is a very broad term that comprises any type of communication device or application that includes television, cellular phones, computers, computer networks, satellites systems, network hardware and software and so on. These also incorporate the various services and applications associate with ICTs, such as video conferencing, e- environment, e- health, e-commerce, smart cities, smart grids (electricity), information management and last but not the least smart transportation systems [3].

Figure 1, shows the opportunities of ICT solutions applied to the subsectors of smart grids, transport, buildings and information management in the context of network, telecom, software and equipment respectively.

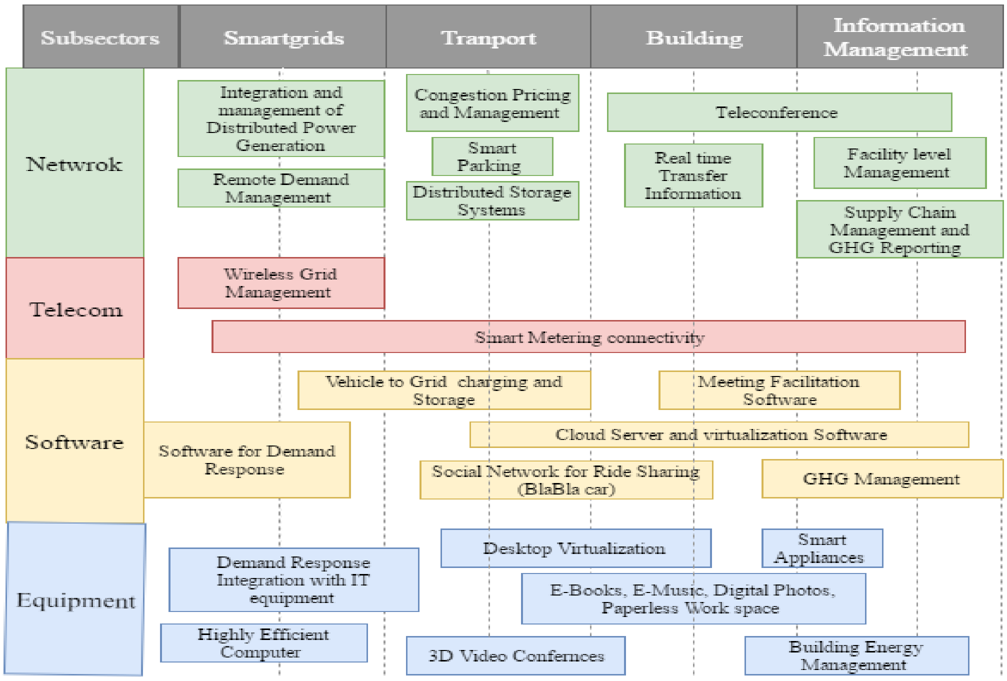

Figure 1: ICT solutions opportunities [4]

Chapter 2, will document literature review related to state-of-art technologies, concepts and details associated to the context of this thesis document. Section 2.1 presents arguments about Information and Communication Technology in transportation domain and its most common application *Intelligent Transport System*, with some of its applications and trends. Section 2.2 shows in-depth discussion about energy efficiency of Information and Communication Technology for the manufacturing systems, with *Smart manufacturing* in the subsection. Section 2.3 briefly discusses methods and some of the well-known technologies used for the analysis data. Finally, Section 2.4 presents visualization methods of data with suitable graphics and diagrams.

2.1 Information and Communication Technology in Transportation Sector

The Transport and logistics are key drivers of social and economical activities in the current society. The scope of transportation is very broad Transportation is a backbone of any country's economy, which serves people to commute and to transport goods over longer distances. The transportation infrastructures of many countries are undergoing a severe pressure due to intensive urbanization and rising population. Transport is a fundamental part of every nation's economy; it allows the people to travel to commute to their work place and guarantee that goods and services are effectively delivered to the inhabitant all over. The road infrastructures of many countries in the world have been designed around personal vehicles and expanding road infrastructure are resulting in congested road networks [12][15].

[4] Figure constructed using online tool: www.draw.io

The modern road traffic needs optimization of traffic flow in order to either resolve or ease the issues i.e. traffic congestions, long line caused by road charging, with the satellite navigation systems widely available such as, Global Positioning Systems (GPS or Sat-Nav) and vehicles efficiently fitted with various data sensors that can be used for traffic control, the task comes up to integrate all the available signals and data sets in order to provide optimal situation awareness and optimized traffic control. This might sound very difficult theoretically but it is not only very complex to achieve, it can be instantly implemented and integrated to overcome the issues of modern life and economy [13].

The answer to all the above mentioned concerns is an effective transport system which answers the every user's needs; here is presented the concept of Intelligent Transport System. ITS emerges from the challenges caused by traffic congestion and a synergy of new information technology for simulation, real-time control and communications networks. ITS is determined to add ICT to transport infrastructure and vehicles [13], to improve efficiency, reliability, safety, and the quality of modes of transportation. Section 2.1.1 document detailed information about ITS systems and some of its uses.

Figure 2, shows the share of ICT solutions applied by the system in the sector of transport.

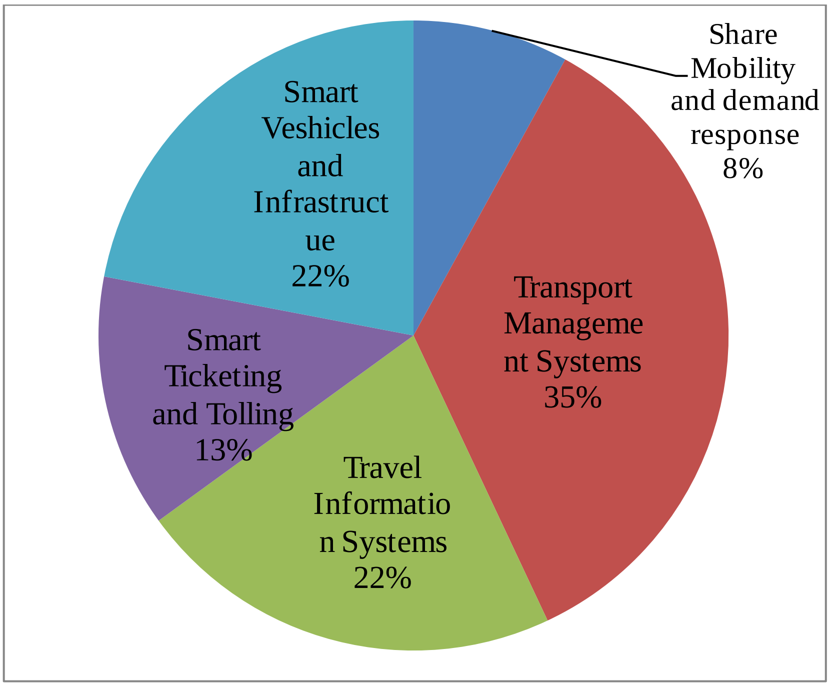

Figure 2: Share of ICT Solutions applied by Systems[5]

[5] Available at: http://www.eia.gov/energyexplained/index.cfm?page=about_home

2.1.1 Intelligent Transport System

ITS (Intelligent Transport System) are developed to help in determining various social and environmental problems caused by modern transportation, with the adaptation of innovative technology. In general terms, ITS is defined as:

"*The system where ICTs are applied in the field of road the transport network, which includes infrastructure, vehicles and the users, the traffic management systems and the mobility management, as well as interfaces for other modes of transport"[15]*.

The development of ITS have resolved several issues caused by modern transportation atmosphere with the use of ICT infrastructure. ICT has helped to overcome issues like, traffic congestion on a particular road due to rush hour traffic, accidents, law violations, weather reports and bus timings using screens at different points. It has also helped in cutting-down the emissions and in turn increasing the efficiency. This is achieved by connecting road side devices such as sensors, induction loops, CCTV, cameras, traffic signal, as well as, connecting vehicles with other elements like road side infrastructure, other vehicles, pedestrians and motorcycles [5][11].

The transport sector is lagging behind due to the difficulties in sharing information rapidly and easily among multiple systems. There are significant numbers of data sources in transport industry which are slowly becoming available, many of which make it possible to measure a variety of different aspects of city's transport infrastructure. The information sources which includes, sensors, satellites cars as well as social media etc. are collected and stored in data warehouses, that indicates that various entities inside a value chain systems does not share information as it should. For a properly functioning ITS to reduce congestion, an integrated approach should be used, to utilize these data sources as effectively [5].

In order for the transport infrastructure to respond appropriately to increasing demands, the sharing of its information requirements to be extended to offer an integrated transport solution. The solution brings together all the actors involved in a city, including the citizens as users, who often know more about the real-time performance of the transport infrastructure than operators and maintainers [5][13]. Figure 3, shows a generics block diagram of information exchange in the transport sector, which can be achieved by implementation of stable ITS for smart cities.

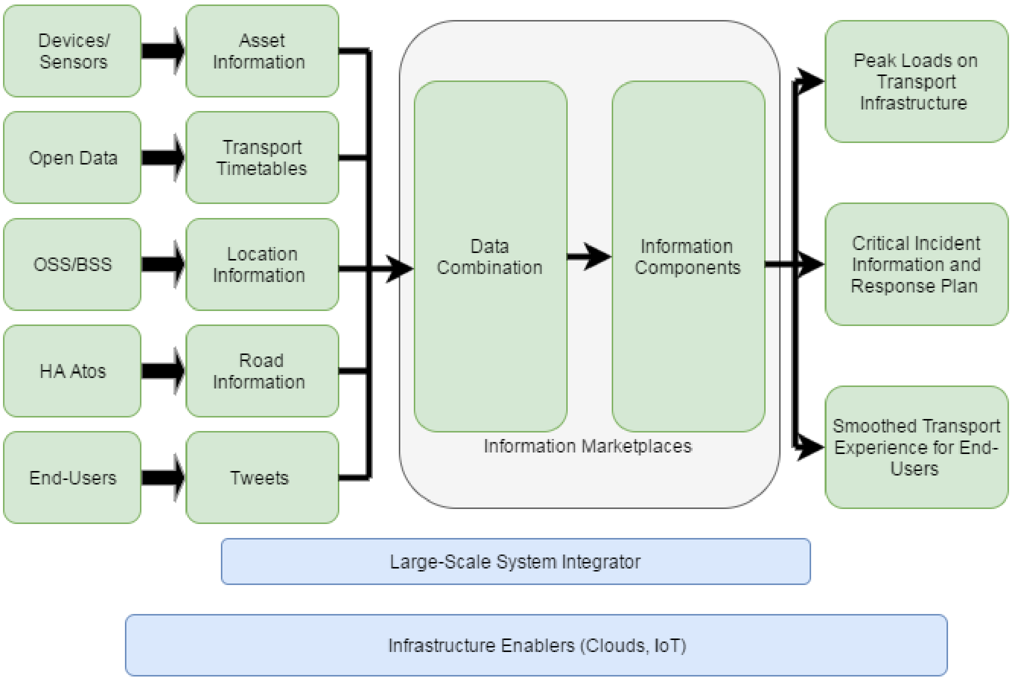

Figure 3: Information exchange in Intelligent Transport System [5]

2.1.2 Trends in Intelligent Transport System

This subsection will explain a list of ITS trends applied to the transport sector. In the current global scenario, with the use of embedded sensors and communication devices inside vehicles, it is now possible to collect significant amounts of data about the performance of not only vehicles but the drivers also. The data stored is used to create the data profile of the drivers, which is used to analyze the driving style of the people, for example, a solution like this is now used by Volvo. The system works on real-time when the truck is approaching a hill the system is able to control the truck to reduce the overall consumption of the truck [5]. Few examples are of ITS systems are listed in the section below.

2.1.3 Vehicle Information and Communication Systems (VICS)

VICS (Vehicle Information and Communication Systems) is one of the many ITS trends used in Japan, it is an ICT system that gathers and process road information related to traffic congestion and restrictions on the VICS center. The information gathered is then transmitted by radio and infrared beacons, broadcasting for display in three forms of data (text, plain graphical and maps) on navigation systems and other vehicle onboard devices. VICS operates 24 hours, and 365 days a year. Japan has over 54 million units of vehicle navigation systems (as of December 2012), out of which 36 million are compatible with real-time VICS road traffic information [12].

VICS provides appropriate route guidance, travel times, traffic congestion and restriction information to improve driver convenience. It has also helped to achieve better fuel efficiency, and thus reducing carbon emissions. TMC (Traffic Message Channel) is the European equivalent of VICS [11]. All the countries in EU offer TMC services using different channels, as National Traffic Information Centre provides services in Italy and V-Traffic in Finland. V-Traffic covers the entire Finland and uses Yle Radio Suomi as a medium of broadcasting messages nationwide. The collection of data by V –Traffic is done through vehicles on the road, data from public authorities, CCTV cameras, radio stations and some other private companies. The service can be used via the majority of the navigation units sold with the vehicles. [12].

2.1.4 Universal Traffic Management System (UTMS)

UTMS helps to achieve a safe and comfortable traffic environment with a comparatively low environmental load, it is achieves this by supplying real-time traffic information to drivers via sophisticated use of ICT , also including two-way communication between individual vehicles and traffic management systems using infrared beacons. It also performs proactive management of traffics streams, including safe driving support, actions for emergencies, and the facilitation of more efficient movements of people and logistics. This contributes to enhance the safety and smooth flow of road traffic and also alleviates traffic pollution [12]. Three services presented by UTMS are presented.

1. Advanced Mobile Information Systems

Advanced Mobile and Information Systems (AMIS) are systems that offer traffic information to on-board devices using infrared beacons in addition to traffic information signs and radio broadcasts. These systems aim to achieve natural dispersion of traffic streams and improve traffic congestion. By the end of 2012, all administrations in Japan had adopted AMIS [12].

2. Fast Emergency Vehicle Preemption Systems

Fast Emergency Vehicle Preemption Systems (FAST), uses infra-red beacons to detect emergency vehicles in areas where emergencies are frequent. It controls traffic signals to give precedence to the emergency vehicles. The main focus of FAST is to cut-down the time it required for emergency vehicles to reach an incident scene or medical facility and to help prevent accidents that can involve to emergency vehicles. As of the end of 2012, 15 city authorities have adopted FAST [12].

3. Public Transportation Priority System

Public Transportation Priority System (PTPS) control traffic signals to give priority to public transport primarily buses. The idea is to reduce journey times and increase user convenience, and thus encouraging people to switch from cars to public transportation. As of the end of 2012, 40 prefectures had adopted PTPS [12] [13].

2.2 Energy Efficiency of ICTs for Manufacturing Systems

Manufacturing and production are closely related terms. Manufacturing includes all industrial actions, from customer to factory and back to customer, while production is used for the process of making goods. There are four sectors in manufacturing: discrete manufacturing, semiconductor manufacturing, process industry and services. Manufacturing contributes 22% to Europe's GDP, it is a key industry. In EU, 70% of the jobs are directly or indirectly depend on manufacturing, discrete manufacturing, with an employ rate of 30% which is around 34 million people [28].

ICT has become the significant factor in the manufacturing domain. The use of ICT in industries has been increasing in the recent times and is providing technological support on each hierarchical level of industry. The use of ICT raises the information flow across all the parts of the industry and makes easier to follow the flow of communication from any point with in any hierarchical system. Power Consumption of ICT is rising rapidly worldwide, as of 2012 an estimated 2% of the global carbon dioxide emission came from the manufacturing and the use of ICT equipment. Global electricity production will be double till 2030, from 16.4 TWh (2004) to 30 TWh, with an increase of 2.4% per year. Europe's share in global energy consumption is about 18 % (10,900 Mtoe) (Million Tons of Oil Equivalent, 1 toe = 11.63 megawatt-hours (MWh). In which the share of manufacturing industry is almost 297 Mtoe[2][63].

Industries should be able to respond instantly to changing market requirements and flexible to adopt new systems and technologies to succeed in the current global manufacturing scenario. When manufacturing system needs to adapt a new system or product, re-implementation of the shop floor related to ICT might be necessary to keep the information system integrated. The industries are also expected to provide extended insight into all levels of the factory's and the capability to expose more information about different levels of factory, so that there is availability of required information at right time to take correct decisions.

The architecture of ICT of manufacturing sector is reflected in a variety of multi-tier models, the most well-known is the Automation Pyramid, shown in Figure 4, compares the Automation Pyramid of manufacturing enterprises to the new reference representation for industrial information infrastructure.

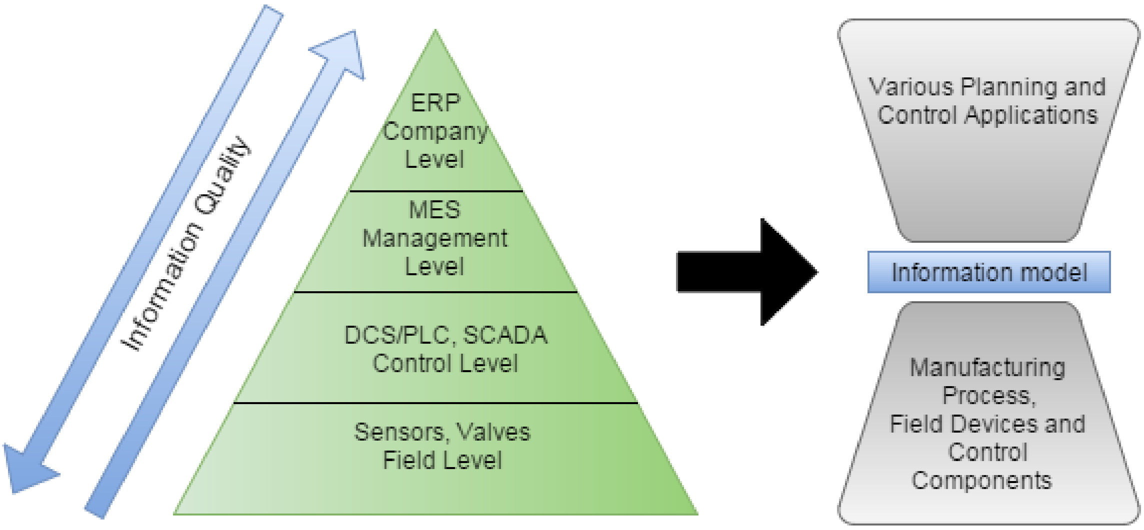

Figure 4: Changing Information Architecture in Manufacturing Enterprise [6] [22]

The automation pyramid is hierarchical layered and different levels represent similar functions. The pyramid highlights the decreasing data flow from device level towards to the top layer for control of the production process, it affects the quality of information is less at device level [22].

2.2.1 Smart Manufacturing

A classic manufacturing plant uses information technology, sensors, intelligent motors, computerized controls, production management software and the tools for managing each specific process. The concept of smart manufacturing will interconnect and better complement these individual stages of manufacturing production to advance plant-wide efficiency [46].

"Smart Manufacturing addresses the goals of optimization concept generation, production and product transaction in manufacturing sector" [46].

SM can be considered as the combination of the entire factor involved in manufacturing i.e., personnel, computer control devices, PROFINET, and high level adaptability among them. The purpose of such integration is to take advanced information and manufacturing technologies to enable flexibility in physical processes to address a dynamic and global marketplace. SM increases the pressure of workforce training for flexibility and utilization of technology rather than specific tasks as required in traditional manufacturing. The creative utilization of SM helps increases product innovation via intelligence collection of feedback from every point inside the supply chain and this innovation will help get information about consumer preferences through production and delivery mechanism [46].

[6] Figure constructed using: www.draw.io

In smart manufacturing, some of the devices are programmed or are dedicated to do processes in a cyclical manner, i.e., robot processing the arriving products or pallets with some predefined system. The deviation in energy consumption by these repeated regular time processes can be detected from its original pattern can be detected by the use control charts. If there is some irregularity in the process energy consumption of the robot, then the control chart will deviate from its original, and if the deviation is larger than three standard deviations then a warning of violation is displayed in the charts [45]. Energy efficiency in the manufacturing sector extends beyond a simple stand-alone approach, for example, a peak load avoidance or single process or machine optimization [26].

Energy Efficient Factory of the Future (EEFF) is an expression, which refer to continuously extracting energy associated information from any certain location at factory floor and combining it with enterprise wide information for global factory optimization. Monitoring the manufacturing facilities energy consumption sources in essential and it is required to create information and processes that are energy aware and attempt for better utilization of resources [26]. Energy efficiency can be brought to the factory floor by including dynamic access and service management. The criteria for the optimizing process, production and logistics can cover not only the expenditure, but can also indexes related to energy. The optimization loops will cover all factories' levels, from automation system to Enterprise Resource Planning (ERP), ensuring multidisciplinary coordination and control. In this way it is possible to have business decisions taken in full knowledge of the energy consumption situation at the factory floor [26].

Figure 5, shows a snapshot of energy aware the business process.

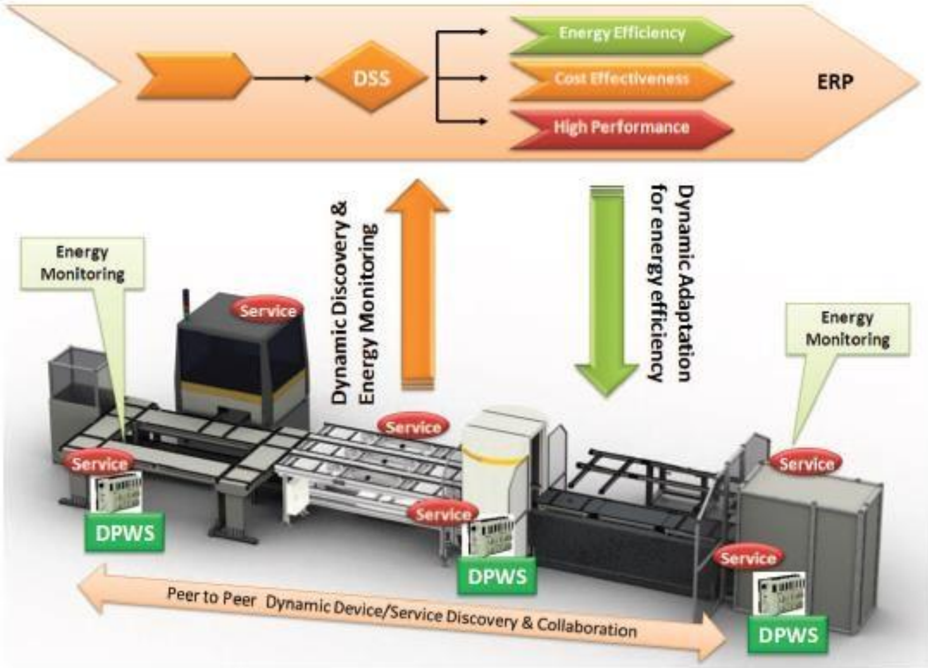

Figure 5: Energy aware business process [26]

2.3 Technologies for Analyzing Data

Technology provides specific set of tools for data analysis and data mining with certain complication and restrictions. Many technologies are developed for data analysis using popular programming languages, i.e. C, C++, JAVA, MALAB, Visual Basic etc.
This subsection briefly discusses methods and some of the well-known technologies used for the analysis and visualization of the data, which are necessary for the context of this thesis.

2.3.1 Microsoft Excel

Microsoft Excel[7] is a part of Microsoft office suite of applications. It features calculation, graphing tools, pivot tables, and macro programming language called "*Visual Basic for Applications*". Excel has the basic features of all spreadsheets, using a grid of cells arranged in horizontal rows and vertical columns, with numbered rows and alphabetical columns to categorize the data manipulations, i.e. mathematical and arithmetic operations. In addition, it is also widely used to visualize analytical data into graphical forms and provide support for displaying data as, histograms, line graphs and charts, in 2D and as well as in 3D formats. Latest version of Excel is Microsoft Excel 2016. Microsoft Excel is primarily used for this thesis for collection and analysis of the data as well as used as a visualization tool.

[7] More detail available at: https://products.office.com/en-us/excel

2.3.2 MATLAB

MATLAB[8] or **MAT**rix **LAB**oratory, is a multi-paradigm numerical computing environment and fourth-generation programming language, developed by MathsWorks. It allows matrix manipulation, and visualization of mathematical function and data. It is also used for implementation of algorithms, formation of user interfaces, and interfacing with programs written in other languages, i.e. C, C++, JAVA, and python. The main functions of MATLAB are intended mostly for numerical computation, an optional toolbox uses the MuPADsymbolic engine, allowing access to symbolic computing abilities. An add-on toolbox, Simulink, adds graphical multi-domain simulation and model-based design for dynamic and embedded systems.. The latest version is MATLAB 9.1 R2016b. MATLAB is used in the context of this thesis to create Sankey diagram.

2.3.3 NetBeans

NetBeans[9] is an *open-source integrated environment*, it is a software development platform written in java. This platform allows applications to be developed from a set of modular software components modules. Applications based on the NetBeans platform, including the Netbeans Integrated Development Environment or IDE. All functions of the IDE are supported by modules; each module provides a well-defined function like, support for the JAVA language and editing. NetBeans IDE is primarily intended for development in JAVA, but also supports other languages like PHP, C and C++. Latest version of the software in use is NetBeans IDE 8.1.

IDE[10] (Integrated Development Environment) is a software application that provides wide range services to developers for software development. Some IDEs, specifically NetBeans and Eclipse, contains a compiler, interpreter, or usually both functionalities. IDEs present a single program where all development is done. The programs usually provide many features for writing, modifying, compiling, deploying and debugging of software. NetBeans is used to develop *"ICT Energy Calculator".*

2.3.4 Eclipse

Eclipse [11] is an IDE used in computer programming, and is the most widely used JAVA IDE. It is frequently written in Java and mostly used to develop JAVA based application. Eclipse is also used to develop application in other programming languages like, C, C++, Python, and JavaScript using plug-ins. Eclipse supports development for Tomcat, GlassFish and many other servers and is able of installing the necessary

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[8] More detail available at: https://se.mathworks.com/products/matlab/
[9] More detail available at: https://netbeans.org/kb/index.html, https://en.wikipedia.org/wiki/NetBeans
[10] More detail available at: https://en.wikipedia.org/wiki/Integrated_development_environment
[11] More detail available at: https://eclipse.org/home/index.php, https://en.wikipedia.org/wiki/Eclipse

server directly from the IDE. Latest version of the software in use is Neon version 4.6. Eclipse aided to JAVA application developed for the "ICT Energy Calculator".

2.4 Tools and Methods for Data Visualization

Visualization of data with suitable graphics, have more demonstrative power than plain data. In *prediction statistics,* it is used to recognize trends within the data that allow the possibility of future estimations. In decision support, different scenarios can be compared with each other, i.e. when selecting a system or device to be installed in multiple strategies.

This subsection explains the tools used to visualize the data. Different types of charts and diagrams are used to explain features of the data. The visualization of data has many advantages, as it is a more powerful method of displaying information than raw data, which leads to meaningful results. Moreover, it allows the opportunity to comparison of different data sets.

The data has been visualized using different tools and methods, which are illustrated as follows,

- Pie-chart
- Pareto chart
- Sankey diagram
- Radar chart

2.4.1 Pie Chart

A pie chart[12] or a circle chart, is a circular statistical graphical for to present data. It is named for its resemblance to a pie which has been sliced; there are variations on the way it can be presented. Pie chart is divided into slices to demonstrate numerical proportion. The arc length of each slice is proportional to the quantity it represents. The earliest known pie charts are credited to *William Playfair's Statistical Breviary*, where two such graphs were used. Pie charts can be implemented in 2D as well as in 3D formats. Numerous visualization soft-wares can be used to create pie charts, i.e. Excel, Visio, MATLAB etc. It is also known to be the simplest method to visualize data sets and is very widely used in the business and the mass media applications.

2.4.2 Pareto Chart

Pareto Chart is one of the *seven basic tools of quality control*. It is the type chart that contains both bars and a line graph, the individual values are represented in descending order by bars, and the total accumulative values are represented by the line. The lengths of the bars represent values, i.e. cost, time, energy, speed etc, the bars are arranged with

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[12] More information on Pie charts: https://en.wikipedia.org/wiki/Pie_chart

longest bars on the left and the shortest to the right, this is the way to show the more significant to less significant values.

Pareto chart is use for analyzing data about the frequency of the problems or causes in a process, when there are many problems or causes and the focus is on the important to less important. Pareto chart can be constructed using Microsoft Excel.

Figure 6, show a generic Pareto chart, showing utility cost of appliances.

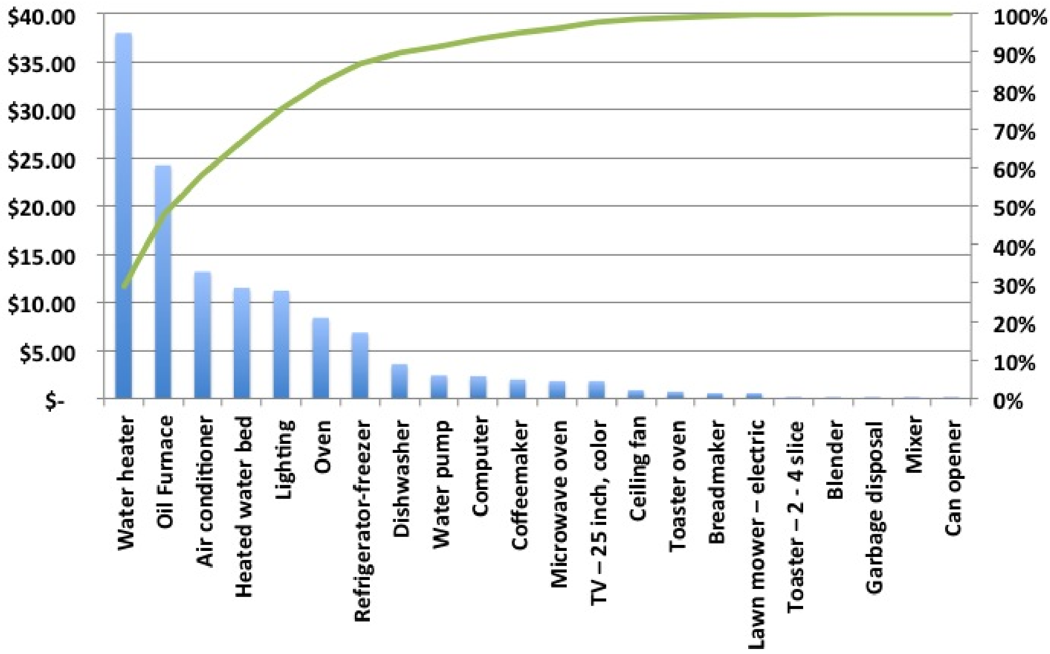

***Figure 6: A generic Pareto chart, showing utility cost of appliances*[13]**

2.4.3 Sankey Diagram

Sankey diagrams are specific type of flow diagrams, where the width of the outgoing arrows refers to the flow quantity of the resources. A Sankey diagram shows visual significance on the major flows and transmission within a system. It is useful in locating the main contributions to an overall flow of a system. Different colors of Sankey diagram represent the degrees of freedom of the diagrams.

Sankey diagram is used for the visualization of any resource, commonly used to visualize energy or material or cost transfers between processes and systems. It can also be used for energy accounts, material flows accounts and the breakdown of the cost of items or services. In energy management systems, it is used for visual representation of all the energy inputs to the process or system and the energy outputs and corresponding losses. Another common use of Sankey diagram is by Eurostat, which has developed

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[13] More information on Pareto chart at: http://www.keywordsuggestions.com/cGFyZXRvIGNoYXJ0/ (Pareto Chart), https://en.wikipedia.org/wiki/Seven_Basic_Tools_of_Quality

an interactive Sankey web based tool to visualize energy data of EU. The tool allows the user to construct and customize own diagram by utilizing different options i.e. country, year, detail, fuel type etc. The Figure 7, refers to the diagram by Eurostat.

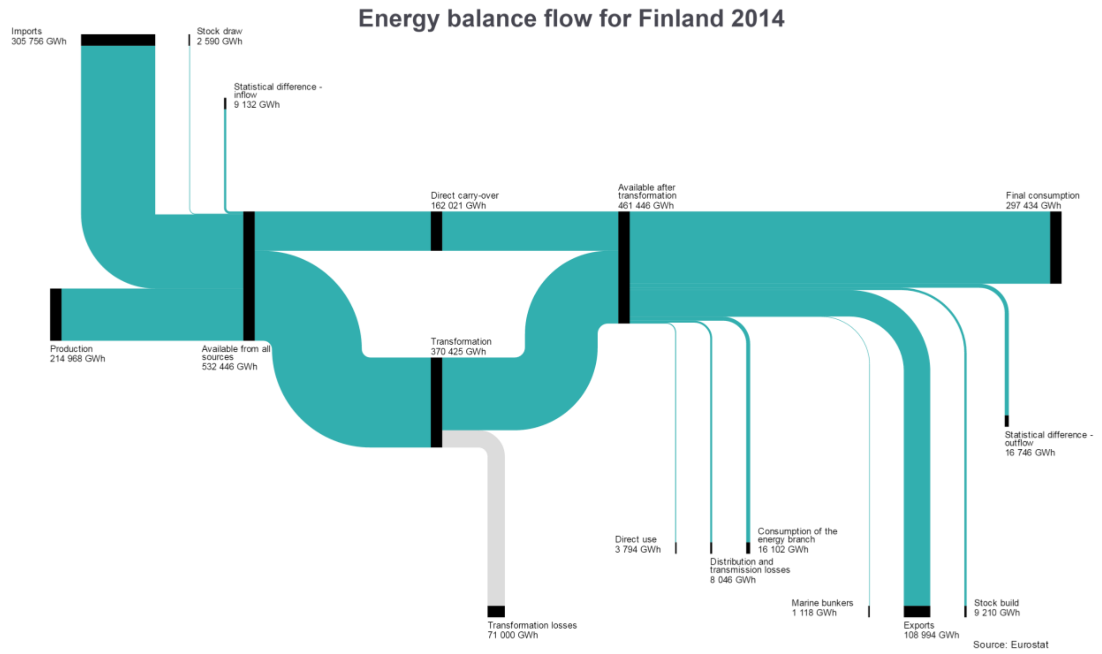

Figure 7: A generic Sankey diagram showing energy flows, Eurostat[14]

2.4.4 Radar Chart

Radar Chart[35] or Spider Chart is a graphical method of displaying statistical values in the form of 2D or 3D Charts of three or more quantitative values. Values are represented on axes arising from the similar point. The relative position and angel of the axes usually does not contain any information.

The radar chart consists of a series of equi-angular bars, known as radii. Each bar represents each of the value. The data length of lines is proportional to the magnitude of the values for the data point relative to the maximum magnitude of the value across all data points. A line connects the data values for each bar of the chart. The figure below shows a generic radar chart. A common application of radar charts is the control of quality improvement to display the performance parameters of any ongoing program. Other application includes, visualization of employees performance data, based on rankings given by their respective supervisors, on a single chart. Radar chart can be constructed using tools like Excel, Visio, and MATLAB etc. Figure 8, shows a generic radar chart, demonstrating energy discharge.

[14] More information on Sankey diagram, EUROSTAT website at: http://ec.europa.eu/eurostat/cache/sankey/sankey.html?geo=FI&year=2014&unit=GWh&fuels=0000&highlight=&nodeDisagg=1111111111&flowDisagg=false

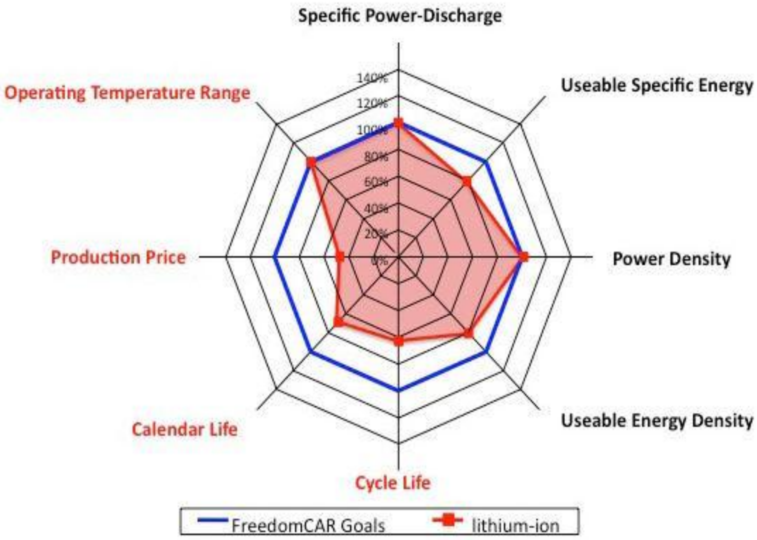

Figure 8: A generic Radar chart, showing power discharge [15]

[15] More information on Radar chart at: http://www.silverbearcafe.com/private/09.12/batteries.html

3. METHODOLOGIES TO MEASURE ICT ENERGY CONSUMPTION

Power consumption of ICT is growing quickly worldwide. In 2007, Gartner estimated that 2% of the global carbon dioxide (CO_2) emissions come as of the manufacture and use of ICT, an estimation equivalent to the direct emissions caused by aviation (Gartner, 2007) [7]. It is predicted that worldwide energy utilization and emissions of ICT are rising faster than those of the energy use in general. Reducing the energy demands helps to achieve sustainable goals in the area of energy security, ecology, energy depletion and economy. The household provides real time feedback about energy use typically results in 5 to 15% in energy savings, whereas indirect feedback results in less energy savings, around 0 to 10% [8].

Improving energy efficiency helps an organizations to create relevant objectives, and identify and prioritize the areas, systems or activities where there is a potential to improve energy efficiency. Many cities are developing efficient procedures for systems to measure the energy consumption of ICT solutions applied to transport domain at city level. Currently, it is quiet difficult to select a single hands one methodology that can be implemented to correctly estimate the authentic utilization of energy of ICT equipment at city level. The estimations done are usually roughly predicted figures or organized by measurement based on the resources available to the city, electricity bills are used to examine the energy consumption by correctly evaluating the working hours of the equipment and the systems [8].

According to the context of this thesis, the following methodologies are considered important. Each of the methodology is described with example in the subsections of this chapter.

1. Continuous measurements of ICT infrastructure
2. Recommendation ITU-T L.1440
3. Energy Star[16] "Energy Calculator Interface"

3.1 Continuous Measurements of ICT Infrastructure

Continuous monitoring and management of ICT energy is an approach, which can be taken into account to increase ICT energy efficiency [8]. Instead of measuring yearly, as

[16] Description available at: http://energy.gov/eere/femp/energy-and-cost-savings-calculators-energy-efficient-products

necessary, the evaluation should be done more frequently, for example, on monthly, daily, hourly or continuously basis.

Continuous measurements of ICT infrastructure in use can be done using variety of methodologies; according to the background of this thesis four major approaches are described.

1. In-line meters, requires breaking the electric circuit to install the meter
2. Clamp-on-meters, wrapped around wires
3. Add-ons to existing energy meters, uses analog or digital ports of existing energy meters
4. Software- only measurement, uses existing network interfaces, protocols and APIs

All the above mentioned techniques and methodologies are discussed in detail in the next sections of this chapter.

Various other measurement and monitoring technologies can also be used to manage energy measurement and use, for example, by switching devices and groups of devices on or off; According to on some predetermined schedule or timetable. Other methodologies focus on taking energy related data from the official data sheet of the equipment, which is provided by the manufacturer, having all its energy and devices specification details. For example, the data sheet provided come from Cisco (Cisco Catalyst 2950 Series Switches) at [16]; it shows the "power requirements" of the device as well as with other technical specifications. The second method is to use energy meters for carefully to estimate the consumption of devices [7].

3.1.1 In-line meters

In line meters are added in electric power circuits of a device or group devices, in general a circuit consists of a number of devices or sometimes dozens of devices connected in a system. Typically, the power to the devices is interrupted for the meter to be installed inside the system, which can be an issue is the devices do not have a redundant power supply [10].

Currently, there are many types of in-line meters and systems in used few of which are described as under.

Plug-in Socket Meters

Plug-in is an electricity monitoring and management system intended for both the residential market and the small business market. It measures electricity consumption at the power-plug of single or groups of individual devices. The circle measurement devices shown in Figure 11 are installed by removing the plug of devices that is to be measure from its power socket, inserting the circle in the socket and then inserting the device power switch in the circle [8][10]. Figure 9, shows a picture of Plug-in socket meter.

Figure 9: Plug-in socket meter [17]

Plugwise is such a company which is the pioneer is designing, developing and producing wireless energy management and control systems. This system helps to increase building efficiency and sustainability. Individuals and organizations receive current and accurate insight on their energy consumption through a wide range of energy monitoring & control systems whereby they can save in between 10 and 40 % of their total power consumption.

The implementation of the system is easy and quick at a very little cost and works everywhere. As the wireless energy management system does not require for a widespread cabling and works independently from energy companies, the system can conveniently be brought along when moving the infrastructure elsewhere [10]. Figure 10, shows plugwise energy measurement devices, top Plugwise Circle (left), Strech lite pro-measurement gateway (right) and Stealth (bottom).

[17] Description: http://hes.lbl.gov/consumer/

Figure 10: Plugwise circle (left), Plugwise Strecch lire-pro measurement gateway (right), Plugwise Stealth (bottom) [10]

The Measurements that are collected through a low-power wireless mesh network based on the ZigBee standard to a central location, e.g. a PC with a Plugwise USB stick. The system is very suitable for evaluation power consumption of ICT devices such as PCs, monitors, etc in an office environment, separately from other office uses of electricity. Technically, Plugwise can also be used to measure electricity use of individual servers in a datacenter, as long as a compatible power plug-ins are used. Measurements can also be stored on a measurement gateway (see Figure 11, right) that connects to the measurement network and that can be accessed via the company network [10].

Figure 11: Plugwise measurement forwarded to a central location[18]

Plugwise management portal presents an insight view of the status of the network, the current and past consumption of power is recorded, and the savings are compared with a normal period in the past. The management portal also provides a greater variety of vis-

[18] Available at: https://www.plugwise.de/management-portal

ualization options of Plugwise data as a source, Plugwise systems can be controlled in a number of buildings from a central point. Figure 12, shows a snapshot of the portal.

Figure 12: Plugwise management portal screenshot [14]

Switched Metered Power Distribution Units

Power Distribution Units (PDUs) are devices fitted with a multiple outputs designed for the distribution of electric power to racks of computers and network equipment inside a data center. Mostly, all the data centers confront issues in power protection and management solutions, which makes data centers dependant on PDU monitoring to improve efficiency. In data centers, PDUs inside a server rack distribute power from one of more feeds to several devices, for example, servers or routers, to measure the power consumed by all the devices in a rack or individual devices in a rack independently. PDUs support remote monitoring and control of the power are also known as switched PDUs, because the power to sockets can be switched on and off remotely.

PDUs have the functionalities of power metering at inlets and outlets and provides support for environment sensors. PDUs may vary from plain rack-mounted power strips to large floor-mounted PDUs, equipped with multiple practicalities like, power filtering to improve quality, intelligent load balancing systems and some complex features like, remote monitoring and control of resources via LAN [10].

Figure 13: Power Distribution Unit (above). Power meter (below) [19]

Rittal is one such company which provide power system modules, that measures voltage in Volts (V), current in Ampere (A), power in kilo-watt-hours (kWh), and output kilo-watt (kW) per feed and per phase. Measurements can be transferred via data-bus and regular connectors (RJ-45) to processing unit (Rittal CMC-TC). An enclosed monitoring unit serves as a gateway which allows management and queries of the PSM through HTTP. Other manufacturers and suppliers of PDUs and energy monitoring and control units are Janitza, Schleifenbauer.

Figure 14: Rittal PSM modules with power meters per bars [20]

[19] Device description detail, available at: http://www.janitza.com/
[20] Device description detail, available at: http://www.rittal.com/

3.1.2 Split Core Clamp Meters

There are certain conditions where interruption of power to a circuit in not possible due to functionality of the device, here split-core clamp meter comes into utilization. Clamp meters mostly consist of a current transformer in its jaws and bar current transformer (CT). Clamp meters works on the principle of current transformer, the reading is displayed. These devices can measure properties of AC in a conductor. This is done without having a physical contact with the conductor or the devices; they can be disconnected and reconnected due to clamp action of these meters. Clamp meters usually remains wrapped around the conductors almost throughout the operational life time of the devices. The measurement potential of these meters range kilo-watt-hour (kWh) [10].

Figure 15: Split-core current clamp meter [10]

Fluksometer is also a power monitoring device, it is a power meter that measures only current via a current clamp meters and gives assumption values about voltage. The measurements are uploaded to a central server, which can be either a server connected to the internet or local server. The application can be downloaded Flukso, which is a web-based community metering application.

Figure 16: Fluksometer, power monitoring device gateway [21]

[21] Device description detail, available at: https://www.flukso.net/

3.1.3 ADD-ON Existing Billing–Grade Energy Meters

Energy measurement systems are usually based on a sensor that is attached to an existing billing-grade energy meters. Usually, sensors are connected to old rotating Ferraris meters. It collects and stores energy usage data minute by minute, 24 hours per day, and can display real-time data of the energy usage on a computer, a smart phone or on its own wireless display. Figure 17, shows the sensor and measurement gateway of ADD-ON meters.

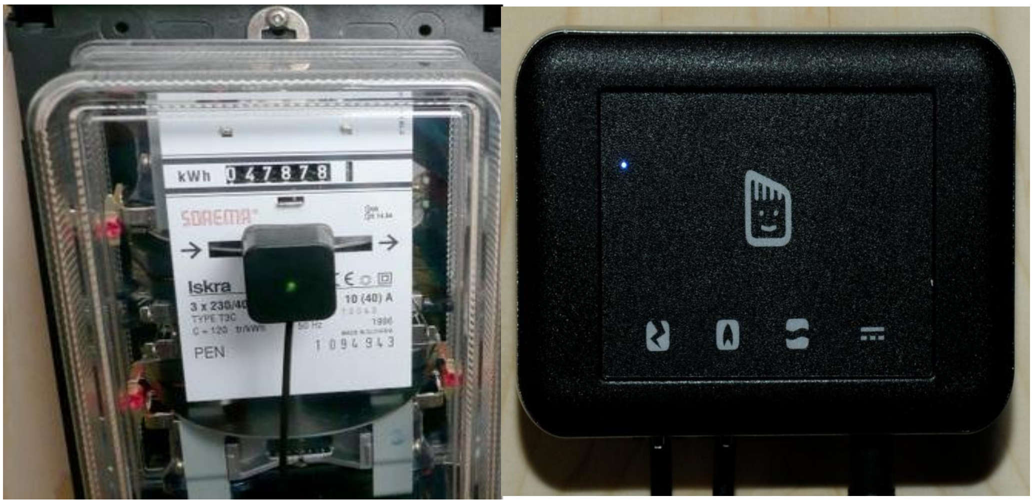

Figure 17: EnyMate Sensor (left) and measurement gateway (right)

EnyMate is a company which produces such types of systems, provides sensors for old ferraris meters[22], LED/impulse sensors and a gateway which can upload all the data related to measurement of the energy to EnyMate Portal. This data can be accessed by the customers through logging in to the system. This type of a system is usually targeted towards individual household customers but can also be applied to small scale ICT integrated systems. The Figure 18 is a snapshot of EnyMate energy monitoring portal.

[22] More detail available at: http://www.landisgyr.com/webfoo/wp-content/uploads/product-files/D000011432_Ferraris_d_en.pdf

Figure 18: EnyMate monitoring portal snapshot [23]

3.1.4 Software- Only Measurement

Software only measurement is a completely different approach from the rest of the above mentioned methodologies. It uses existing network interfaces, protocols and Application Program Interfaces (APIs) for monitoring and control of the power consumption of the computers and connected devices present inside the networks. The network attached devices and leverages existing software APIs of these devices helps to report their energy usage [10].

JouleX Energy Manager (JEM) is such type of software type energy monitoring tool, that can monitor and control any IP based device without adding hardware energy meters to the systems. It works without any end devices like, additional hardware or software, or making any change to the existing system, thus saves the cost spent, installation time and modification that should be done to the system.

Figure 19, shows the architecture of devices which can be evaluated with the help of Software-only measurement. Figure 20, shows a snapshot of JouleX dashboard portal and JouleX report screen snapshot

[23] Information at: http://www.enymate.nl/over_enymate/fotoalbum

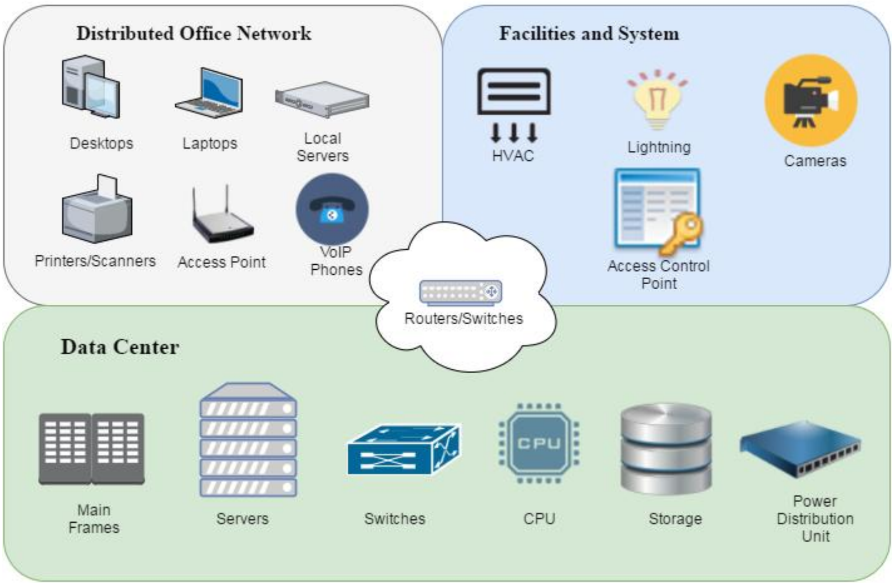

Figure 19: Types of devices that can be monitored by the JouleX Energy Manager software [10]

Figure 20: JouleX dashboard portal snapshot (left) and JouleX report screen snapshot (right) [10]

3.1.5 Summary of Methodologies for Continuous Measurement of ICT Infrastructure

This Section summarizes all the above mentioned techniques and methodologies for "Continuous measurements of ICT infrastructure".

Table 1: Continuous measurements of ICT infrastructure

Sr. no.	Methodologies	Sub-types	Application	Description of Application
1	In-line meters	Plug-in Socket Meters Switched Metered Power Distribution Units	Requires breaking the electric circuit to install the meter	In line meters are added in electric power circuits of a device or group devices, in general a circuit consists of a number of devices or sometimes dozens of devices connected in a system. Typically, the power to the devices is interrupted for the meter to be installed inside the system.
2	Clamp-on-meters	Split Core Clamp Meters	Remains wrapped around wires	Clamp meters mostly consist of a current transformer in its jaws and bar current transformer (CT). Clamp meters works on the principle of current transformer, the reading is displayed. These devices can measure properties of AC in a conductor. This is done without having a physical contact with the conductor or the devices; they can be disconnected and reconnected due to clamp action of these meters. Clamp meters usually remains wrapped around the conductors almost throughout the operational life time of the devices.
3	Add-ons to existing energy meters		Uses analog or digital ports of existing energy meters	Energy measurement systems are usually based on a sensor that is attached to an existing billing-grade energy meters. Usually, sensors are connected to old rotating Ferraris meters. It collects and stores energy usage data minute by minute, 24 hours per day, and can display real-time data of the energy usage on a computer, a smart phone or on its own wireless display.
4	Software-only measurement		Uses existing network interfaces, protocols and APIs	Software only measurement is a completely different approach from the rest of the above mentioned methodologies. It uses existing network interfaces, protocols and Application Program Interfaces (APIs) for monitoring and control of the power consumption of the computers and connected devices present inside the networks. The network attached devices and leverages existing software APIs of these devices helps to report their energy usage.

3.2 International Telecommunication Union, Telecommunication Standardization Sector (ITU-T)

The ITU Telecommunication Standardization Sector (ITU-T) [24] is one of the three sectors of the International Telecommunication Union (ITU). It is an integration of standards for telecommunications. The primary task of the ITU-T is to ensure the efficient and timely production of standards consisting of all the fields of telecommunications on a global level. It is also essential for defining tariff and accounting principles for international telecommunication services. The international standards that are produced by the ITU-T are referred to as "*Recommendation*".

In the modern times, cities are home to half the global population. The rural growth is rapid and consumes almost 2/3 of the global energy resources and accounts for more than 70% of global GHG emissions. The use of ICT can reduce the environmental impact of cities, but the deployment of ICT also consumes increasing amount of energy and resources [52]. These effects of ICT in cities are the systematic effects related to citizens' behaviors and behavioral changes. These changes are also linked to structural changes by the use of ICT.

A number of methodologies have been developed in order to evaluate the energy consumption of ICTs at city level. Though, this “*Recommendation”* provides specific direction on the estimation of the overall energy utilization and environmental impact of ICT, as well as control over the assessment of city-level ICT projects and services [52].

3.2.1 ITU-T L.1440: Methodology for Impact Assessment of ICTs within cities

The “*Recommendation”* focuses on assessing the impact of ICT solutions in cities, it is suggested the first order impact of ICT in relation to the overall impact of ICT. The ICT first impact is co optimized with its potential ability to facilitate the increase in energy efficiency and the decrease GHG emissions [51].

It recommends methods in which ICT should be used to reduce the rate of GHG in the environment by increasing the energy efficiency. This work on this Recommendation is still in the initial stages, as of the beginning of 2012 [52]. Figure 21, shows a general structure of *“Recommendation”* of ITU-T L. 1440,

[24] Information available at: https://www.itu.int/md/T13-SG05-C-0247/en, https://en.wikipedia.org/wiki/ITU-T

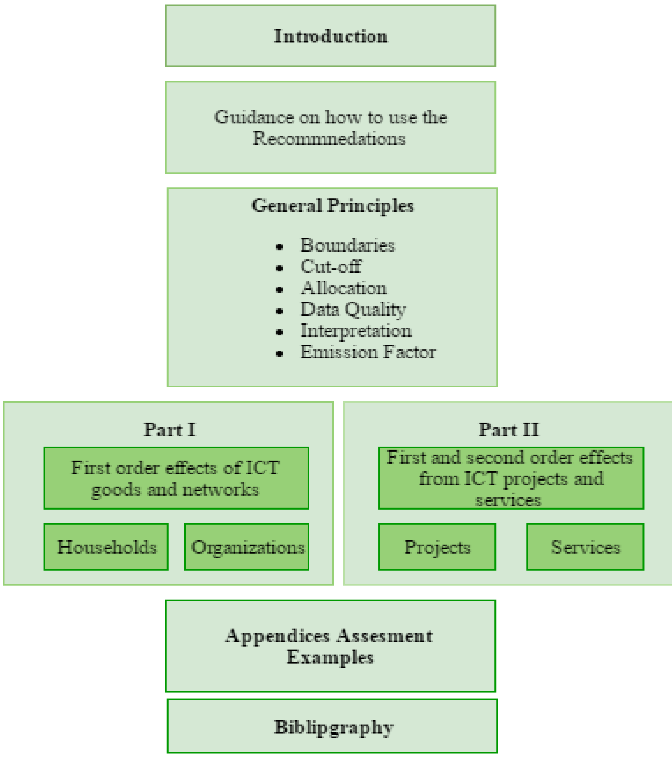

Figure 21: Structure of Recommendation ITU-T L.1440 [52][25]

The *Recommendation* focuses on assessing the impact of ICT solutions in cities, it is suggested the first order impact of ICT in relation to the overall impact of ICT. In order to ensure a balanced approach should be adopted while undertaking the climate change and the ICT first impact is co-optimized with its potential ability to facilitate the decrease GHG emissions [54].

3.2.1 Terms defined by Recommendation ITU-T L.1440

The terms that are defined in the *Recommendation* ITU-T L.1440 are given below.

1. Assessment boundary

The assessment boundary defines as, what to evaluate and considered in the project boundaries, services boundaries, city boundaries and system boundaries applicable to the assessment [51].

2. City

Municipality that consists of one or several governments or planning authorities, which are defined by their geographical boundaries [51].

[25] Image created using: https://www.draw.io/

3. City boundaries

City boundaries refer to the geographical boundaries of the city or city area which is to be evaluated [51].

4. First order effect of ICT solutions at city level

The city level impact created by the physical existence of ICT solutions and the processes implicated, For example, GHG emissions, e-waste, use of hazardous substances and use of scarce, non-renewable resources [51].

5. Supplementary effects of ICT solutions at city level

Effects of ICT solutions at city level that are not first or second order effects; other effects can be related to changes of behavior, of social, working or living lifestyle and can include, for example, rebound effects [51].

6. Project boundaries

The project boundaries identify the geographical boundaries of the project deployment and the ICT solutions and networks that are part of the Green House Gases (GHG) and energy ICT related projects [51].

7. Second order effect of ICT solutions at city level

The city level impacts and opportunities created by the use and application of ICT projects and services. This includes environmental load reduction effects which can be either actual or potential [51].

8. Service boundaries

The service boundaries identify the geographical boundaries of the service deployment and the ICT goods and networks that are part of the ICT service [51].

9. Tier 1 assessment

An assessment of the impacts of ICT solutions, where the energy consumption and GHG emissions of the use-phase of ICT are evaluated. As the "energy consumption" refers to the secondary energy usage in the use stage; "GHG emissions" due to this energy consumption also includes the emissions related to energy production [51].

10. Tier 2 assessment

An assessment of the impact of ICT where the impacts of the energy consumption and GHG emissions for the whole life cycle of ICT are estimated, as well as those occurring outside city boundaries. As "energy consumption" refers to the secondary energy use in the use stage; "GHG emissions" due to this energy consumption also include the emissions related to energy production [51].

3.3 Energy Star Database

Energy Star[26] is a U.S. Environmental Protection Agency (EPA) that helps in minimizing climate change by increasing the energy efficiency of products. The Energy Star is an online database which contains the products that are available on the EU markets and qualified under the latest active Energy Star specifications. Using this database, energy consumption of office related ICT equipment can be extracted. There are two methods where Energy Star database can be used for the estimation. The ideal way is to get the numbers of devices and search for each device for its consumption, according to the specification of the device, build, type and the configuration. On the other hand, another approximation method can be applied by using 'energy calculator interface' of EU energy-star website. This will enable the users to assess the energy usage of the device by denoting type and its usage profile [8].

City authorities can measure the energy consumption of their ICT assets and analyze the results. It is therefore suggested that the City's first step for measuring their ICT assets should be based on an independent analysis. The city should have a record of their ICT equipments in use. The Energy Star EU database shows energy consumption and performance data as supplied by the manufacturers of the specific product [8].

3.3.1 Steps for Data Collection

For the collection of data the following steps should be taken into account,

Organizational Scope: The organizational boundaries define which parts of the organization to include in the energy consumption. Organizations should take into account all facilities used for the operation [8].

Define the assets: Collection of data on the speciation and number of ICT devices included in the system [8].

Number of devices: Estimating the number of devices in used [8].

Time estimation: Time in hours, on average, equipment is in use and is on standby, on an annual basis [8].

[26] More information on Energy Star database available at: https://www.eu-energystar.org/index.html

Calculation: How much energy, in terms of kilowatt hours (kWh) each asset type consumes, both when in "active" and on "standby", using the energy consumption values and the number of each equipment [8].

Summarize: The result should be reported by the organization or City [8].

Figure 22, shows, a snapshot of Energy Star database, and different sets of devices available on EU Energy Star database. The database shows energy consumption and main performance data as supplied by the manufacturers.

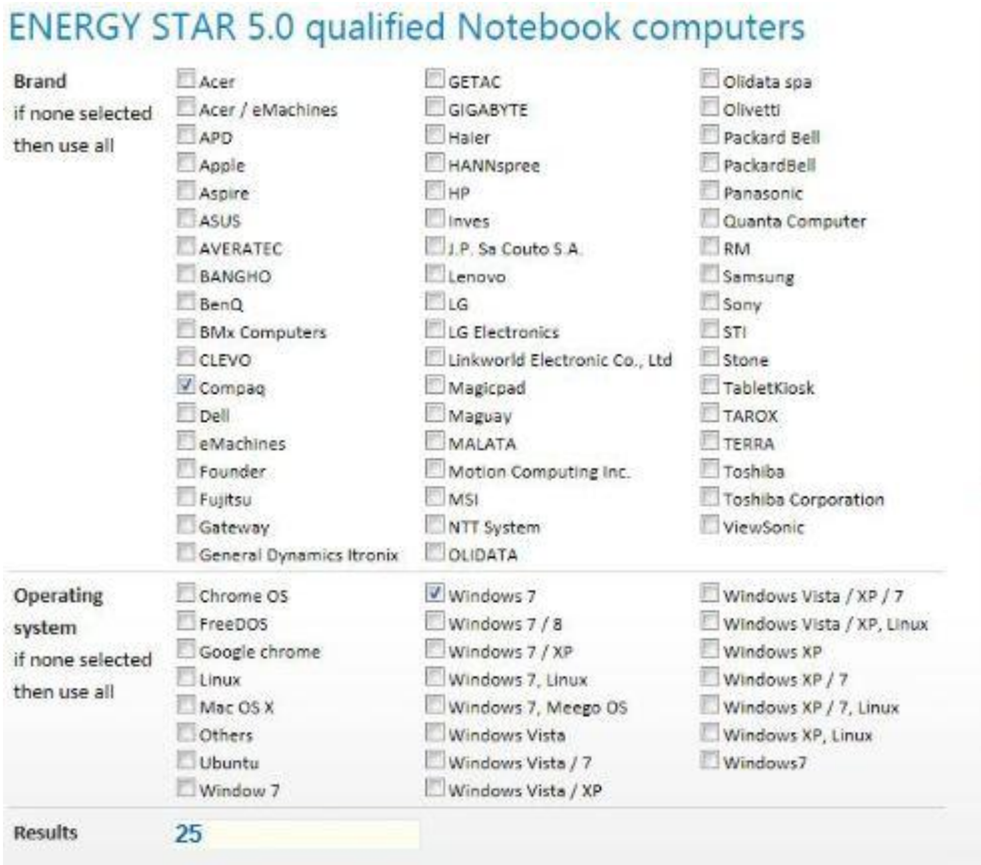

Figure 22: Energy Star database[27]

Figure 23, shows the "Energy Calculator" provided by Energy Star. The interface can be accessed from EU Energy Star website.

[27] More information on Energy Star database available at: https://www.eu-energystar.org/index.html

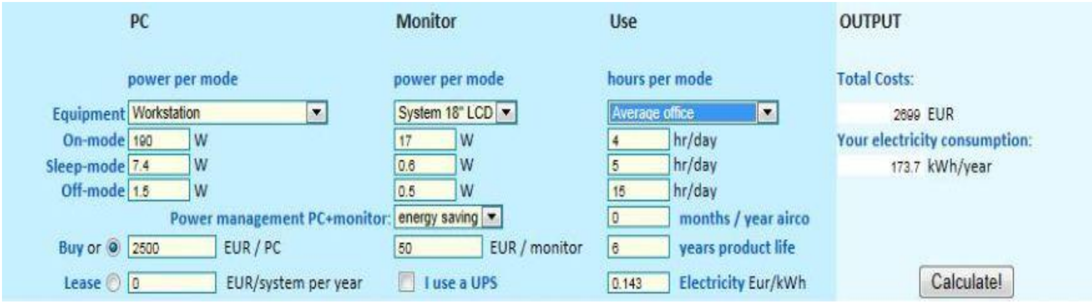

Figure 23: Energy Calculator, Energy Star [8]

The “Energy Calculator” is also available in the form of an Excel file, which can also be used to calculate the energy consumption of ICT devices. It has predefined set of devices and their energy values. The specifications of all the devices are provided by the manufacturers.

3.4 Comparison of Methodologies

This Subsection illustrates some comparison of the methodologies. All the methodologies are considered keeping in mind the requirements of MoveUS and the level of application required. The above mentioned methodology and the one followed for the evaluation for this work, the thesis also focuses on approaches to calculate the “continuous real time measurement of ICT consumed energy” [10]. Another method is the Energy Star data base. The Energy Star is an online database, using this database; energy consumption of office related ICT equipment can be extracted. The ideal technique is to obtain the number of devices and search for each device for its consumption, according to the specification of the device, assembly, type and the configuration. The approximation method can be applied by using “Energy Calculator interface” of EU energy-star website. This enables the users to evaluate the energy usage of the device by denoting type and its usage profile [8].

Table 2, presents a brief comparison between different methodologies for evaluation of ICTs at different level of application.

Table 2: Comparison of the methodologies [52] [53] [54]

Sr. no.	Methodologies	Main Focus	Level of Application				Sector of Application	
			Equipment level	System level	Organization level	City level	Transportation	Manufacturing
1	Continuous measurements of ICT infrastructure	Continuous monitoring and management of ICT solutions energy is an approach, which can be taken into account to increase ICT energy efficiency.	X	X	X	X	X	X
2	Recommendation ITU-T L.1440	Defines use of ICT equipment and networks at a level of city's organizations and households.	X	X	X	X	X	X
3	Energy Star[28] "Energy Calculator Interface"	Provides estimation of energy and cost savings for energy products categories using interactive calculators provided by the Energy Star.	X	X	X		X	

In relevance to MoveUS the convenient methodology is the "Recommendation ITU-T L. 1440". Concluded from the comparison in the table above, the most relevant are the "Continuous measurements of ICT infrastructure" and "Recommendation ITU-T L.1440" methodologies, which both have the highest level of application. These can be applied to city level problems, in particular transport sector. "Energy Star database Energy Calculator Interface" follows the same procedures but lack the complexity in the level of application as well as it is not proven that this methodology can be applied to complex problems on a larger scale such as city level domain.

4. METHODOLOGY

This chapter will give an overview of the tools and methods that are used to measure the energy consumption of ICT solutions; Section 4.1 contains the methodology for assessment of ICT energy consumption at a city level and Section 4.2 contains the methodology for the data collection used for this document.

4.1 Methodology for Evaluation of ICT at City Level

The "*Recommendation"* (see section focuses on assessing the impact of ICT solutions in cities, it is suggested the first order impact of ICT in relation to the overall impact of ICT. The ICT first impact is co optimized with its potential ability to facilitate the increase in energy efficiency and the decrease GHG emissions [51].

Recommendation ITU-T L.1440 gives a general guidance on city-level environmental assessments related to Information and Communication Technologies (ICT) and provides an explanation of the methodologies to be used for the evaluation of the "environmental impacts of ICT solutions" at city level. The first edition of this *"Recommendation"* is limited to the assessment of energy consumption and evaluation of the amount of Green House Gases (GHG) emissions [52].

Recommendation can be categorized into two main parts,

Part I: It relates the first order effects from the use of ICT equipment and networks at a level of city's organizations and households.

Part II: It relates to the first and second order effects from ICT projects and services applied at city level.

Recommendation specifies guidance on setting city boundaries, preparing and performing the assessment of ICT related GHG emissions and energy consumption at city level [51].

4.1.1 Instructions to Use the *Recommendation ITU-T L. 1440*

This section describes the proposed use of this *Recommendation,* The Table 3, summarizes the different use cases for the *Recommendation.*

Table 3: Use cases for Recommendation ITU-T L1440 [51]

	Type of Assessment	Scope	Purpose
Part I	Assessment of ICT related first order impacts of the households	**ICT first order effects:** ICT in households of the city	Understand the first order effects of the ICT used by households within the city boundaries. Such results can serve as an input for assessments according to Part II of the methodology, or serve as a tool for the city stakeholders to monitor the impact of ICT used within the city boundaries.
	Assessment of ICT related first order impacts of organizations	**ICT first order effects:** ICT in organizations of the city	Understand the first order effects of the ICT of the organizations of the city. Such results can serve as a reference for assessments according to Part II of the methodology, or serve as a tool for the city stakeholders to monitor the impact of ICT used within the city boundaries.
Part II	Assessment of an ICT project's first and second order impacts	**ICT first and second order effects**: One or more ICT projects with city level impact	Understand the first and second order effects of one or more ICT project(s). Such results can give a projection on how planned ICT projects will impact on the reduction of the GHG emissions and energy consumption of the city. Such assessments can also be used to monitor the impact of the actual project.
	Assessment of an ICT service's first and second order impacts	**ICT first and second order effects**: One or more ICT services with city level impact	Understand the first and second order effects of one or more ICT service(s). Such results can give a projection on how planned ICT services will impact on the reduction of the GHG emissions and energy consumption of the city. Such assessments can also be used to monitor the impact of the actual service.
	Assessment of the expected impact of an ICT project or ICT service based on the experiences encountered in other cities	**ICT first and second order effects**: One or more ICT projects or ICT services with city level impact	Understand how assessment results of one city or a pilot project may be used to understand how an ICT project or service would impact another city

Performing this sort of assessment at a city level in the context of this thesis and MoveUS, there should guarantee consistency in data collection, calculation and reporting. In generic terms, the cities should use the most accurate and complete sets of data in order to perform these kinds of evaluations.

4.1.2 Estimation of the ICT Solutions on Pilots Cities

City authorities are concerned in understanding the impact from a particular ICT service or project applied at a city level, based on small scale implementations of ICT solutions, by the pilot projects or past ideas implemented in other cities [52].

Some of the cities have already gained experiences from the use of ICT solutions and their impact on energy consumption and GHG emissions. Thus, it is valuable if experiences gained by one pilot city could be used to help another city for better estimation of its possible gains from adopting the similar or parallel services.

Adding to the previous argument made, it is clear that all cities differ to each other with respect to population density, age distribution, development level, ICT solutions awareness among inhabitants, availability of ICT, geographic conditions and authority setup.

All the above mentioned factors may impact the uptake of a solution or service and thus, its energy and environmental impacts. To utilize the previous ICT solutions applied to a city or pilot assessment scenario, the obtained results to create an understanding of ICT's ability potential in a specific city, without details on the use-case being available, it is necessary to understand similarities and differences between the cities (or between the city and the pilot project) at a upper level [52].

There are few steps illustrated below, for the assessment of results comparing one pilot city or reference city to another city or targeted city are:

- Identify the reference ICT solutions applied or project and the reference.
- Analyze the estimated potential of the reference situation and how this potential was derived to ensure that it has sufficient quality to be used.
- Identify the target city, city area or city region.
- Define system boundaries for the target city and the reference.
- Define a common reference unit.
- Select relevant high-level profile data for the target city and the reference.
- Compare the target city and the reference pilot study or reference city.
- Compare solution specific parameters.
- Build a use scenario (users, use profiles, ICT) for the targeted city also using the profile data.
- Create a quantitative scaling for applicable parameters.
- Create a qualitative analysis of other parameters.
- Summarize and interpret the results. [51]

The data collected for the pilot city and the reference city in general include data which are needed to make scenarios for the ICT solutions and to interpret results. This includes data such as population, geographical boundary, ICT solution's development level, drivers and barriers and sector specific data [51].

4.2 Methodology for Data Collection of ICT Solutions

This section illustrates the method followed to collect the data for this thesis. The data documented in this thesis was collected with the help of ITS Tampere, Municipality of Tampere and partners related to the pilot cities, Madrid, Genoa and Tampere (or the company/people responsible for that services) to successfully calculate the 'energy consumption of ICT solutions' for MoveUS project. The method considered here follows the same actions and procedures as the methodology *Recommendation* ITU-T L.1440.

4.2.1 Steps Followed for Data Collection

The first step, towards the collection the power measurements of the pilot sites ICT equipment. It is necessary to identify the devices and services provided in that infrastructure of the smart city for example, sensors, routers server, PC to laptop computers as documented in the result section of the thesis. The second step was the formation of energy tables in Microsoft Excel which were then sent to the service providers and organizations of the pilot sites to gather the data. As far as this thesis is concerned the data was provides by ITS Factory Tampere and the Municipality of Tampere (TRE). The research was limited till City of Tampere as it was initialized to take place of all three pilot cities Madrid, Tampere and Genoa.

The task which looked convenient initially became a large and time consuming job because the lack of time and massive of the ICT infrastructure implemented in those pilot cities. It is also considered as the limitation of this thesis as the planned amount of data collection originally intended, but the evaluation was done using only the available information.

4.2.2 Contributions to the Energy Consumption Table

The most notable ICT issue is the power consumption of all kinds of ICT equipments during their operational lifetime. A significant concern in this course is the power consumption of devices during their active-mode. There is wide variety of information that is necessary for this sort of evaluation. The first foremost important detail is about the list of devices inside the systems that is collected by the different service providers of the pilot cities. After collecting details of all the devices it is necessary to get the number of devices of all sorts. Following the number of devices than it arrives at the task of getting the energy based information of those equipments and systems. Finally, all the information collected is used to calculate the energy consumption of the ICT solutions applied.

The collection of data was done by using Microsoft Excel. A list of formulas was developed with the detailed instructions to fill the sheets.

The details for the each sheet and their instructions are illustrated in the points below.

- First Sheet (ICT): Number of devices present inside a system should be added to this table, for each service. (For example, 1, 2, 3 …).
  Rows list the Services from each pilot city, Madrid (M1 to M12), Genoa (G1 to G14) and Tampere (T1 to T7). Columns list the possible Devices present (or could be present) inside a service (A to R).
- Second Sheet (Energy consumed by each device): The energy consumption of each device should be input into this table, energy must be mentioned in Watt (W), (for example: in case of mW=0.001W)
  The list of Devices per each service is mentioned in columns and Services are mentioned in rows respectively.
  The example of Tampere service T3, presents Server with energy consumption of 425 W and computer with 60 W.
- Third Sheet (Total energy consumed): The third sheet will automatically calculate 'the product of number of devices with their energy consumption' from the first and second sheet and sum up all the energy values to give the results as 'Total energy consumed by each service'.
  For Example, ((ICT!D46*'Energy Consumed by each device'!C46)+(ICT!E46*'Energy Consumed by each device'!D46)).
  Finally, it sums up all the energy values of the services and calculates the 'Total energy consumed' by each pilot city in kW (Kilo Watt)
  As shown in the example of Tampere service T3, having total energy consumption of 485 W, which is also the total energy consumption of the pilot city now.
- Fourth Sheet (Example from TUT): A simple example of 'Energy consumption by a small ICT infrastructure', for a better understanding of the method used to make the calculations (Average energy values were taken, in Watt).

Finally, the results collected were refined and documented in the result section of the thesis along with their visualization.

5. IMPLEMENTATION

The methodology was used for evaluating and monitoring as a part of MoveUS project in three European cities. The first section introduces the three European cities, discusses detail about the Information and Communication Technology infrastructure implemented in those cities. The methodology followed in one of the cities, Tampere and is then used as an example, some consideration about the technical infrastructure are presented about the all the three cities, and finally, second section of the Chapter deals with the units of conversation and their definitions, used for conversation and evaluation of different quantities used in this thesis.

5.1 Introduction to MoveUS Pilot Sites and Their Technical Architectures

World is growing every day, with rising population in the urban population. This drastic rise in population in cities is causing a transport problem i.e. congested road, overloaded public transport. European cities have identify that energy consumption in transport domain will rise with an exponential rate per year, which cannot be stopped completely but can be managed to slow down to a certain level. This issue should be addressed in a convenient and energy efficient way, with the implementation of ICTs in the transportation domain to obtain a sustainable system.

In the section below, the pilot cities included in the MoveUS project is discussed. There are three pilot sites in the MoveUs project.

1. Madrid, capital city of Spain.
2. Genoa, capital city of Liguaria region in Italy
3. Tampere, situated in Pirkanmaa region of Finland

The main objective of MoveUS for all three of the pilot Cities is to improve the "*urban mobility*". Which can be achieved by promoting the use of greener transport modes, such as increasing the use of public transport, utilization of Alternative Modes of transportation (walking and cycling) and reducing the usage of personnel vehicles by encouraging car pooling .

5.1.1 Technical Architecture of Madrid City

Madrid is the biggest city and as well as the capital city of Spain. City of Madrid has a population 3.5 million inhabitants, having a metropolitan area population of around 6.5 million inhabitants. Madrid is the third largest city in Europe.

The City is developing procedures to promote the use of minimum polluting vehicles for transport and encourages increasing use of non-conventional fuels, among which is deployment of electric charging points to encourage the users to utilize alternative fuels and as well as to fulfill the current needs of electrical or hybrid vehicle users, electricity is available and now in use in Madrid's transport sector.

The public transport consist of bus service, which is supported by an information system and a "Journey Planner" online platform, deployed by a transport company providing one of the most advance transport systems in the city. The public transport information is available frequently on the bus stops and various screens trough out the cities, and online. This public transport provides relevant and up-to-date information which helps in identifying the routes of the journey, bus stop to the destination, travel time and stops [36].

The City of Madrid has 300km of cycle paths and a "green ring" for bikers with some space reserved for pedestrians and resting areas to promote "Alternative Modes". The City also has around 70 KM of bike-friendly streets and lanes between the service areas. All the bike related information is available to the users online; the City operates a website, from where the users can retrieve the information on cycling routes, bike friendly streets, bike share, parking areas and resting areas [19].

Figure 24, shows a generic diagram of technical infrastructure of Madrid City.

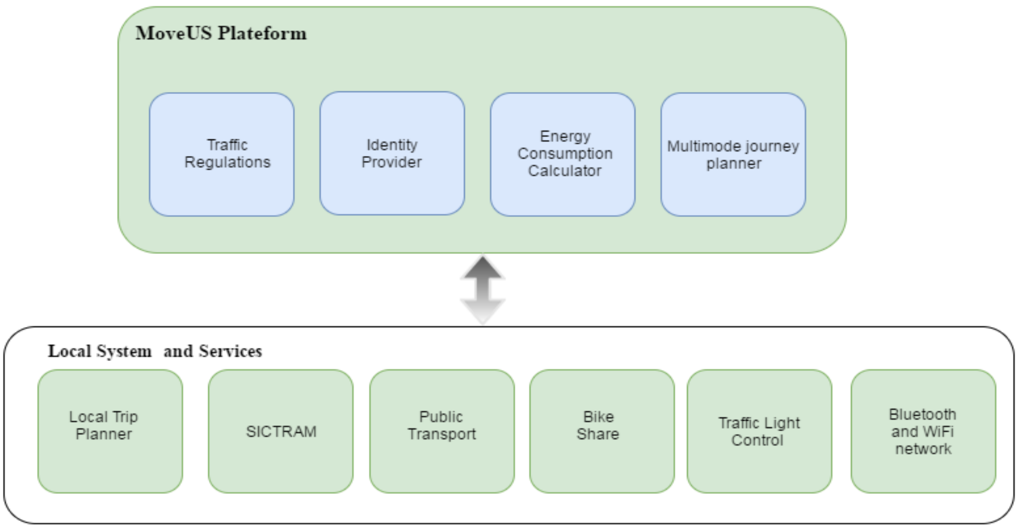

Figure 24: A generic diagram of technical infrastructure of Madrid City [36][29]

[29] Image constructed using online tool: www.draw.io

5.1.2 Technical Architecture of Genoa City

Genoa city is a commune and the capital city of Liguaria in Italy. It is the sixth largest city in Italy according to population, with inhabitants of 588,700 people. The total population including the urban area known as Genoa Metropolitan City has a population of about 1 million people.

The urban traffic of Genoa city mostly consists of private cars, 2 wheelers and light duty vehicles, numbers of which are approximately 290,000 units, 140,000 units and 25,000 units respectively. The City's bus service uses conventional roads carrying passengers on shorter journeys, buses operates with low or medium capacity, under inexpensive price, with several stops. Transport system annually transport around 15 million passengers, which includes local citizens and tourists. Electricity is a key driver among all other conventional fuels [36]. Another aspect of Genoa is the number of cars has grown from 340,000 to more than 400,000 representing an increment of 18% in 13 years. In contrast the city inhabitants have decreased from 610,000 to less than 600,000 from 2001 to 2013 [19].

The optimization of transportation system has enormous impact on improving the users' awareness. By the services provided by MoveUs the inhabitants can use efficient transfer routes with appropriate means of transportation. For example, the Multimode Journey Planner (MJP) consists of a route search that allows the users to enter the departure point and destination in addition to the time and date of departure. After the user provides that information the system calculates the route and gives the user several suggestions, which includes the bus number, its time in departure and destination place, and the distance that the user have walk to arrive at the final destination [19].

Figure 25, shows a generic diagram of technical infrastructure of Genoa City.

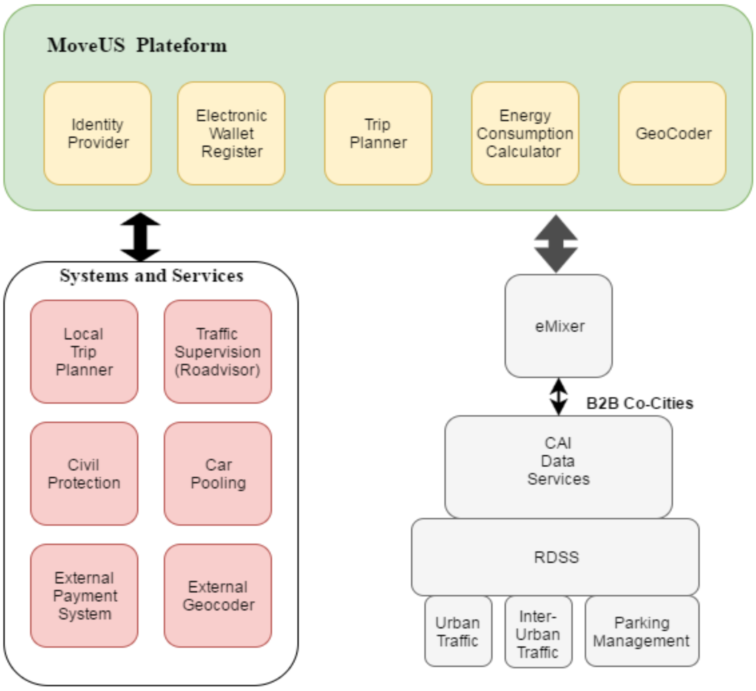

Figure 25: A generic diagram of technical infrastructure of Genoa City [36]

5.1.3 Technical Architecture of Tampere City

The city of Tampere is situated in Pirkanmaa region of Finland; it is regarded as the most populous inland city of the Nordic region, the second largest urban area and third most populous municipality in Finland. It has a population of 314,000 citizens including the urban and rural areas combined.

Tampere city is one of the leading city in the field of ICT solutions and ITS. Tampere city's infrastructure is quite convenient for this study as it has a large traffic infrastructure and different companies provide services to the municipality of Tampere. There are a number of open data sources available, the data is already gathered and is available for transportation information. The data and services are used for the public transportation, parking facilities, charging stations for electric vehicles [36].

Tampere city has an advance transportation infrastructure that offers an excellent platform for intelligent transport. The physical transport system to Tampere region serves as the test environment for ITS factory. The information regarding flow of vehicles and its status is gathered continuously from various sources, the monitoring of the systems is done in real time, supplementary information on parking, pedestrians and cyclists is also accessible [36].

ITS factory is working to make the data more useful and available to general public for transportation [36]. The city has been implementing different strategies such as extending bus services, lanes and traffic light priorities in order to promote the use of public transport. The public transport service in the City has maps that contains the public transport routes and books with more detail information about times and stops for each bus line. For example, Journey Planner allows the users to enter the departure and destination as well as the time and date of arrival. By using that information, the system calculates the route and provides the users with several suggestions, which include the bus number, its time in departure and destination place [19].

The "Alternative Modes", such as cycling has been also growing; Tampere has 602 KM of cycle paths which allows the users to freely select the path from the available routes. These information on routes are can be accessed online. The City also has several projects under development for the encouragement of "Alternative Modes". For example, Pedestrian and bicycle paths exporting the digital road-II, bike parking information, walking and cycling computations and waterway [19].

Figure 26, shows a generic diagram of technical infrastructure of Tampere City.

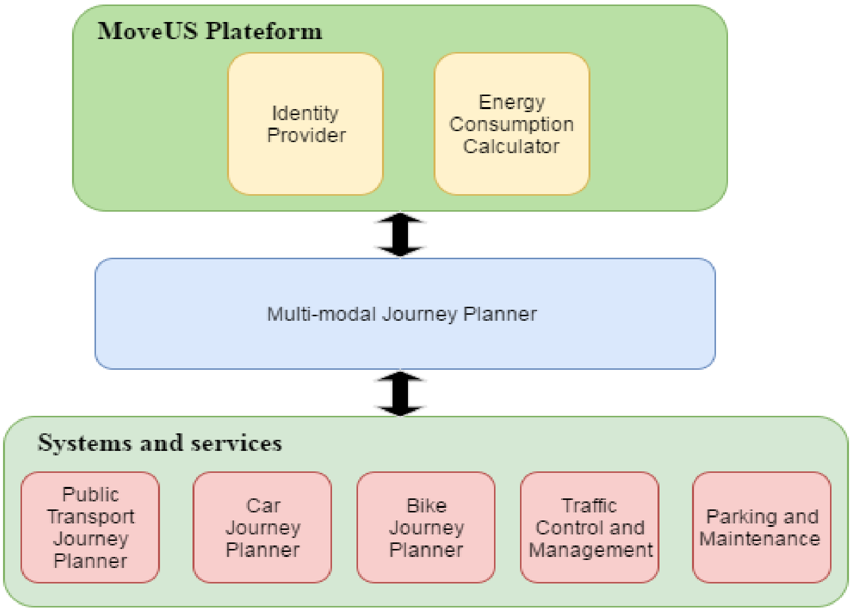

Figure 26: A generic diagram of technical infrastructure of Tampere City [36][30]

5.2 Definitions and Conversation of Units for Power

This subsection explains the units and formula for conversations. All the possible conversations according to the context of this study are explained briefly.

Kilowatt hour [31](kWh) is defined as; the energy transmitted or used at a constant rate (power) over a period of time, the total energy in kilowatt-hours is the power in kilowatts multiplied by the time in hours.

[30] Image constructed using online tool: www.draw.io
For more information on ITS and Smart Transport in Finland: http://www.itsfinland.fi/index.php/en/palvelut.html

1 Watt is the power from a current of 1 Ampere flowing through 1 Volt.
1 kilowatt (kW) = 1000 Watts.

1 kilowatt-hour (kWh) = 3.6 x 10^6 Joules and 1 Watt= 1 Joule/second

1 kilowatt-hour (kWh) is the energy of 1 kilowatt (kW) power for one hour.

1 megawatt (mWh) is the energy of 1 megawatt (mW) power for one hour.

746 Watts= 1 Horsepower

A BTU[32] (British thermal unit) is the amount of heat necessary to raise one pound of water by 1 degree Fahrenheit (F).

1 kilowatt-hour (kWh) of electricity = 3,412 BTU

1 megawatt hour (mWh) of electricity=3,412 x 10^3 BTU

1,000 kWh = 3.41 x10^6 BTU

1 Horse Power (hp) = 745.7 watts

$$Power = Current\ x\ Voltage$$

$$\boldsymbol{P = I\ V} \qquad (1)$$

$$\boldsymbol{E = P \times t} \qquad (2)$$

$$\boldsymbol{E\ (kWh) = P\ (W) \times t\ (hr)\ /\ 1000} \qquad (3)\ [66]$$

Equation (3) shows, Energy 'E' in kilowatt-hours (kWh) is calculated by the product of energy 'E' in watt (W) and time 't' in hours divided by the factor of 1000 [66].

---

[31] More information : https://en.wikipedia.org/wiki/Kilowatt_hour#cite_note-1

[32] More Information on units of conversation available on: http://www.energy-101.org/units-of-measurement

6. RESULTS

This section documents the results and discussion of all the work done during this thesis, subsection 6.1 presents the visualization of data using different tools and Section 6.2 shows detail about the JAVA based “ICT Energy Calculator”.

The most notable ICT issue is the power consumption of all kinds of ICT equipments during their operational lifetime. Firstly, an important issue in this course is the power consumption of devices during their active-mode. Secondly, another issue is the quantity of devices in usage globally, i.e. ranging from 30 million volume servers, 1.5 billion TVs to 60 thousand high-end server and the percentage of time in active mode has a great influence, ranging from being active 24 hours a day and 7 days a week for many servers to devices where the standby power consumption is even much higher than the active consumption.[6][32].

The servers range from a small volume server of an average consumption of 220W, to mid-range server with an average consumption of 700W to high-end server of 10000 W. To estimate within these ranges, consider that electrical consumption increases with higher clock-speed CPUs, larger numbers of memory cards typically, DIMMs and physical disks, and with greater processor utilization. Servers that accommodate into one of the listed categories can have usually power estimated by multiplying the nameplate rating by 70 percent. This estimation is reasonable only for a large population of servers, such as a whole data center. It is not accurate with any granularity, and certainly not at the single server level [6].

6.1 Data Collection and Visualization

In order to measure and evaluate the share of energy consumption of ICTs within a smart infrastructure, the initial step is to identify the ICT solutions applied to the system. It is important to know the energy consumption of each piece of equipment that is present inside the infrastructure separately. Microsoft Excel is used for calculation and compilation of those values.

Table 4, document the results collected, all the values evaluated till now. Data Centre (cooling) contains the amount of power it takes to cool down the Data Centre. Due to a wide range of technologies involved, values of servers, router, switches and firewall are estimated, the overall consumption is believed to be higher than it is calculated due to other devices and systems might be included in the system. Data Centers are complex and energy-intensive environments. All in one approach do not fit its efficiency. It needs careful planning and active energy management approaches.

Table 4: Data collected for analysis

Sr. no.	**Devices**	**Num-ber of devices**	**Energy consumed per each device (Watt)**	**Total energy consumed (Watt)**
1	LCD Display	4	190 (0.29/in^2)	760
2	Plasma Displays	2	330 (0.34/in^2)	660
3	Servers	2	180-300=250(avg)	500
4	Data center (Cooling)	1	280	280
5	Desktop with LCD Display	2	100	200
6	Switches	2	96	192
7	Laptop PC	5	30	150
8	Firewall	1	74	74
9	Router	4	4-8=6(avg)	24
10	Gateway	2	7	14
			Total	**2854 Watts**

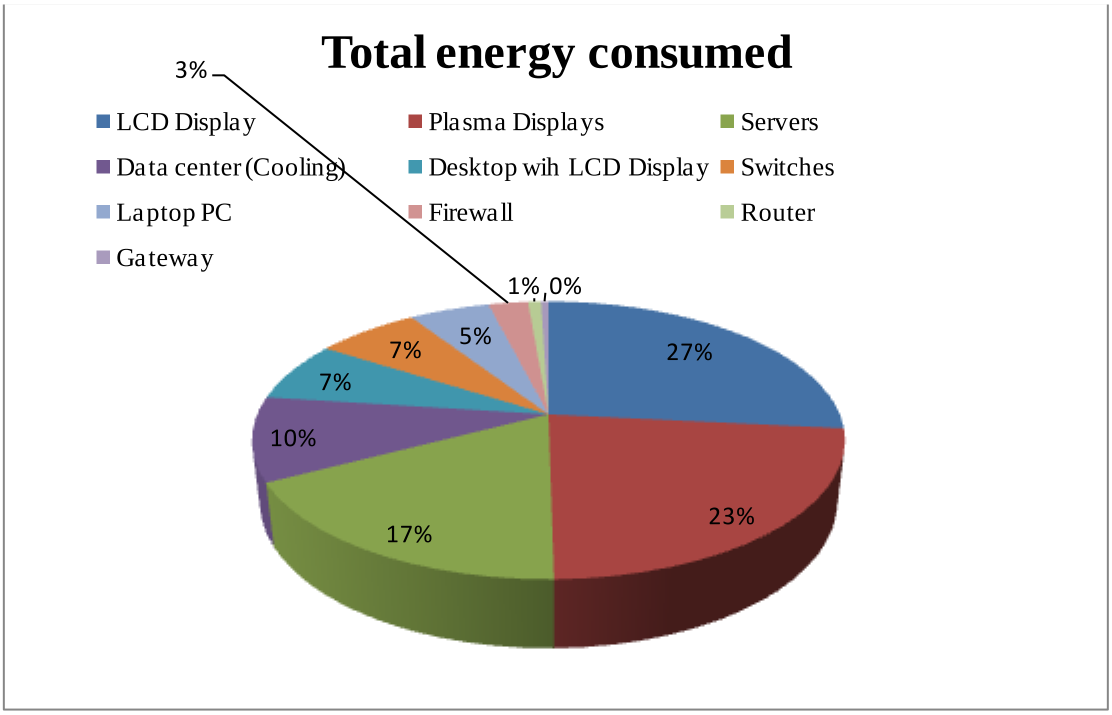

Figure 27: Pie-chart showing the power distribution

Figure 27, shows a simple visualization of the data provided in table 2. The current total energy consumed is about 2854W, which is rounded off to about 2.8 kilowatt-hours (KWh), which is the estimation of for the city of Tampere till this period of time.

6.1.1 Pareto Chart

Pareto Chart is one of the *seven basic tools of quality control*. It is the type chart that contains both bars and a line graph, the individual values are represented in descending order by bars, and the total accumulative values are represented by the line. The lengths of the bars represent values, i.e. cost, time, energy, speed etc, the bars are arranged with longest bars on the left and the shortest to the right, this is the way to show the more significant to less significant values.

Table 5, calculates the percentages calculated to evaluate Pareto chart. The graph starts from 27% and rise up to 100%. The values from largest to smallest are, LCD display 27%, plasma display 23%, Servers 17%, data center (cooling) 10%, desktop with LCD displays 7%, switches 7%, laptop PC 5%, routers 1% and gateway contribute to less than 1% of the total power consumption.

Table 5: Percentages for Pareto chart

Sr. no.	Devices	Number of devices	Energy consumed per each device (Watt)	Total energy consumed (Watt)	Accumulated	Percentage
1	LCD Display	4	190 (0.29/in^2)	760	760	27%
2	Plasma Displays	2	330 (0.34/in^2)	660	1420	50%
3	Servers	2	180-300=250(avg)	500	1920	67%
4	Data center (Cooling)	1	280	280	2200	77%
5	Desktop with LCD Display	2	100	200	2400	84%
6	Switches	2	96	192	2592	91%
7	Laptop PC	5	30	150	2742	96%
8	Firewall	1	74	74	2816	99%
9	Router	4	4-8=6(avg)	24	2840	100%
10	Gateway	2	7	14	2854	100%
			Total	2854		

Figure 28, shows the visualization of the measurements mentioned in Table 5, the graph is made in Microsoft Excel.

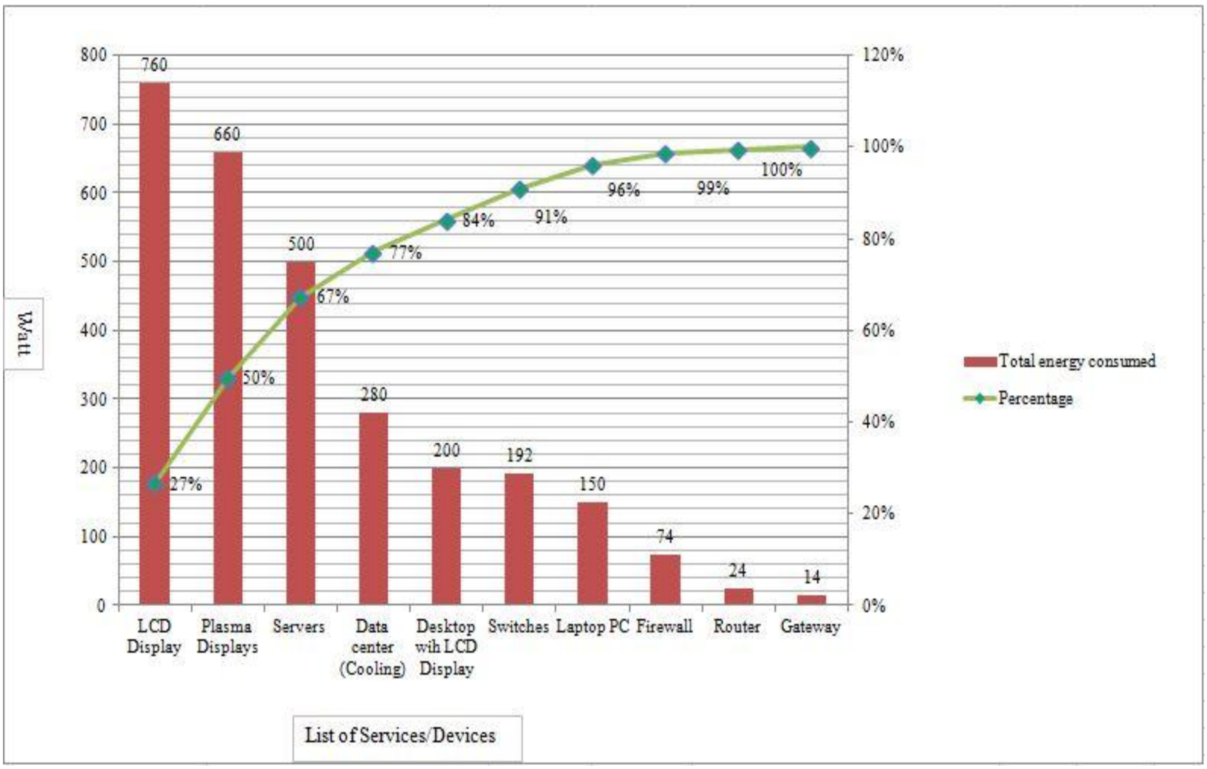

Figure 28: Pareto chart for the measurements

6.1.2 Sankey Diagram

Sankey diagram is quite simple but helpful diagram to show the energy input(s) and output(s) across an asset, device or process. Figure 29; illustrate the Sankey diagram from the successful implementation of the values collected during the project research.

On the left hand side the "Total Power" input to the system is displayed which is 2856 W, the out flowing power are displayed with each of their degree of freedom, starting from the largest value on the top to the smallest value at the bottom, gradually decreasing the widths of the arrows as the values become smaller. The values of each degree of freedom are displayed in the percentages of the "Total Power" input to the system.

Table 6: Percentages calculation for Sankey Diagram

Sr. no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
Devices	LCD Display	Plasma Displays	Servers	Data center (Cooling)	Desktop with LCD Display	Switches	Laptop PC	Firewall	Router	Gate way	**TOTAL**
Percentage	26.6%	23.1%	17.5%	9.8%	7.0%	6.7%	5.3%	2.6%	0.8%	0.5 %	100%

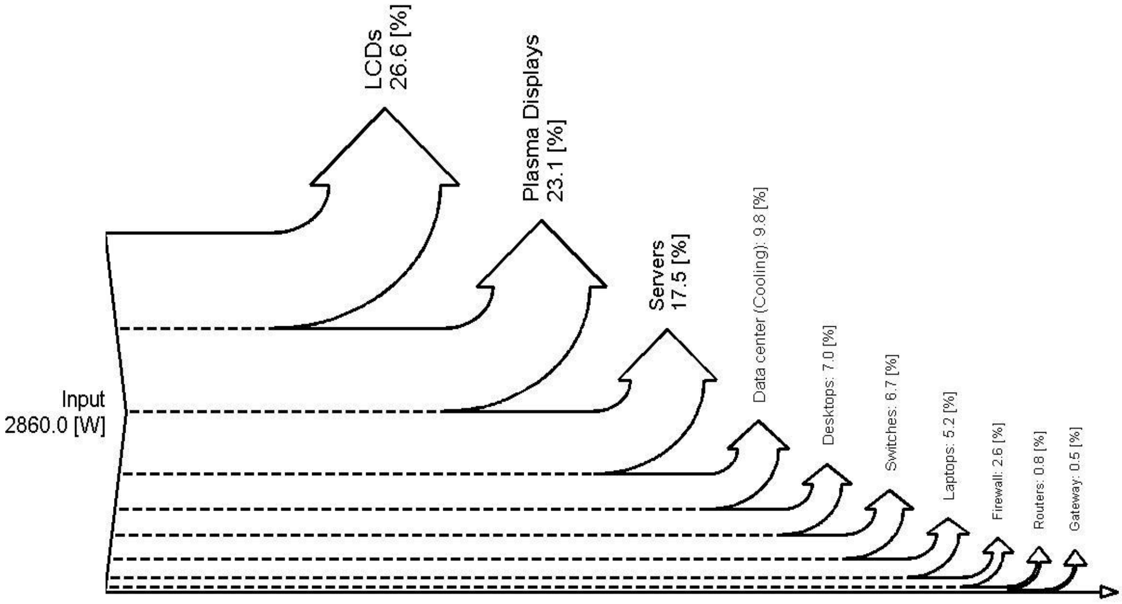

Figure 29: Sankey diagram for the collected results

The values from largest to smallest are, LCD display 26.6%, plasma display 23.1%, Servers 17.5%, data center (cooling) 9.8%, desktop with LCS displays 7%, switches 6.7%, laptop PC 5.2%, firewall 2.6%, routers and gateway contribute to less than 0.8% and 0.5% respectively, of the total power consumption.

Sankey chart is constructed using MATLAB, the general syntax is as below,

```
 inputs = [75 32]; losses = [10 5 2.8]; unit = 'MW'; sep = [1,3];
   labels = {'Main Input','Aux Input','Losses I','Losses II','Losses
III','Output'};

   drawSankey(inputs, losses, unit, labels, sep);
```

Sample 1: General MATLAB syntax for Sankey diagram

The sample 1 shows, generic syntax for Sankey diagram, complete syntax for Figure 32 is shown and explained in the “Appendix B” of the thesis.

6.1.3 Radar Chart

The resulting Figure 30, obtained from the values illustrated in Table 7 below. The axes of the radar chart are automatically adjusted corresponding to the maximum and minimum values and they can also be manually adjusted. The radar chart shows the comparison of the values in KW and KWh of the resulted values, the chart is prepared using Excel.

Table 7: Total power consumption in Watt and Kilo-Watt-Hour (kWh)

Sr. no.	**Devices**	**Number of devices**	**Energy consumed per each device (Watt)**	**Total energy consumed (Watt)**	**Percentage of total consumption**	**Total power Consumed (Kilo-Watt-Hour)**
1	LCD Display	4	190 (0.29/in^2)	760	26.6%	6.08
2	Plasma Displays	2	330 (0.34/in^2)	660	23.1%	5.28
3	Servers	2	180-300=250(avg)	500	17.5%	4.00
4	Data center (Cooling)	1	280	280	9.8%	2.24
5	Desktop with LCD Display	2	100	200	7.0%	1.60
6	Switches	2	96	192	6.7%	1.53
7	Laptop PC	5	30	150	5.3%	1.20
8	Firewall	1	74	74	2.6%	0.59
9	Router	4	4-8=6(avg)	24	0.8%	0.19
10	Gateway	2	7	14	0.5%	0.11
			Total	2854	100%	22.83

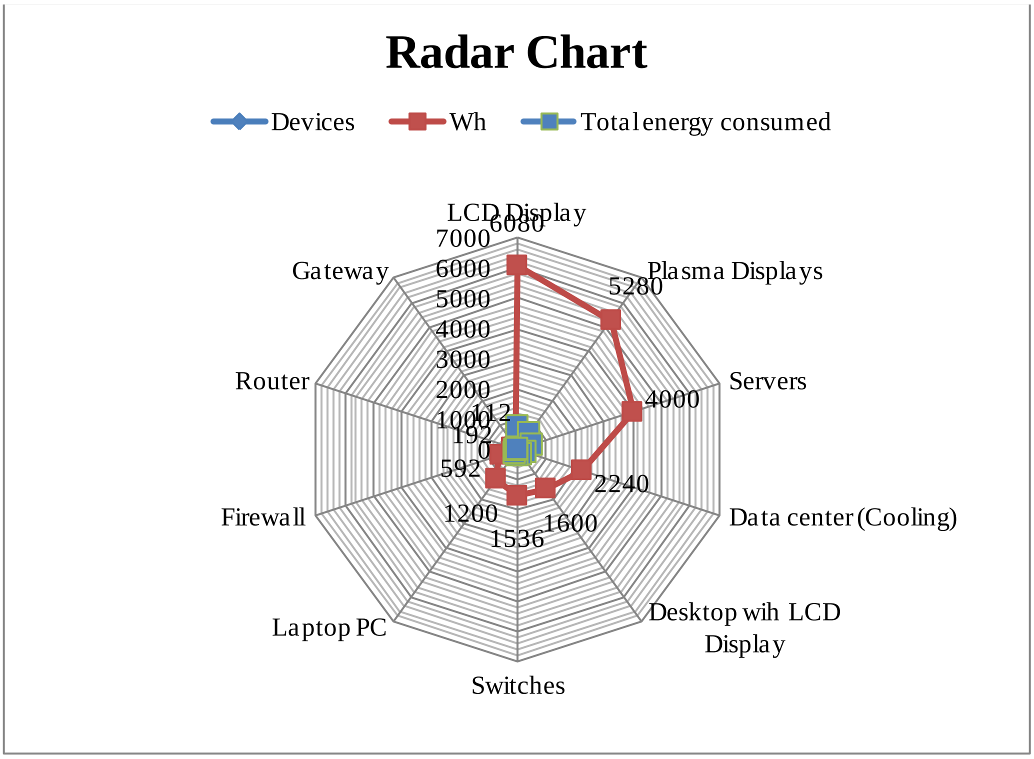

Figure 30: Radar Chart for total energy consumed in Watt and Kilo-Watthour

The values from largest to smallest are, LCD display 6.08 kWh, plasma display 5.28 kWh, Servers 4.00 kWh, data center (cooling) 2.24 kWh, desktop with LCS displays 1.60 Wh, switches 1.53 Wh, laptop PC 1.20 kWh, firewall 0.592 kWh, routers and gateway contribute to less than 0.192 kWh and 112 kWh respectively, of the total power consumption.

6.2 ICT Energy Calculator

This section explains the development and implementation of the "ICT Energy Calculator" developed for this thesis. Subsection 6.2.1 presents the development details of the application and Subsection 6.2.2 shows the implementation and 6.2.3 explains the functionality of the application.

6.2.1 Development

The "ICT Energy Calculator" is developed in NetBeans, an *open-source integrated environment*, it is a software development platform written in JAVA, (see section 4.2.3 for details on NetBeans and IDE). Basically, it is done using "drag and drop" procedure, the boxes are added to the windows by selecting them from pre-defined sets of tools and procedures given on the left hand side of the Netbeans windows. After adding the boxes to the interface, all the boxes are connected to the corresponding boxes and all the variables are initialized. The formulas for calculation of power consumption are manually added to the computer generated code which is created using the drag and drop procedure.

6.2.2 Implementation

The application takes "Device Name" as string, "Number of Devices (n)" as integer, "Power Rating" as float and yield the results as " Accumulated Power", "Total power Consumption of System" and "Power Consumption KW" as float. The code can be directly used to any application software. Figure 31, shows a snapshot of the application under construction.

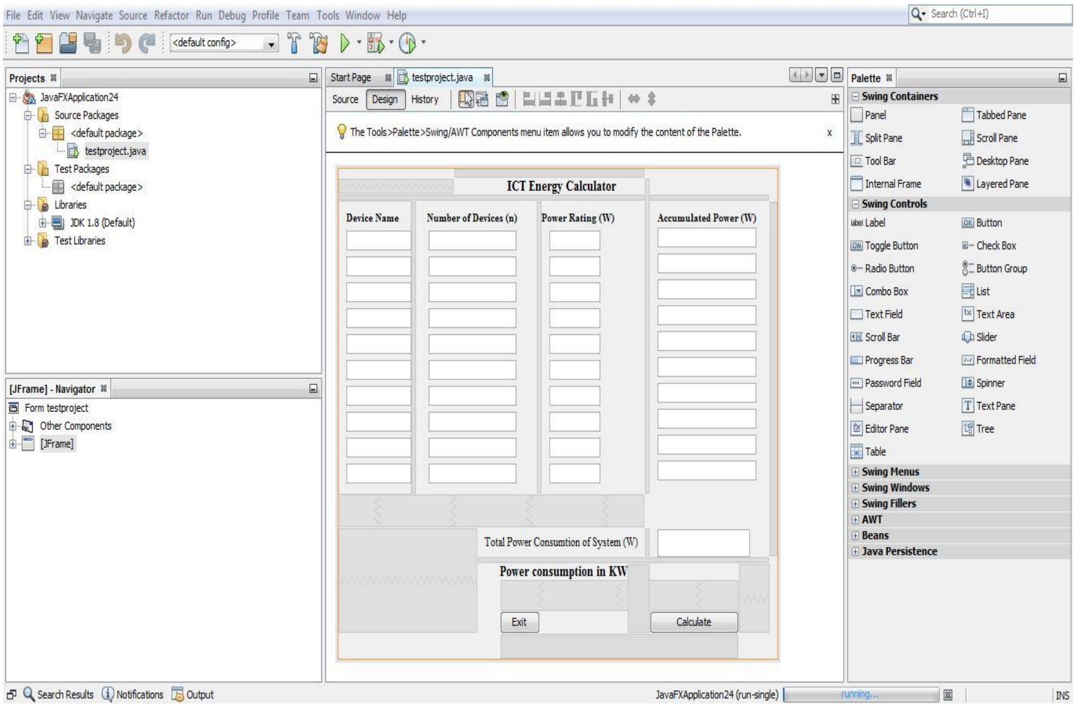

Figure 31: Energy Calculator under development stage

Equations below are the formulas used for calculation, Equation (4) is used to calculate accumulated power, Equation (5) is the addition of all the accumulated powers and finally, Equation (6) calculates the total power consumption in 'KW'.

$$\textit{Accumulated Power} = \textit{Number of Devices} \times \textit{Power Rating (W)} \qquad (4)$$

$$\textit{Total Power Consumption of System} = \Sigma\, \textit{Accumulated Power}_{(i)} \qquad (5)$$

$$\textit{Power Consumption in KW} = \frac{\textit{Total Power Consumption of System}}{1000} \qquad (6)$$

6.2.3 Functionality

The application takes device names in the first column "Device Name", the number of devices in the second set of columns, "Number of Devices" and multiple these values with the corresponding power rating given to the application in the third columns, "Power Rating (W)". The total accumulated power is calculated and displayed in column four, "Accumulated Power". All the values in columns four, "Total Power Consumption of System (W)" and are added together and total power is calculated and displayed, finally the power conversation to kilowatt, "Power Consumption in KW" is calculated and displayed. The panel left hand side of the screen shot contains all the useful addable content to the application. "Calculate" button on the application shows the result in a pop-up menu, and "Exit" is used to quite the application.

Figure 32, shows a snapshot of the final form of the "ICT Energy Calculator".

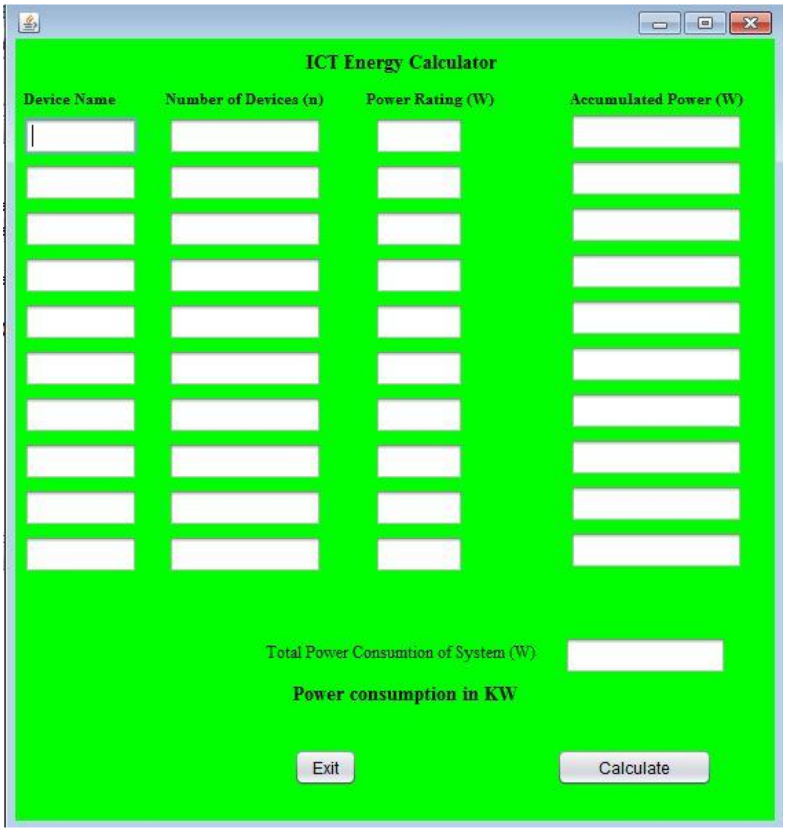

Figure 32: Application front panel

The most notable ICT issue is the power consumption of all kinds of ICT equipments during their operational lifetime. An important factor in this course is the power consumption of devices during their active-mode. The test results from the projects are used in the "ICT energy calculator". The ICT energy calculator is used to estimate all the results. All the power ratings of the devices considered as an example in Table 8 are in active mode. The application with example from the project results is shown in the Figure 33.

Table 8: Total power consumption

Sr. no.	Devices	Number of devices	Energy consumed per each device (Watt)	Total energy consumed (Watt)
1	LCD Display	4	190 (0.29/in^2)	760
2	Plasma Displays	2	330 (0.34/in^2)	660
3	Servers	2	180-300=250(avg)	500
4	Data center (Cooling)	1	280	280
5	Desktop with LCD Display	2	100	200
6	Switches	2	96	192
7	Laptop PC	5	30	150
8	Firewall	1	74	74
9	Router	4	4-8=6(avg)	24
10	Gateway	2	7	14
			Total	2854

Figure 33: ICT Energy Calculator

Sample 2 shows, the JAVA code of the "ICT Energy Calculator", which showing some of its basic contents.

```
    public testproject() {

        initComponents();

        getContentPane().setBackground(Color.GREEN);  //color  of  the  Applica-
tion


        jPanel1.setBackground(Color.GREEN); //color of the Application

        jPanel2.setBackground(Color.GREEN); //color of the Application

        jPanel3.setBackground(Color.GREEN); //color of the Application


        jPanel5.setBackground(Color.GREEN); //color of the Application

    }

        result=mul+mul1+mul2+mul3+mul4+mul5+mul6+mul7+mul8+mul9;

        final JFrame parent=new JFrame();

        System.out.print(result);

        parent.pack();

        parent.setVisible(false);

        int result;

        result=mul+mul1+mul2+mul3+mul4+mul5+mul6+mul7+mul8+mul9; /*addition of
all the values*/
        TotalTR.setText(Integer.toString(result)); /* result to string */

        float mega=(float)result/1000; /* result of mega watt shown in float
*/
        MW.setText(Float.toString(mega)); /* display result in Megawatt */
```

Sample 2: Sample Code for JAVA application

The JAVA code for the complete application is presented in the “Appendix A” of the thesis.

7. CONCLUSION

This Chapter contains the conclusion on the thesis. Section 7.1 contains thesis conclusion and the lesson learned from this study and Section 7.2 concludes the thesis with the recommendations and future work.

7.1 Thesis Conclusion

The percent of power consumption by smart infrastructure in the transportation domain mostly depends on the amount of power consumed by Information and Communication Technology infrastructure. A prominent issue is the power consumption of all kinds of ICT equipments during their operational lifetime, an important concern in this type of power consumption of the devices is their “active-mode”. But some time the “standby-mode” requires much more energy than its “active-mode” consumption. Increasing the amount of ICT equipment also means the rise in the energy consumption and Green House Gases emissions. So, the systems not in use should be turned “off” like interfaces of the servers and routers. Other devices such as, monitors, servers and energy extensive devices such as desktop PC for which a schedule of operations should be defined, to operate the equipment, to set it “on” when it is in use and set it to “off” when the equipment is not in use, which will increase the efficiency of the infrastructure and reduce the energy consumption. This will also help in reducing the amount of carbon emissions in the environment as a supplementary outcome.

Bigger and more power consuming devices, such as monitors and display screens account for a large amount of energy consumption; minimal usage can increase the total energy efficiency to an immense degree. Efficient ICT equipment handling reduces direct consumption as well as indirect consumption such as the amount of energy consumed for the cooling of the systems and the amount of heating it is required for the organizational practices.

There are a number of methodologies explained in this thesis, including continuous measurement of ICTs. However, the *Recommendation* ITU-T L. 1440 methodology illustrated in this thesis can be made more effective by the implementation of further research, that will help increase in the energy efficiency of the systems and will reduce the total energy consumption in an exponential trend and will decrease the amount of Green House Gases up to several percent per year, millions of tons in decades to come. This strategy will help us in more sustainable and energy efficient systems and will shape a better greener future for the future generations.

7.2 Recommendations and Future Work

This evaluation will be used to calculate the energy efficiency attained as the result of successful implementation of ICT infrastructure. There is not a single widely approved methodology that can be implemented to correctly evaluate the energy consumption of the ICTs because of the variant nature of ICT infrastructures in each system. For the further extension of this research, the whole infrastructure of the Tampere city can be evaluated. The same infrastructure evaluation methodologies discussed in Section 4.1 and 4.2 can be applied to evaluate the ICT infrastructures of the pilot sites of Genoa and Madrid.

The research process is limited till evaluating the infrastructure of City of Tampere, as it is the most approachable of all the three pilot sites, Madrid, Tampere and Genoa. The task which looked like as minute and convenient at first became outsized and time consuming task because of the lack of time and massive application of the ICT infrastructure implemented in these pilot cities. It is also considered as the limitation of this thesis as the planned amount of data analysis initially intended was not achieved, but this research can be a stepping stone towards future research.

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APPENDIX A: JAVA CODE FOR ICT ENERGY CALCULATOR

```
import static java.lang.System.exit;
import javax.swing.JFrame;
import javax.swing.JOptionPane;

public class testproject extends javax.swing.JFrame {


    /**
     * Creates new form testproject
     */
    int no,powerrating;

    int mul=0,mul1=0,mul2=0,mul3=0,mul4=0,mul5=0,mul6=0,mul7=0,mul8=0,mul9=0;

/**initialization of values/**

    public testproject() {
        initComponents();
        getContentPane().setBackground(Color.GREEN); //color of the Applica-
tion

        jPanel1.setBackground(Color.GREEN); //color of the Application
        jPanel2.setBackground(Color.GREEN); //color of the Application
        jPanel3.setBackground(Color.GREEN); //color of the Application


        jPanel5.setBackground(Color.GREEN); //color of the Application
    }
    /**
     * This method is called from within the constructor to initialize the
form.
     */
    @SuppressWarnings("unchecked")
    // <editor-fold defaultstate="collapsed" desc="Generated Code">//GEN-
BEGIN:initComponents
    private void initComponents() {


        jPopupMenu1 = new javax.swing.JPopupMenu();
        jLabel1 = new javax.swing.JLabel();
        jButton1 = new javax.swing.JButton();*/ buttons /*
        jButton2 = new javax.swing.JButton();*/ buttons /*

        jLabel2 = new javax.swing.JLabel();  */ label/*

        jTextField10 = new javax.swing.JTextField();


        MW = new javax.swing.JLabel();  */megawatt labels


        jLabel7 = new javax.swing.JLabel();
        setDefaultCloseOperation(javax.swing.WindowConstants.EXIT_ON_CLOSE);
        setBackground(new java.awt.Color(102, 255, 51));
```

```
        jLabel1.setText("                        ICT Energy Calculator ");
/*
 * Heading of the calculator
*/
        jButton1.addActionListener(new java.awt.event.ActionListener() {
            public void actionPerformed(java.awt.event.ActionEvent evt) {
                jButton1ActionPerformed(evt);  */CALCULATE  application  button
label /*

        });
        jButton2.setText("Exit");  /*EXIT application button label /*
        jButton2.addActionListener(new java.awt.event.ActionListener() {
            public void actionPerformed(java.awt.event.ActionEvent evt) {
                jButton2ActionPerformed(evt);
            }
        });
        jLabel3.setText("Number of devices (n)"); /* Number of devices */


        javax.swing.GroupLayout          jPanel1Layout          =          new
javax.swing.GroupLayout(jPanel1);
        jPanel1.setLayout(jPanel1Layout);
        jPanel1Layout.setHorizontalGroup(

jPanel1Layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADING)
            .addGroup(jPanel1Layout.createSequentialGroup()
                .addGap(14, 14, 14)
        pr24.addActionListener(new java.awt.event.ActionListener() {
            public void actionPerformed(java.awt.event.ActionEvent evt) {
                pr24ActionPerformed(evt);
            }

.addGroup(jPanel2Layout.createParallelGroup(javax.swing.GroupLayout.Alignment
.LEADING)
                    .addGroup(jPanel2Layout.createSequentialGroup()
                        .addGap(2, 2, 2)
                        .addComponent(jLabel4))

.addGroup(jPanel2Layout.createParallelGroup(javax.swing.GroupLayout.Alignment
.TRAILING, false)
                        .addComponent(pr23,
javax.swing.GroupLayout.Alignment.LEADING)
                .addContainerGap(javax.swing.GroupLayout.DEFAULT_SIZE,
Short.MAX_VALUE))
        );
        jLabel2.setText("Device name");  /* Device name ”label” */


        javax.swing.GroupLayout          jPanel3Layout          =          new
javax.swing.GroupLayout(jPanel3);
        jPanel3.setLayout(jPanel3Layout);
        jPanel3Layout.setHorizontalGroup(

.addGroup(jPanel3Layout.createParallelGroup(javax.swing.GroupLayout.Alignment
.TRAILING, false)
                    .addComponent(jLabel2,
javax.swing.GroupLayout.Alignment.LEADING,
javax.swing.GroupLayout.DEFAULT_SIZE,    javax.swing.GroupLayout.DEFAULT_SIZE,
Short.MAX_VALUE)
```

```
                    .addComponent(jTextField3,
javax.swing.GroupLayout.Alignment.LEADING)
                    .addComponent(jTextField2,
javax.swing.GroupLayout.Alignment.LEADING)
                .addGap(16, 16, 16))
        );
        APR10.setText("Total Power");  */total power consumption label //
        APR10.addActionListener(new java.awt.event.ActionListener() {
            public void actionPerformed(java.awt.event.ActionEvent evt) {
                APR10ActionPerformed(evt);
            }
        });


        jLabel6.setText("Accumulated Power (W)"); */ accumulated power calcu-
lation


        TotalTR.setToolTipText("");
        TotalTR.addActionListener(new java.awt.event.ActionListener() {
            public void actionPerformed(java.awt.event.ActionEvent evt) {
                TotalTRActionPerformed(evt);
            }
        });


        javax.swing.GroupLayout          jPanel5Layout          =          new
javax.swing.GroupLayout(jPanel5);
        jPanel5.setLayout(jPanel5Layout);
        jPanel5Layout.setHorizontalGroup(

jPanel5Layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADING)
            .addGroup(jPanel5Layout.createSequentialGroup()
                .addContainerGap()

.addGroup(jPanel5Layout.createParallelGroup(javax.swing.GroupLayout.Alignment
.LEADING, false)

                    .addComponent(APR3)
                    .addComponent(APR4)

javax.swing.GroupLayout.DEFAULT_SIZE,    javax.swing.GroupLayout.DEFAULT_SIZE,
Short.MAX_VALUE)
                    .addComponent(TotalTR))
                .addContainerGap(13, Short.MAX_VALUE))
        );
        jPanel5Layout.setVerticalGroup(

.addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)
                .addComponent(APR2,    javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)

.addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)
                .addComponent(APR3,    javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
        jLabel5.setText("    Total Power Consumtion of System (W)"); //result
label MegaWatt
```

```
        jLabel7.setText("KW"); //result  MegaWatt

        javax.swing.GroupLayout            layout            =            new
javax.swing.GroupLayout(getContentPane());
        getContentPane().setLayout(layout);
        layout.setHorizontalGroup(
            lay-
out.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADING)
            .addGroup(layout.createSequentialGroup()
                .addContainerGap()

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
                    .addGroup(javax.swing.GroupLayout.Alignment.TRAILING,
layout.createSequentialGroup()
                        .addGap(0, 0, Short.MAX_VALUE)
                        .addComponent(jLabel1,
javax.swing.GroupLayout.PREFERRED_SIZE,                                243,
javax.swing.GroupLayout.PREFERRED_SIZE)
                        .addGap(110, 110, 110))
                    .addGroup(layout.createSequentialGroup()

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)

.addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED,      41,
Short.MAX_VALUE))

.addGroup(javax.swing.GroupLayout.Alignment.TRAILING,                    lay-
out.createSequentialGroup()
                                .addGap(0, 0, Short.MAX_VALUE)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)

.addGroup(javax.swing.GroupLayout.Alignment.TRAILING,                    lay-
out.createSequentialGroup()
                                        .addComponent(jLabel5,
javax.swing.GroupLayout.PREFERRED_SIZE,                                248,
javax.swing.GroupLayout.PREFERRED_SIZE)
                                        .addGap(18, 18, 18))

.addGroup(javax.swing.GroupLayout.Alignment.TRAILING,                    lay-
out.createSequentialGroup()

                                            .addComponent(jButton2)
                                            .addComponent(jLabel7))
                                        .addGap(28, 28, 28)))))

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
                            .addComponent(jPanel5,
javax.swing.GroupLayout.DEFAULT_SIZE,    javax.swing.GroupLayout.DEFAULT_SIZE,
Short.MAX_VALUE)
                            .addGroup(layout.createSequentialGroup()

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.TRAILI
NG)
```

```
                                    .addComponent(jButton1,
javax.swing.GroupLayout.PREFERRED_SIZE,                              114,
javax.swing.GroupLayout.PREFERRED_SIZE)
                                    .addComponent(MW,
javax.swing.GroupLayout.PREFERRED_SIZE,                               96,
javax.swing.GroupLayout.PREFERRED_SIZE))
                                .addGap(0, 0, Short.MAX_VALUE)))
                        .addContainerGap())))
        );
        layout.setVerticalGroup(
            lay-
out.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADING)
            .addGroup(layout.createSequentialGroup()
                .addComponent(jLabel1)
                            .addComponent(jPanel3,
javax.swing.GroupLayout.DEFAULT_SIZE,    javax.swing.GroupLayout.DEFAULT_SIZE,
Short.MAX_VALUE))
                        .addGap(35, 35, 35)

.addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
                    .addComponent(MW, javax.swing.GroupLayout.PREFERRED_SIZE,
16, javax.swing.GroupLayout.PREFERRED_SIZE)
                    .addComponent(jLabel7))

.addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED,      42,
Short.MAX_VALUE)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.BASELI
NE)
                    .addComponent(jButton1)
                    .addComponent(jButton2))
                .addGap(25, 25, 25))
        );


        pack();
    }// </editor-fold>//GEN-END:initComponents
    private void pr23ActionPerformed(java.awt.event.ActionEvent evt) {//GEN-
FIRST:event_pr23ActionPerformed
         no=Integer.parseInt(n13.getText());
        powerrating=Integer.parseInt(pr23.getText());
        mul2=no*powerrating;
        APR3.setText(Integer.toString(mul2));
    }//GEN-LAST:event_pr23ActionPerformed


        int result;
        result=mul+mul1+mul2+mul3+mul4+mul5+mul6+mul7+mul8+mul9;
        final JFrame parent=new JFrame();
        System.out.print(result);
        parent.pack();
        parent.setVisible(false);
        TotalTR.setText(Integer.toString(result));
        JOptionPane.showMessageDialog(parent,                           Inte-
ger.toString(result),"Result!" ,1);
```

```
    }//GEN-LAST:event_jButton1ActionPerformed
    private void jButton2ActionPerformed(java.awt.event.ActionEvent evt)
        exit(0);


private  void  TotalTRActionPerformed(java.awt.event.ActionEvent  evt)  {//GEN-
FIRST:event_TotalTRActionPerformed
        // TODO add your handling code here:

        int result;

        result=mul+mul1+mul2+mul3+mul4+mul5+mul6+mul7+mul8+mul9;    /*addition
of all the values*/
        TotalTR.setText(Integer.toString(result)); /* result to string */

        float mega=(float)result/1000; /* result of mega watt shown in float
*/
        MW.setText(Float.toString(mega)); /* display result in Megawatt */


    public static void main(String args[]) {
        /* Set the Nimbus look and feel */
        try {
            for       (javax.swing.UIManager.LookAndFeelInfo       info       :
javax.swing.UIManager.getInstalledLookAndFeels()) {
                if ("Nimbus".equals(info.getName())) {
            }
        } catch (ClassNotFoundException ex) {
            ja-
va.util.logging.Logger.getLogger(testproject.class.getName()).log(java.util.l
ogging.Level.SEVERE, null, ex);
        }
        //</editor-fold>


        /* Create and display the form */

        java.awt.EventQueue.invokeLater(new Runnable() {
            public void run() {
                new testproject().setVisible(true);

            }
    // Variables declaration //
    private javax.swing.JTextField APR1;
    private javax.swing.JTextField APR2;

    private javax.swing.JLabel MW;                         */ Value of megawatt/*

    private javax.swing.JTextField TotalTR;

    private javax.swing.JLabel jLabel1;
    private javax.swing.JLabel jLabel2;

    private javax.swing.JPopupMenu jPopupMenu1;          */for popup menu /*
    private javax.swing.JTextField jTextField1;

    // End of variables declaration//GEN-END:variables
); }
```

APPENDIX B: MATLAB SYNTAX FOR SANKEY DIAGRAM

```
clear all;
clc;

inputs = [2860];
losses = [760 660 500 280 200 192 150 74 24 14];
unit = 'W'; sep = [1,2,3,4,5,6,7,8];

labels = {'Input','LCDs','Plasma Displays','Servers','Data center (Cool-
ing)','Desktops','Switches','Laptops','Firewall','Routers','Gateway'};

  drawSankey(inputs, losses, unit, labels, sep);
clc;
```

"drawSankey" is a MATLAB function that draws single-direction Sankey diagrams (i.e no feedback loops), however, multiple inputs and outputs(losses) can be specified.

Inputs: A vector containing the flow inputs, the first of which will be considered the main input and drawn centrally, other inputs will be shown below this.

Losses: A vector containing all of the losses (putput) from the system, which will be displayed along the top of the Sankey diagram.

Unit: A string indicating the unit in which the flows in the chart are expressed

Labels: A cell list of the labels for the different flows, starting with the labels for the inputs, then the losses and finally the output

Sep: An (optional) list of position for separating lines, placed after the loss corresponding to the indexes provided