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IoT Applications in Energy Supply Systems and Traffic

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Master's thesis
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ABSTRAKT

Nyckelord: sakernas internet, energi, trafik

Sakernas internet (Internet of Things, IoT) är en snabbt växande trend inom teknologisektorn. Dess funktionslogik bygger på att sammankoppla teknologi som samlar data från omgivningen, i praktiken sensorer, med varandra, lagra dessa data, analysera data och på basis av det göra väl avvägda beslut.

IoT kan komma att spela en avgörande roll inom energi- och transportsektorn eftersom de båda strävar efter ökad hållbarhet och resurseffektivitet. Fördelen med IoT är att då teknologin blir billigare blir det mera lönsamt att mäta varje aspekt hos ett komplicerat ekosystem, såsom ett kraftverks produktionskedja.

Denna magisteravhandling beskriver några IoT-tillämpningar inom energi och trafik. En referensmodell för planering av IoT-tillämpningar beskrivs och valideras med hjälp av fyra fallstudier.

Fallstudierna utfördes inom ramen för ett samarbetsprojekt mellan Åbo Akademi och Yrkeshögskolan Novia. IoT-tillämpningar för egnahemshus, hus med lägenheter, utställningscenter med egen elförsörjning och energiförbrukning i trafik undersöktes och förslag till fortsatta forskning gavs.

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ABSTRACT

Key words: Internet of Things, energy, traffic

Internet of Things is a rapidly growing trend in the technology sector. Its working principle is to interconnect devices collecting data from our surroundings, such as sensors, storing large amounts of data, analyse the data and making better and more accurate decisions based on gathered data.

IoT can become to play a crucial role in the energy and transport sector that strive towards increasing sustainability through effective use of resources. As the technology required decreases in cost, it becomes more beneficial to monitor and interconnect more devices, leading to a better data of whole ecosystems, such as a power plant supply chain.

This thesis describes some IoT applications for the energy and traffic industry, introduces a reference model for planning IoT applications and analyses four case studies based on the reference model in order to determine whether the proposed model could be suitable for planning IoT applications.

The mentioned case studies were conducted by a project collaboration between Åbo Akademi university and Novia University of Applied Sciences and discovered possible IoT implementations for a remote-area exhibition centre, a detached house, a housing with several apartments and energy consumption in traffic. Each case study is analysed separately and recommendations for further development are given.

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ACKNOWLEDGEMENTS

This thesis was written for Åbo Akademi University with case studies taken from the project IoT in Energy Systems (IoT i energisystem), a collaboration with Novia University of Applied Sciences and financed by the Regional Council of Ostrobothnia and Högskolestiftelsen i Österbotten. I have been working at Åbo Akademi as a research assistant on the project mentioned and wrote the thesis about that.

I would first like to thank Professor Margareta Björklund-Sänkiaho at Åbo Akademi for giving me the opportunity to study the trend that I believe will have a huge impact on our society and way of life. Furthermore, I would like to thank my colleagues Sören Andersson, Hans Lindén, Sami Lieskoski, Joachim Högväg, Lisabet Sandin, Jessica Tuuf and all the other staff at Åbo Akademi and Novia University of Applied Sciences who have helped me along the way.

Thanks also to family and friends who have supported me during this writing process, your help has been highly appreciated.

LIST OF SYMBOLS AND ABBREVIATIONS

AI	Artificial Intelligence. Intelligence and functions typically associated with humans performed by machines.
IoT	Internet of Things. A word for describing interconnected devices that gather and publish data for making decisions.
Raspberry Pi	A credit card sized computer.
VANET	Vehicular Ad-hoc Network. A temporary network used by autonomous vehicles to send and receive information about route and future actions.

1 INTRODUCTION

Internet of Things, or IoT, has been a rapidly growing trend in the technology sector recently. Ericsson (2018) estimates that the number of cellular IoT connections will reach 3.5 billion in 2023 at an annual growth rate of 30%.

Briefly described, IoT means linking physical devices together in a digital network. As there are many implementations for IoT, this thesis will mainly focus on IoT's role in the energy and traffic sector by reviewing literature and by analyzing four case studies in the energy and transport sector to determine how IoT can help solve the particular problems in each case. Broadly speaking, the strength of IoT is gathering large amounts of data about the surroundings. As the energy sector strives towards increasing sustainability, IoT can help by measuring all aspects of an energy system and by analyzing that data, the process can be optimized.

The four case studies described in this thesis were part of a collaboration project between Åbo Akademi University and Novia University of applied Sciences, with the aim to strengthen regional knowledge about the technological trend as well as strengthening university collaboration in energy technology research. Regional knowledge about technological trends is crucial, since the companies of the Vaasa region energy cluster provide highly sophisticated technology for the global energy sector. Regional knowledge also means implementing the new technologies in education and research.

In the literature review it was concluded that the IoT market is currently experimental. To aid the future implementation of IoT devices, this thesis examines a reference model for planning IoT applications as a way of managing future development of new solutions. The reference model was then tested on the four case studies to determine whether the reference model was viable or not.

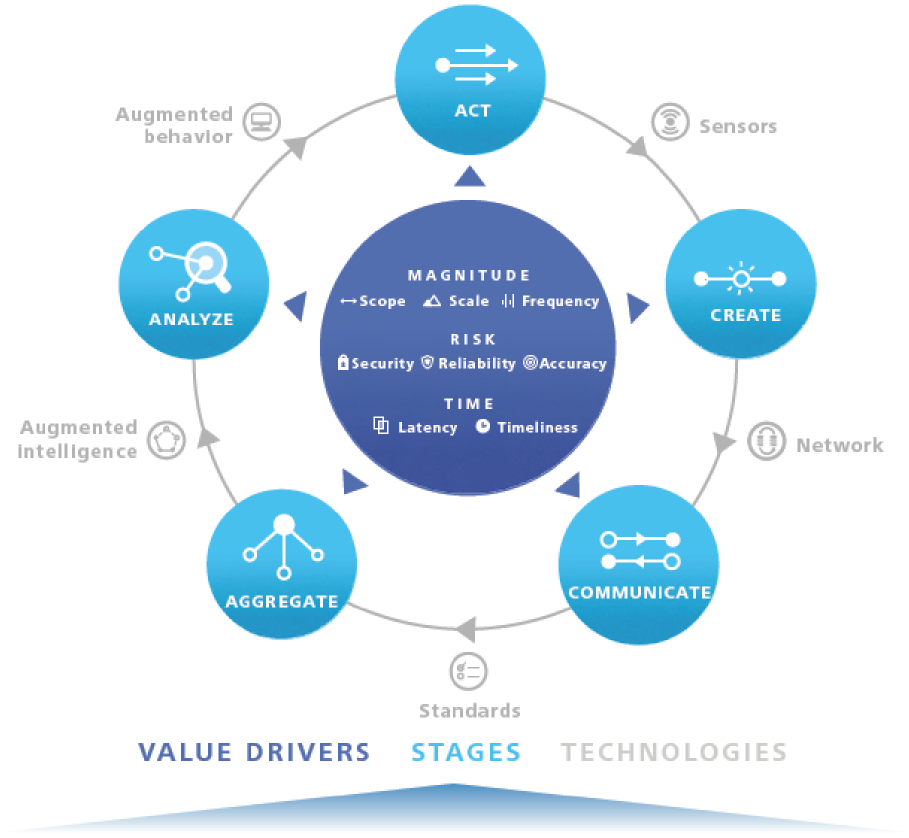
To summarize, the following questions are answered in this thesis: how can IoT help the energy and transport sector move towards increasing sustainability and automation? Is there a model for planning IoT projects that considers the various technologies included? How can IoT be implemented in energy technology education?

2 RATIONALE

The rationale of this thesis was restricted to focus on the basics for understanding an energy supply system, IoT and how they can be linked together to create value. The purposes and technical aspect of different components in an IoT system are explained. This chapter provides the reader with technical expertise in order to understand the case studies.

2.1 What is IoT?

In their article “Internet of Things: Technology and Value Added” (2015), Felix Wortmann and Kristina Flüchter have gathered some definitions of Internet of Things. One definition by The International Telecommunication Union is “a global infrastructure for the Information Society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies”. Another aspect is the interconnections in the manufacturing industry between different production sites and processes, referred to as Industry 4.0. One does not need to physically visit a factory to supervise the production happening at that exact moment, due to the manufacturing process being constantly monitored by sensors and evaluated and controlled by artificial intelligence. Some other implementations of IoT are smart homes, where heating, water usage and air conditioning are monitored and controlled using IoT and vehicle fleet management in public transportation, giving real-time information about the locations of buses and estimating when it will arrive to the bus stop. The core idea of these definitions is to measure, analyze and present real-time data about events that are of interest to humans.



CREATE: The use of sensors to generate information about a physical event or state.
COMMUNICATE: The transmission of information from one place to another.
AGGREGATE: The gathering together of information created at different times or from different sources.
ANALYZE: The discernment of patterns or relationships among phenomena that leads to descriptions, predictions, or prescriptions for action.
ACT: Initiating, maintaining, or changing a physical event or state.

Source: Deloitte analysis. Graphic: Deloitte University Press | DUPress.com

Figure 1. The information value loop (Holodowsky, Mahto, Raynor, & Cotteleer, 2015)

A report from Deloitte University Press (2015) describes IoT using The Information Value loop, a continuous loop with five steps: Create, Communicate, Aggregate, Analyze and Act, as seen in Figure 1. Create means that sensors emit real-time data about an activity. Communicate means that data is moved from the sensors to another location via a network. Data is then Aggregated, gathered together from different sources and structured into manageable form. The structured data is Analyzed to determine patterns or relationships in the physical events measured. Based on patterns and relationships, it’s time to Act, by using previously discovered patterns to alter or maintain the physical activity that was observed.

The report Internet of Things: Position Paper on Standardization for IoT Technologies (2015) defines IoT as:

“A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies. Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled. From a broader perspective, the

IoT can be perceived as a vision with technological and societal implications."

The report focuses on the need for global standardization in IoT, with the authors concluding that it is not beneficial for the European Union, nor for the world and its businesses, to operate non-compatible digital tools. Global standardization could unite the world in a way unseen since the invention and implementation of the internet. Problems arise when issues like data security and privacy are addressed.

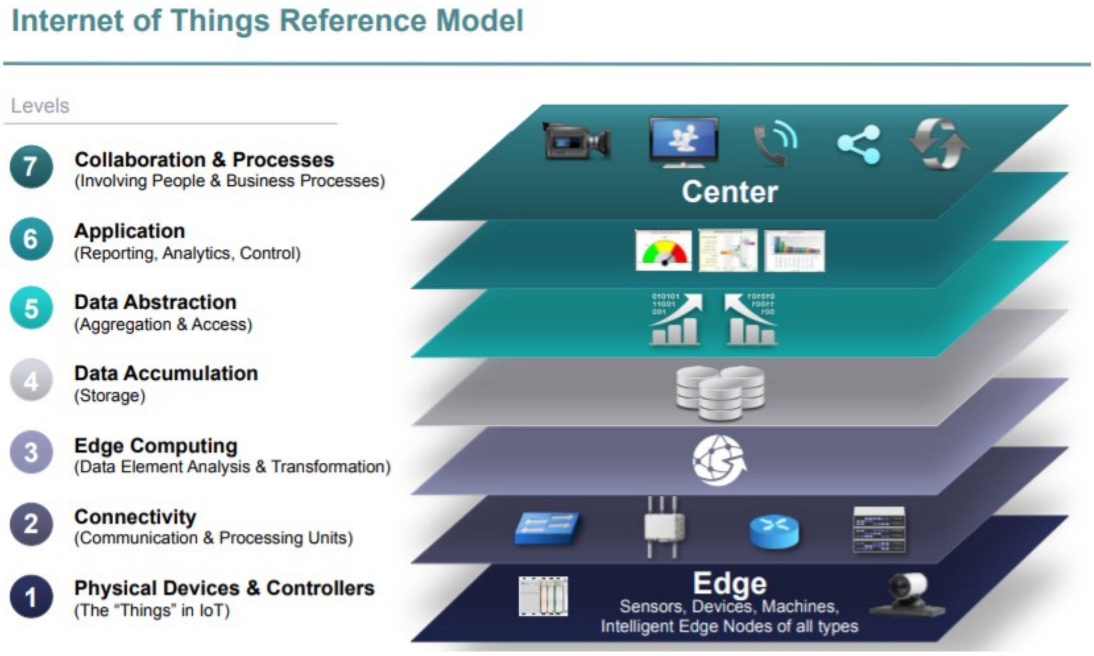


Figure 2. Cisco's seven-layer reference model for IoT (Cisco, 2013)

The company Cisco uses a seven-layer reference model to describe what IoT is (Figure 2). When comparing this with Deloitte's Information Value Loop both similarities and differences can be seen. Deloitte describes the activities happening while Cisco has a so-called building block approach, listing the needed components. They do however have many similarities: both mention sensors, communication and analysis. (Cisco, 2013)

From my understanding there is no correct answer to what IoT is, just different ways of explaining it. The common denominators seem to be gathering data from physical objects with sensors, transferring the data via a network, storing, analyzing and creating useful insights and actions using the gathered data. As I wanted to acquire a more systematic approach in explaining the case studies in chapter 3, I decided to use Cisco's reference model to test whether it is a usable model for IoT projects.

2.2 Concept for modeling an energy supply system

In their article Modeling of Energy-Service Supply Systems Groscurth, et al. (1995) define different kinds of energy-service supply systems (ESSS) with the goal to simplify optimization problems when trying to minimize costs. An energy supply system consists of three parts: commodity flows, information and equipment. Commodity flows are energy carrying matters, such as fuel or electricity entering or exiting the process. Equipment are physical objects that interact with the commodity flows, such as heat exchangers or furnaces. Information gives the physical state of the commodity flows, such as pressure and temperature. The energy supply system is part of a surrounding energy-supply system (SESS) which is part of a natural and socioeconomic environment (NSEE) as seen in Figure 3. There are different types of processes, each describing different types of energy supply systems.

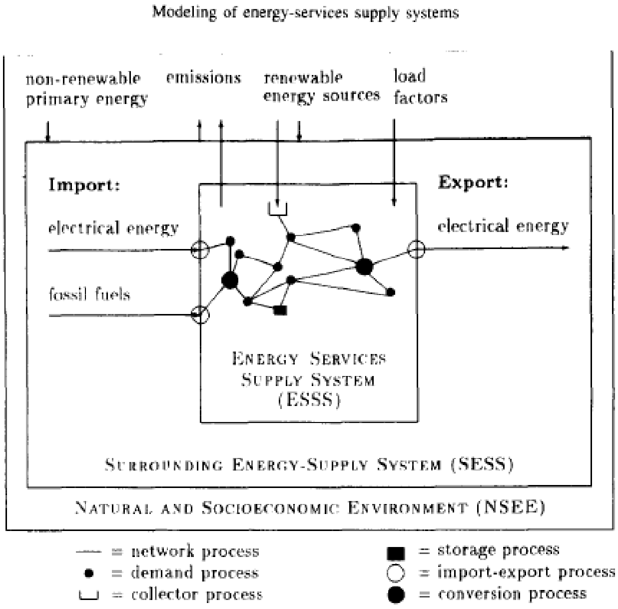


Figure 3. An example of modelling an energy-services supply system (Groscurth, Bruckner, & Kümmel, 1995)

2.2.1 Demand process

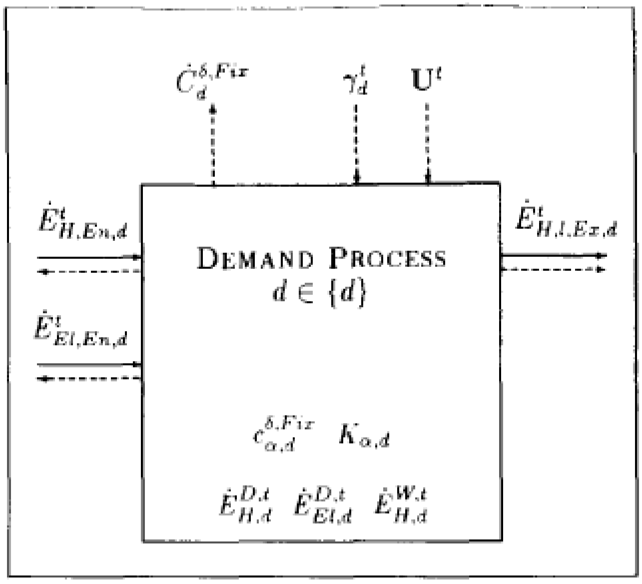


Figure 4. Flows of commodity and information. Solid arrows represent commodity flows and dashed arrows indicate data flows. (Groscurth, Bruckner, & Kümmel, 1995)

Figure 4 describes a demand process. Primary energy (in this case an enthalpy flow and electrical energy) enter the equipment as commodity flows and a single enthalpy flow exits the equipment. Alongside each commodity flow there is a flow of information. This information makes it possible to calculate the numerical value of the enthalpy flow. Enthalpy cannot be measured directly, but temperature, pressure, velocity and what the transported matter is can be measured. With this information the enthalpy can be calculated. There is also information entering and exiting the equipment. C is the fixed cost for this process, γ is the load factor for demand processes (a kind of efficiency number) and U is the environmental data vector containing technical data about the surroundings. U and γ can be functions of the other flows, but they must be accounted for in the process. In demand processes no flow can be zero, that would mean nothing is happening in the process. Demand processes are normally used when modeling energy demand. (Groscurth, Bruckner, & Kümmel, 1995)

2.2.2 Conversion process

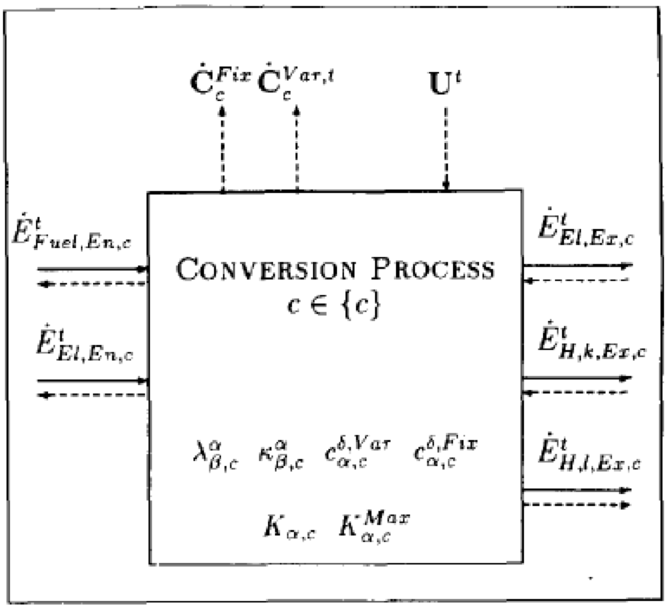


Figure 5. A conversion process. (Groscurth, Bruckner, & Kümmel, 1995)

In conversion processes (Figure 5), chemical energy (fuel) enters the equipment along with electrical energy. Exiting the equipment is electrical energy, energy intended to be produced by the equipment (subscript k) and waste energy (subscript l). Information exiting the equipment are fixed costs and variable costs. Variable costs can be linked to factors such as fuel input. One unit of fuel costs x amount of money, thus increasing the fuel input increases the variable costs. Common applications for this model are furnaces and boilers. The model also accounts for induction ovens when the fuel flow is zero. (Groscurth, Bruckner, & Kümmel, 1995)

2.2.3 Network process

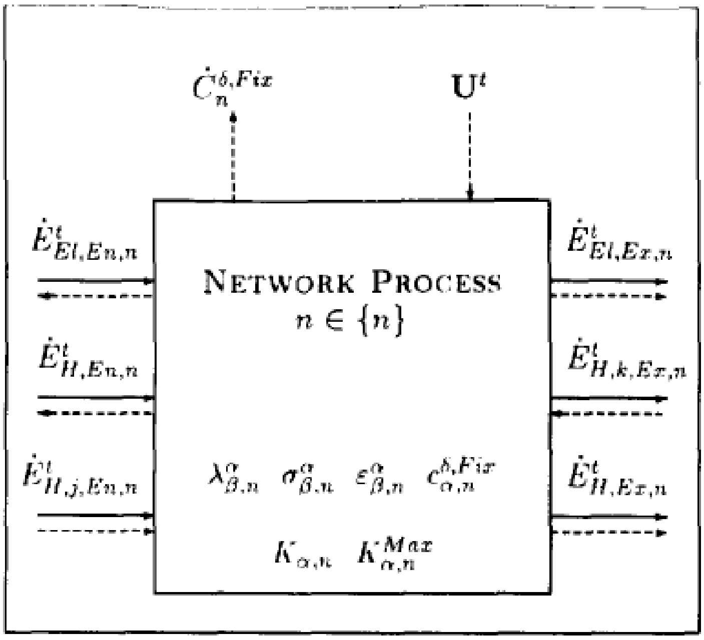


Figure 6. Network process. (Groscurth, Bruckner, & Kümmel, 1995)

A network process (Figure 6) is used when modelling entropy-producing transportation of enthalpy from a conversion process to a demand process, for example heat from a heat source (conversion) to a house (demand). A network process can also include waste heat transfer. Heat pumps are a typical example of a network process. If electricity is produced from waste heat, there is also electricity exiting the equipment. Network processes have no variable costs, only fixed costs. (Groscurth, Bruckner, & Kümmel, 1995)

2.2.4 Import-export process

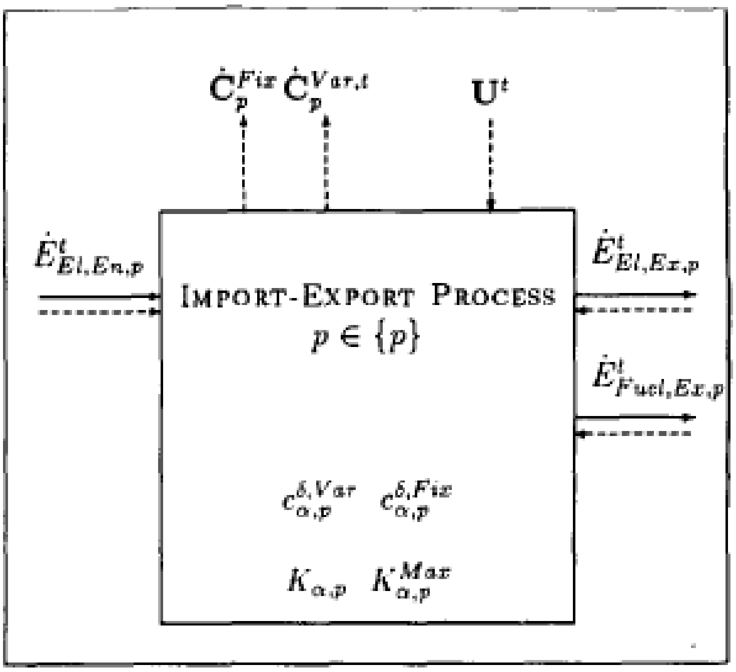


Figure 7. Import-export process. (Groscurth, Bruckner, & Kümmel, 1995)

An import-export process (Figure 7) is used for modelling import or export between the ESSS and SESS, like electrical energy from an outside source into the ESSS generating a cost or excess electrical energy produced by the ESSS exported to the SESS (in this case the grid) generating a decrease in cost (profit from selling the surplus energy). However, exported electricity should normally be lower than the imported electricity. If that is not the case, imported electricity may be exported again which could result in unwanted expenses. There are no links between what enters and what exits an import-export process, the energy balance is accounted for in the ESSS. (Groscurth, Bruckner, & Kümmel, 1995)

2.2.5 Storage process

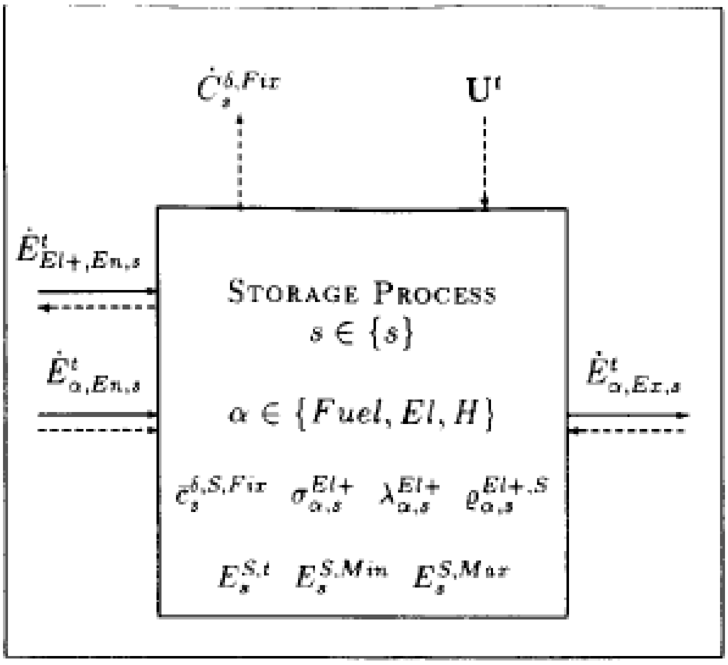


Figure 8. Storage process. (Groscurth, Bruckner, & Kümmel, 1995)

Storage processes (Figure 8) are used for modelling the storage of heat, electricity, biomass and other fuels. Each process can store only one energy form or fuel. Electricity for the storage itself must also be accounted for. Dynamic load management in electrical systems can also be modelled with the storage process. When accounting for costs, the fixed cost of storage cannot be optimized. There are no variable costs in a storage process. (Groscurth, Bruckner, & Kümmel, 1995)

2.2.6 Collector process

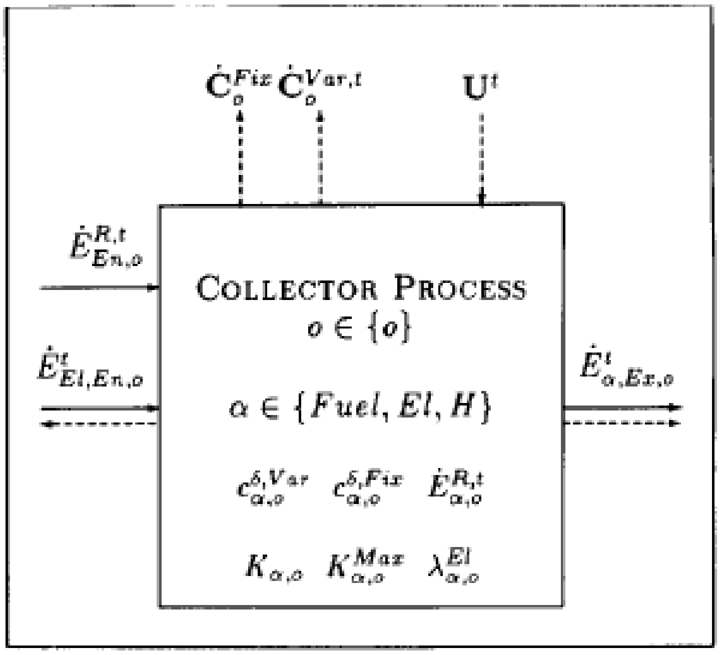


Figure 9. Collector process. (Groscurth, Bruckner, & Kümmel, 1995)

The collector process (Figure 9) is used to model the collection of energy from renewable energy sources such as solar panels, windmill farms and the growing of biomass. The information is contained in the environmental-data vector (wind speed, solar exposure etc), meaning that the entering energy does not contain any information, since that is determined by the environmental conditions. Limitations in the equipment also need to be considered. A windmill has limitations on the rotation speed and a solar panel has limitations on how much energy it can capture. Another aspect to consider is how to define the maximum capacity of a collector process. For example: a roof has four solar panels, but the roof they are mounted on can fit 16 panels. Are we then using only 25% of our capacity? What if the roof is big enough for 16 solar panels but its structure only supports eight panels? If we in that case are using four panels, are we using 25% or 50% of our capacity? The external factors that limit the maximum capacity of our process need to be well thought out and defined before optimizing the system. The variable costs of the process are proportional to the energy produced. (Groscurth, Bruckner, & Kümmel, 1995)

2.2.7 Virtual-supply process

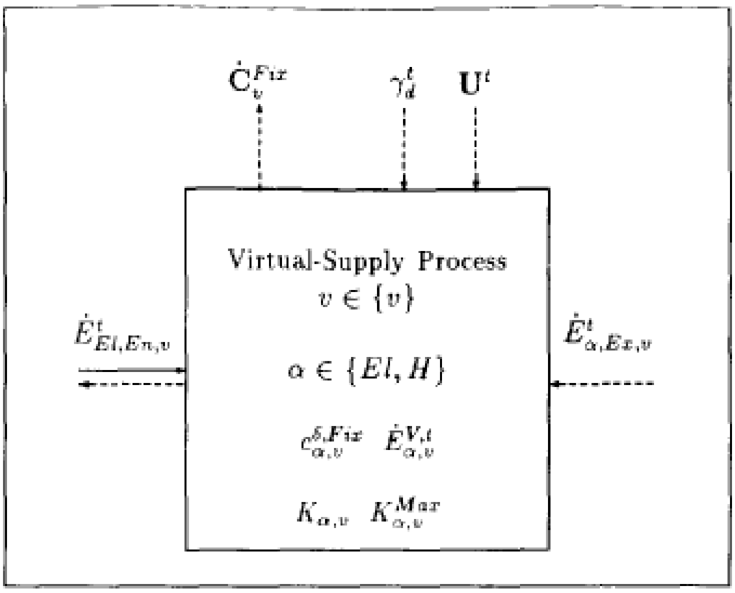


Figure 10. Virtual-supply process. (Groscurth, Bruckner, & Kümmel, 1995)

Virtual-supply processes (Figure 10) are used to optimize cost benefits occurring when the energy demand is lowered, for example by switching to equipment that demands less energy or minimizing heat losses. A virtual supply process does not transfer commodity. Commodity is entered to the equipment, but only information comes out. In the article an example is given: how much money can be saved if the insulation of district heat pipes is improved? This is simulated by lowering the demand that drives the process by calculating how much less enthalpy is needed to achieve the same result.

2.3 Why implement IoT in energy supply systems?

According to the report BP Statistical Review of World Energy (2018), the global consumption of primary energy grew 2.2% to 13,511 Mtoe in 2017, the fastest growth since 2013. The carbon emissions increased by 1.6% after almost no increase from 2014 to 2016 and coal consumption rose for the first time in four years. Bob Dudley, group chief executive of BP, says that the energy sector accounts for one third of the global primary energy. In October 2016 the Paris agreement was put into effect. It was signed by 197 countries that commit to slowing down the global temperature rise to 1.5°C above pre-industrial levels (United Nations Framework Convention on Climate Change, 2015). These insights and agreements push the energy sector to act.

In their article, Shakerighadi et al. (2018) have collected recent findings in the field of energy in IoT systems. They use the term Energy Internet, meaning the integration of energy systems and Information and Communications Technology (ICT).

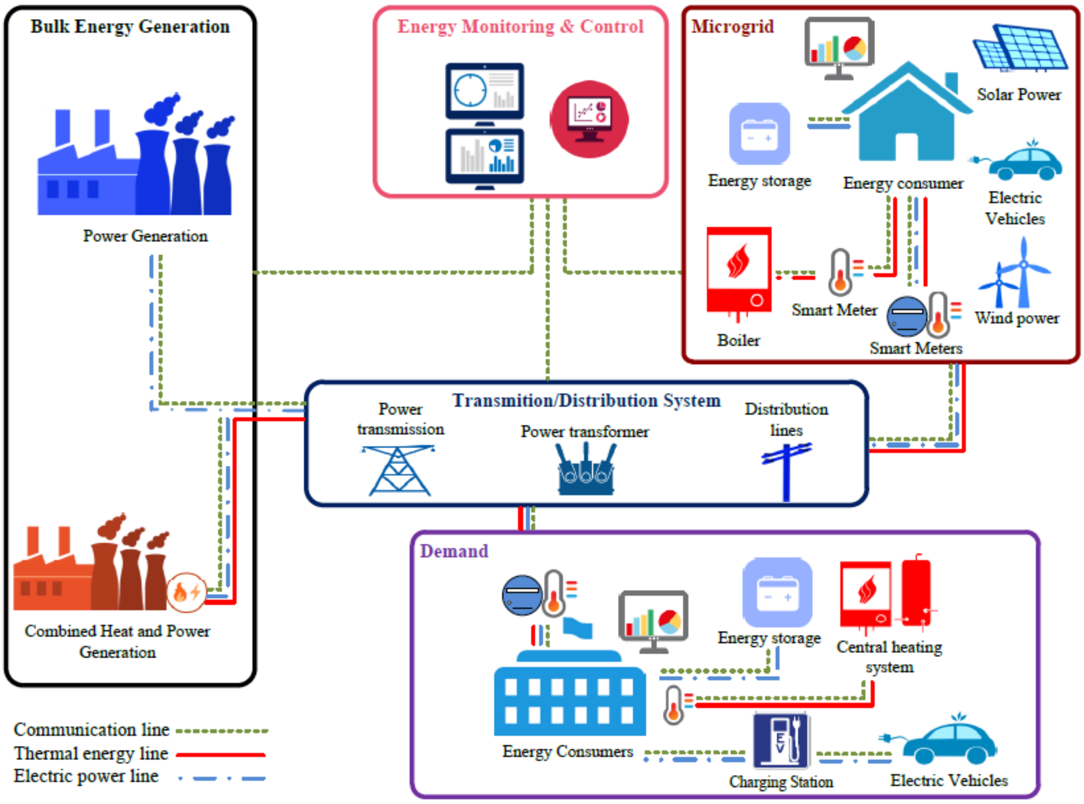


Figure 11. Energy system scheme with electrical, thermal and communication infrastructure (Shakerighadi, Vasquez, Anvari-Moghaddam, & Guererro, 2018)

In Figure 11, similarities with Groscurth et al. (chapter 2.2) approach of modelling an energy supply system can be seen, as commodities and information flow across a map of a fictional city with different equipment. In Figure 11 the authors describe the modern energy supply system. Opposed to the old way of supplying energy, where there is one producer (powerplant) and one consumer, the modern energy supply system must account for small decentralized energy production, such as solar panels and electric cars can contribute to the grid. Consumers can now be producers. The authors refer to these small and decentralized producers as Microgrids.

The introduction of microgrids calls for a new infrastructure that typically has not been a part of an energy supply system: communication. When many different actors contribute to the grid or produce and store their own electricity with renewables such as wind or solar power, the real-time demand for each house must be monitored and factors such as grid stability and reliability become more complex as dynamic production methods (sun and wind) become more common.

Another issue that arises with decentralized energy production is what type of management system should be used. The article describes two strategies: the interactive management scheme and the passive management scheme. The interactive management scheme can be divided into three groups: centralized, decentralized and hybrid. Centralized interactive management schemes are controlled with one decision maker which receives information (such as energy demand, energy production capacity, weather predictions, energy storage capacity) from every node in the system and decides how to optimally distribute the energy. The individual node has no influence on the energy distribution. Centralized schemes are typical for microgrids in remote locations. Decentralized schemes communicate with all data points in the system and gather information for independently deciding how to optimize their performance. Decentralized schemes are more reliable but require a more complicated communication infrastructure, since there are more data connections than in a centralized scheme. Passive management schemes are autonomous and have no information about the neighbouring nodes. They are used when communication infrastructure is too costly to build or operate and should only be used for local optimization. (Shakerighadi, Vasquez, Anvari-Moghaddam, & Guererro, 2018)

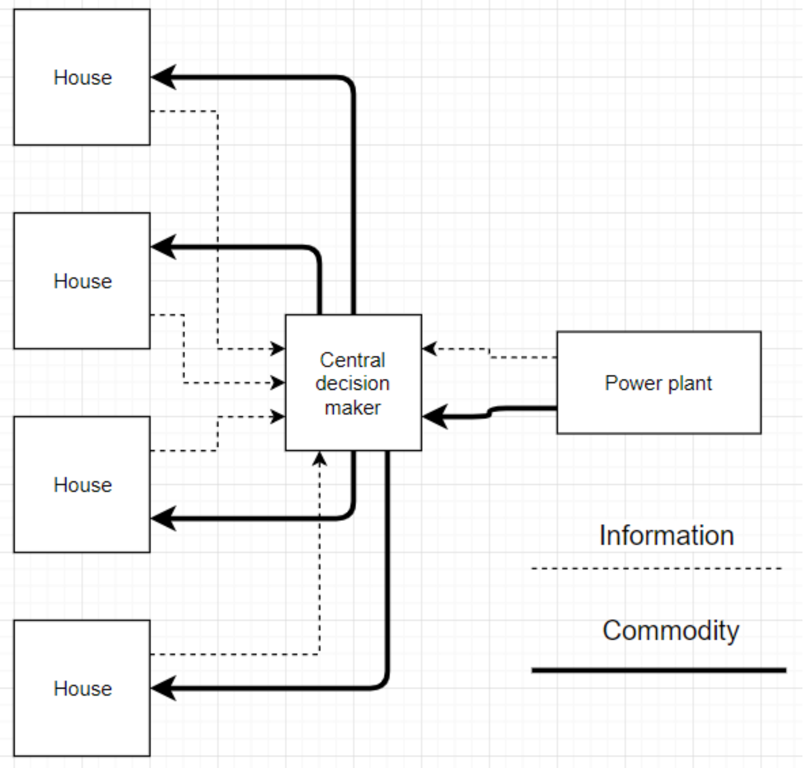


Figure 12. An interactive centralized energy management scheme

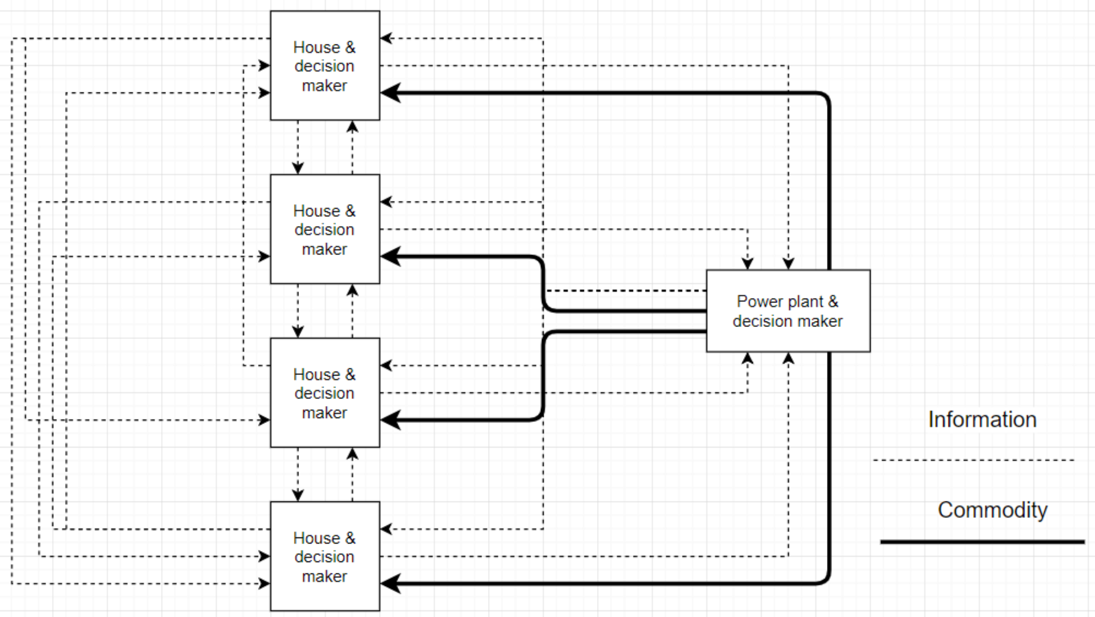


Figure 13. Interactive decentralized energy management scheme

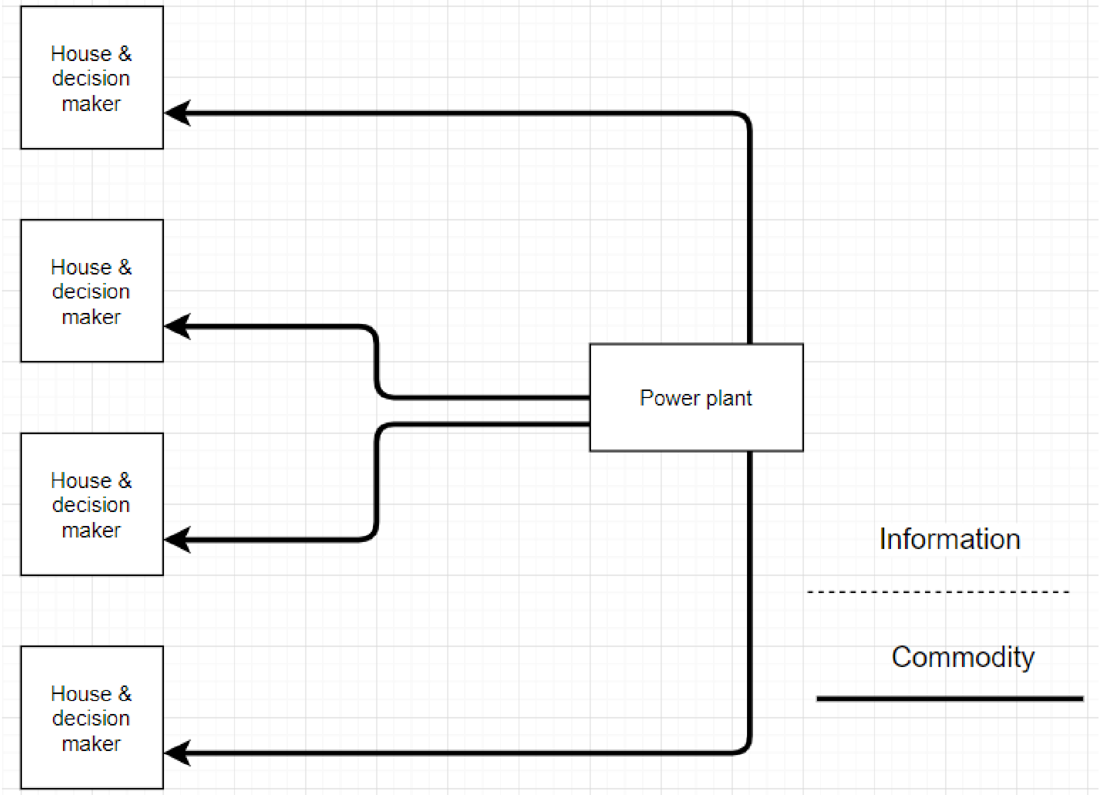


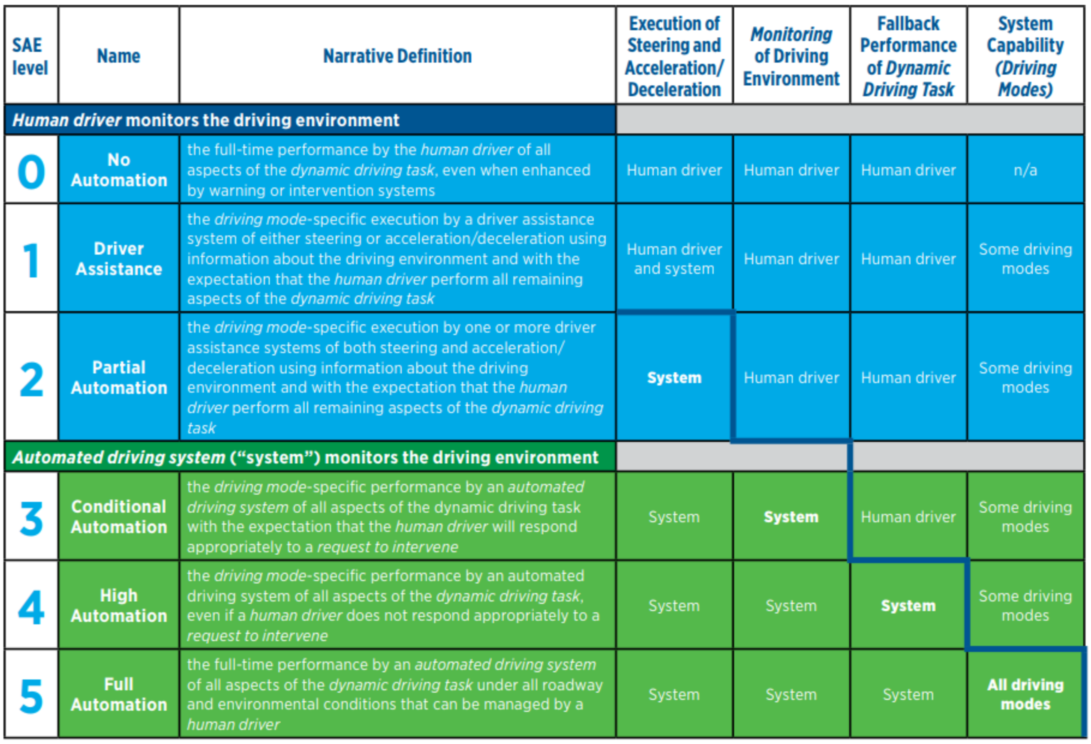
Figure 14. Passive energy management scheme

In Figure 12, Figure 13 and Figure 14 the differences in energy management schemes are illustrated based on the text in the article. As mentioned, in a centralized interactive scheme the consumer cannot influence any decisions. In a decentralized management scheme, every node has influence over the system, but the information flow is complex. In the passive energy management scheme, no information is transferred between the nodes, since decisions are made locally. (Shakerighadi, Vasquez, Anvari-Moghaddam, & Guererro, 2018)

In the podcast The IoT Business Show, Prith Banerjee shares his experiences with implementing IoT at Schneider Electric. Banerjee states that IoT has been the driver for transforming the company's business model. They used to be a hardware company in the electrical industry, now they are in a phase where they focus on both hardware and services. Banerjee and his team conducted a survey with their 2600 closest customers in the electricity, utility and infrastructure sector asking them their thoughts on IoT. 75% were certain that IoT could help them create new business models. When asked about real world IoT applications, customers reported savings up to 50% in operational costs, 40% faster fail search and 39% increase in production efficiency. Banerjee's vision for the future of energy production is that utility companies will sell services instead of the homeowner investing in heaters and solar panels etc. He states that IoT enables utility companies to provide energy as a service and install the wanted energy producing hardware for the house owners, while the house owners pay a monthly fee. Furthermore, a smart energy management system in a house could include the resident into making energy aware decisions. For example, if a house has solar panels and an energy storage unit and buys the rest of their electricity from the grid, the house management system could inform the resident: the battery storage is low, do you want to start the dishwasher when there is enough electricity stored or buy electricity from the grid? (The Internet of Things Business Show, 2018)

2.4 Why implement IoT in traffic?

Perhaps the most notable use of IoT in traffic is self-driving vehicles. Self-driving vehicles are defined as “capable of travelling without input from a human operator, by means of computer systems working in conjunction with on-board sensors”. (Oxford Living Dictionaries, 2019)



SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver **monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system **(“system”) monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 15. SAE Levels of Automation for On-road Vehicles (SAE International, 2014)

Figure 15 shows how Society of Automotive Engineers (SAE) have defined what level of autonomy a vehicle is considered to have using six categories, from no autonomy to full autonomy with no human interaction. The degree of autonomy depends on how much of acceleration, steering, environment monitoring and fallback is left to human interaction. The less factors that are controlled by humans, the more automated the vehicle is. (SAE International, 2014)

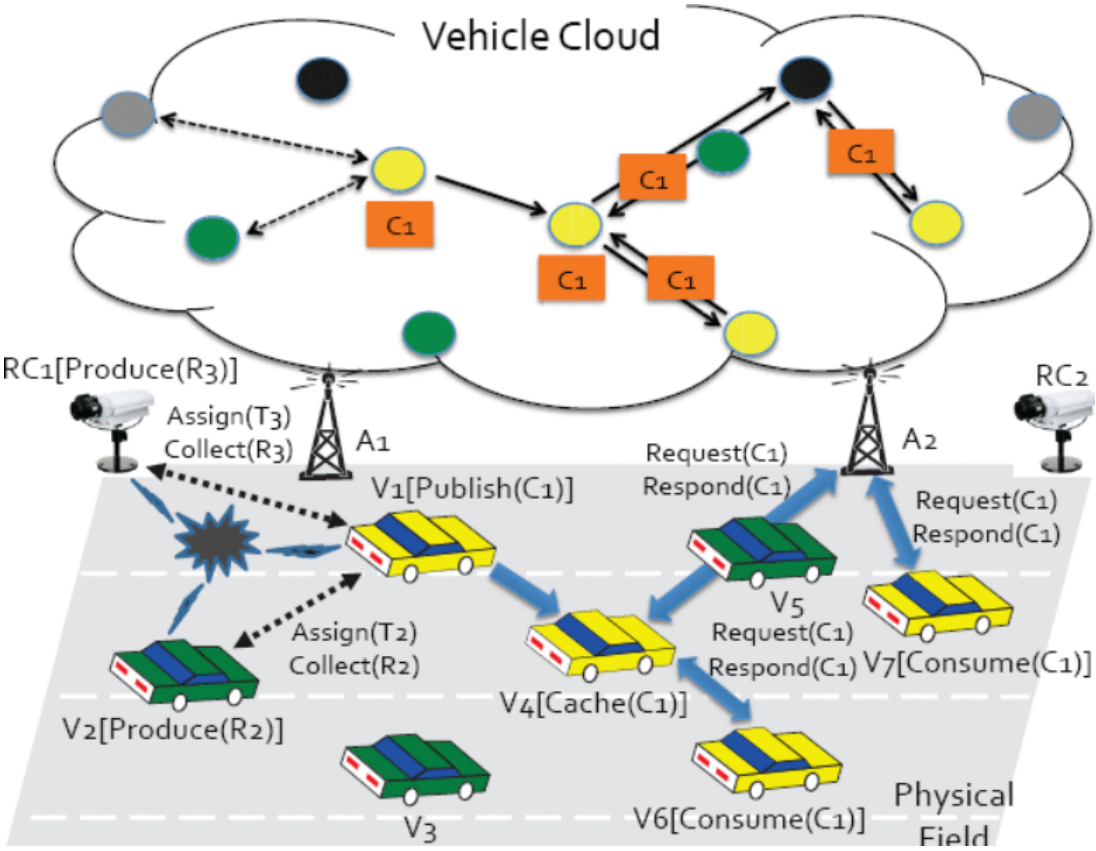


Figure 16. Vehicle cloud network. Vehicles are represented as V, vehicle to vehicle communication is V2V, vehicle to infrastructure communication is V2I, internet transmitters are A and cameras are RC. (Gerla, Lee, Pau, & Lee, 2014)

Gerla, et al. propose a network architecture for autonomous vehicles, as seen in Figure 16. In the figure we see different vehicles (V) interacting with each other using vehicle-to-vehicle communication (V2V) and with the infrastructure using vehicle-to-infrastructure communication (V2I), consisting of internet transmitters and cameras (A and RC). The vehicles create a VANET (vehicular ad-hoc network) when in range of an internet transmitter. Vehicles publish their data to the cloud providing information about e.g. traffic fluency, while receiving messages of interest, such as abnormal traffic conditions and information about points of interest such as nearby gas stations or shopping opportunities. (Gerla, Lee, Pau, & Lee, 2014)

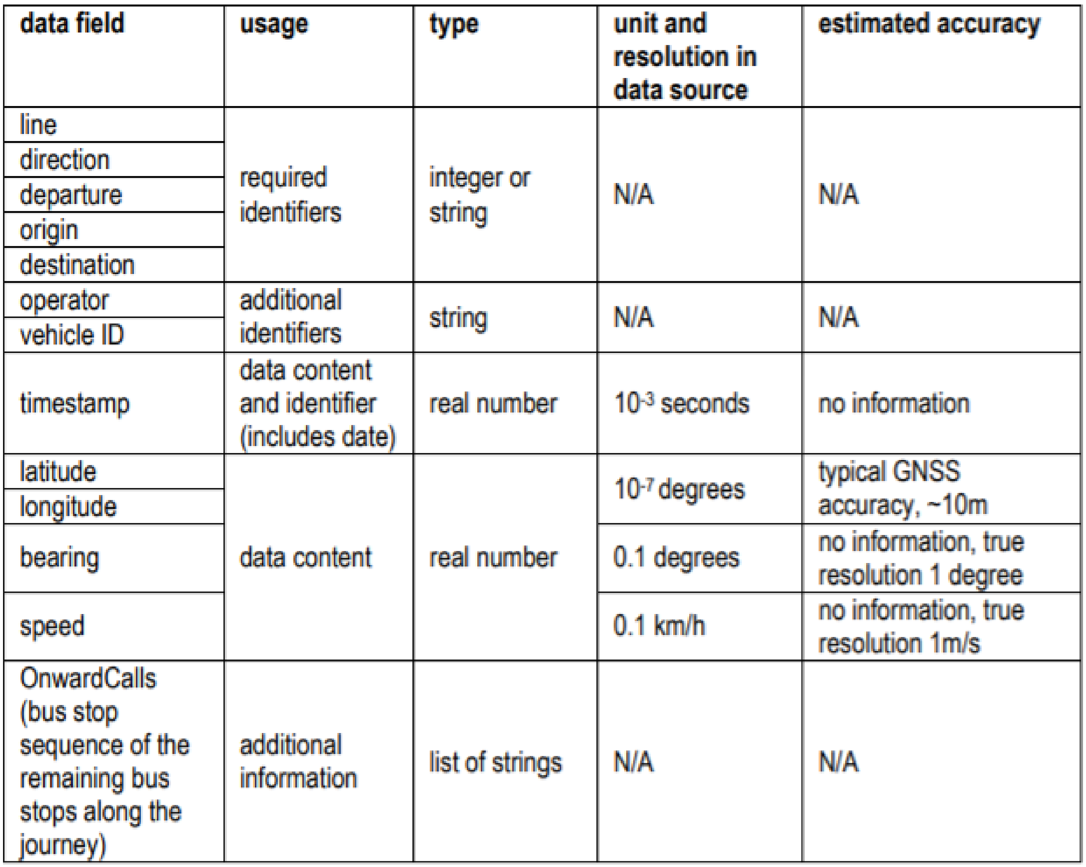
In their article, Krasniqi & Hajrizi list advantages and disadvantages of autonomous vehicles. Advantages include improved traffic safety, as the human factor is eliminated from the driving, better mobility for the young, elderly and disabled, improved traffic fluency, improved fuel efficiency as traffic flows are smoother, and decreased need for parking in urban areas. Disadvantages include economic impacts on business as their business model is being disrupted, a cost reduction in driving may increase traffic congestion and increased car costs for the user. The authors also list key issues regarding autonomous vehicles. The key issues are a lack of reliable software, lack of good maps, lack of fail-safe sensors, liability issues in insurance and consistent regulation between countries as well as taxing mechanisms to share the costs and benefits between the public and private sector. (Krasniqi & Hajrizi, 2016)

In her doctoral thesis, Paula Syrjärinne (2016) presents a method to evaluate public transportation and overall fluency of traffic using data from buses in Tampere. Syrjärinne begins by stating the problems occurring in urban traffic networks as global urbanisation propagates: traffic volumes increase, the citizen’s quality of life deteriorates, and pollution starts occurring. Cities are often faced with three choices: build more roads, minimize traffic demand or develop the transportation experience using new technology.

Syrjärinne explains the importance of real-time, high quality data to describe the current state of the traffic fluency accurately. She mentions some existing methods for traffic management. Fixed sensors, such as inductive magnetic detectors moulded in the road, can measure things like traffic density and the number of vehicles. Traffic cameras can provide visual data for analyses of road condition and traffic fluency. These technologies have been used for a long time and are considered robust. However, they cover only the surrounding area, being unaware of the rest of the traffic network. In order to measure, for example, average velocity using inductive loops two or more sensors are needed and the time spent travelling between the two needs to be known. A way to solve this would be to connect all the loops to a WLAN-network. To the authors knowledge, this has not been implemented on a large scale.

Vehicles of today have much data in them, such as on-board diagnostics and position data. When accessed, they give trustworthy and real-time data about the vehicle. The problem is that the data often stays in the vehicle and serious effort is needed to access it. Some vehicles have the data open for use, so called probe vehicles. Probe vehicles are an essential part when managing a company’s vehicle fleet, for example. Research on the best way to interconnect vehicles is conducted all over the world.

Position data from mobile devices can be used for traffic management applications and route planning. This way a human carrying a mobile device becomes a probe vehicle of sorts. The more probe vehicles (or probe humans) there are, the better the average velocity can be monitored and problem areas in traffic can be highlighted. Travel times can be estimated and the fastest route at the moment can be determined.



data field	usage	type	unit and resolution in data source	estimated accuracy
line	required identifiers	integer or string	N/A	N/A
direction				
departure				
origin				
destination				
operator	additional identifiers	string	N/A	N/A
vehicle ID				
timestamp	data content and identifier (includes date)	real number	10^{-3} seconds	no information
latitude	data content	real number	10^{-7} degrees	typical GNSS accuracy, ~10m
longitude				
bearing			0.1 degrees	no information, true resolution 1 degree
speed			0.1 km/h	no information, true resolution 1m/s
OnwardCalls (bus stop sequence of the remaining bus stops along the journey)	additional information	list of strings	N/A	N/A

Figure 17. Structure of bus location records (Syrjärinne, 2016)

Figure 17 shows what data are collected from the buses in Tampere. These data are uploaded to an API that is updated once a second and can be accessed by anyone for further application development or research (Syrjärinne, 2016).

2.5 IoT Project Design Reference Model

In chapter 2.1 it became clear that the IoT market is quite experimental at the moment, since no commonly adopted definition for describing the technology was found. The Cisco 7 Layer Reference Model was found to be best suited for a project management style of thinking after literature studies and practical experiences with the case studies described in chapter 3. Chaudhuri (2018) advocates the model in his book. Here the Cisco 7 Layer Reference Model will be described further, with some examples to help the reader conceptualize what it is and how to implement it.

2.5.1 Layer 1: physical devices and controllers

Physical devices and controllers are either things that produce data (sensors) or things that are controlled by data (actuators). Sensors measure different physical conditions in their surroundings and emit electrical impulses that can be converted to human-readable data. Data can also be produced e.g. from a website that broadcasts weather predictions, stock market performance or someone's Twitter feed. An actuator is a device or software which actions can be altered by data. Common industrial appliances like valves and electric motors are actuators as well as software, which behaviour alters when fed differentiating data.

There is a wide variety of physical devices and controllers and all cannot be accounted for in this thesis. It is still relevant to have some basic criteria when choosing sensors or actuators. First, the background physical phenomena must be determined. For example, if the energy content in water carried heating systems is measured, temperature and flow must be measured, as is known from common energy calculations. It is preferred to have a mathematical model of the system to determine which individual parameters should be measured.

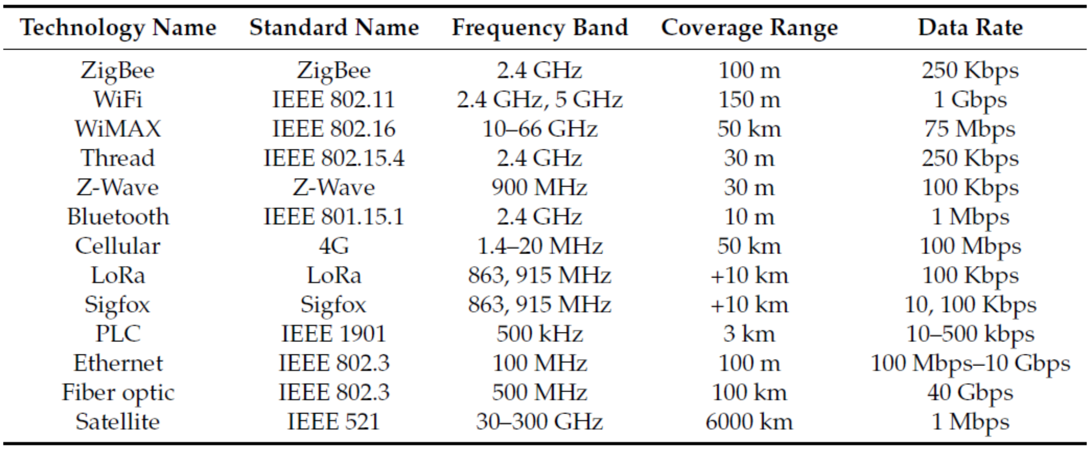
Accuracy and repeatability should be chosen at such a level that the system can complete its intended task with satisfiable results, since too inaccurate data leads to inaccurate actions. With increased accuracy and repeatability comes a higher cost of hardware, so some trade-offs may have to be made. For example: an autonomous forklift and a surgical robot both require some perception of distance. When the forklift can manage with 5 mm accuracy, the same accuracy would be a disaster for the surgical robot.

As mentioned earlier, sensors and actuators operate by electrical impulses. Sensors emit them, and actuators require impulses to change action. It is important to be certain about the characteristics of the sensors and actuators. For example, some sensors have a linear relation between electrical impulses and the phenomena measured, while others have a logarithmic or exponential relation.

It should always be investigated under what circumstances the sensors and actuators are able to perform. Abnormal conditions can be e.g. high or low temperatures, humidity, dust, vibrations or risk of explosion.

A common practise when choosing a sensor or actuator is to have a complete datasheet available and if any doubts arise contact the manufacturer for recommendations. (Teodorescu, 2016) (electronicshub.org, 2017)

2.5.2 Layer 2: connectivity



Technology Name	Standard Name	Frequency Band	Coverage Range	Data Rate
ZigBee	ZigBee	2.4 GHz	100 m	250 Kbps
WiFi	IEEE 802.11	2.4 GHz, 5 GHz	150 m	1 Gbps
WiMAX	IEEE 802.16	10–66 GHz	50 km	75 Mbps
Thread	IEEE 802.15.4	2.4 GHz	30 m	250 Kbps
Z-Wave	Z-Wave	900 MHz	30 m	100 Kbps
Bluetooth	IEEE 801.15.1	2.4 GHz	10 m	1 Mbps
Cellular	4G	1.4–20 MHz	50 km	100 Mbps
LoRa	LoRa	863, 915 MHz	+10 km	100 Kbps
Sigfox	Sigfox	863, 915 MHz	+10 km	10, 100 Kbps
PLC	IEEE 1901	500 kHz	3 km	10–500 kbps
Ethernet	IEEE 802.3	100 MHz	100 m	100 Mbps–10 Gbps
Fiber optic	IEEE 802.3	500 MHz	100 km	40 Gbps
Satellite	IEEE 521	30–300 GHz	6000 km	1 Mbps

Figure 18. Different technologies for wireless communication (Shakerighadi, Vasquez, Anvari-Moghaddam, & Guererro, 2018)

3GPP Narrowband Cellular Standards [edit]

V · T · E [11][12]	LTE Cat 1	LTE-M				NB-IoT		EC-GSM-IoT
		LC-LTE/MTCe	eMTC					
		LTE Cat 0	LTE Cat M1	LTE Cat M2	non-BL	LTE Cat NB1	LTE Cat NB2	
3GPP Release	Release 8	Release 12	Release 13	Release 14	Release 14	Release 13	Release 14	Release 13
Downlink Peak Rate	10 Mbit/s	1 Mbit/s	1 Mbit/s			250 kbit/s		474 kbit/s (EDGE) 2 Mbit/s (EGPRS2B)
Uplink Peak Rate	5 Mbit/s	1 Mbit/s	1 Mbit/s			250 kbit/s (multi-tone) 20 kbit/s (single-tone)		474 kbit/s (EDGE) 2 Mbit/s (EGPRS2B)
Latency	50–100ms	not deployed	10ms–15ms			1.6s–10s		700ms–2s
Number of Antennas	2	1	1			1		1–2
Duplex Mode	Full Duplex	Full or Half Duplex	Full or Half Duplex			Half Duplex		Half Duplex
Device Receive Bandwidth	1.4 – 20 MHz	1.4 – 20 MHz	1.4 MHz			180 kHz		200 kHz
Receiver Chains	2 (MIMO)	1 (SISO)	1 (SISO)			1 (SISO)		1–2
Device Transmit Power	23 dBm	23 dBm	20 / 23 dBm			20 / 23 dBm		23 / 33 dBm

Figure 19. 3GPP Narrowband cellular standards (wikipedia.org, 2015)

In Figure 18 and Figure 19, different technologies for communication are listed. Figure 18 lists the most common means of communication, while Figure 19 lists technologies designed with for IoT communications. Communication technologies designed for IoT are characterized by low cost, long battery life, long range and fast data transfer. (GSMA, 2019)

The purpose of communication is to transfer data between layers (sensor to storage) or inside a layer (sensor to actuator). Hence, there might be different requirements on the communication that transfer data to storage and communication that transfers data to actuators. When choosing proper communication, factors such as transfer speed, reliability, range, compatibility between technologies and cost should be considered (Chaudhuri, 2018). Another aspect which can make planning easier is to have a gateway where all physical devices are connected. A Raspberry Pi was used as a gateway in the housing and detached house case study described in chapter 3. The sensors were connected with cables to the Raspberry Pi and sent the collected data onward via 4G to data storage.

2.5.3 Layer 3: edge computing

Edge computing means to reduce and simplify the data that is transferred to storage in advance, with the aim to reduce storage capacity needs and therefore reducing strain on communications. Such tasks can include converting electrical impulses to more human readable form or converting between units. The benefit of having computation at the edge, as close to the data source as possible, is that it minimizes risk of data loss and delays. Edge computing is characterized by limited processing capacity and thus more complex calculations may be executed at a later stage. (Chaudhuri, 2018)

2.5.4 Layer 4: data accumulation

Data accumulation is another word for data storage. When choosing between different storage options, an estimation of the amount of data and how fast it grows is needed. In a small scale experiment an external hard drive may be enough, but a smart building such as a skyscraper produces data at several terabytes a minute and a large factory at the rate of several terabytes a second. A solution to this can be to only store data that differs from a set normal point, since this is the data that is often interesting and require further analysis and action. Furthermore, it should be decided whether to store the data on an in-house server or use a cloud storage solution. If choosing an in-house server, security and maintenance should be accounted for in the operations. (The Internet of Things Business Show, 2019)

2.5.5 Layer 5: data abstraction

Data abstraction means organizing streams of data so that it is easy to extract for different purposes in layers six and seven. Common practises are time-matching data from different measurements, indexing streams of data and normalizing. Since this layer typically has more computational capacity than layer 3, more complex calculations can be executed (Chaudhuri, 2018). Data abstraction can be described as the essential information rather than detailed information. Sekhar Srinivas describes data abstraction with the following example: consider an employee named Filip working as a salesman, with a salary of 100 000€ per year and the employee number 1000. If a database of several employees is to be made, the details cannot be as specific. Common factors applying to all employees must be defined, in this case employee name, job title, salary and employee number. With this method, the factors are abstracted. (Srinivas, 2013)

2.5.6 Layer 6: application

In the application layer, data needs to be visualized. It can be in the form of an automatically generated report, a graph showing real-time and historical points of interest or a digital control panel to control some process (Chaudhuri, 2018). In case Meteoria described in chapter 3, a digital control panel was made to show the energy consumption and weather conditions at Meteoria. From the digital control panel, it is possible to start the diesel generator without being physically present at Meteorian.

2.5.7 Layer 7: collaboration and processes

Perhaps the most fundamental question when designing an IoT system: how does this benefit humans and how can it change our behaviour? As Steve Stover from Predixion Software says: “Don’t just make a report. Think about what that report should change!” (The Internet of Things Business Show, 2019). At layer 7 a dialog with the user could be helpful to identify what challenges should be solved and what is expected of the system once implemented.

2.6 Design methodology

In technical product development, common design methodologies are top-down and bottom-up. Top-down means to start with a broader picture, often a written specification or idea, and tailoring technical solutions to fulfil said goals. Bottom-up means to start with known technical solutions, altering them if necessary and dimensioning them to meet a said goal.

To explain the differences better, some analogies from the field of mechanical engineering will be used, as said methodology is often implemented in the field. As described in an article written by Matthew Lowe (2013), the bottom-up approach is useful when the overall technical concept is known. This makes it easy to use of-the-shelf components, such as standard valves and pipes as long as they are dimensioned properly. A bottom-up approach reduces the design time because of this. Using the top-down approach every aspect must be project specific to meet the requirements, which often leads to unique components being designed, such as a completely new valve. A top-down approach is suitable when designing entirely new concepts, but is often time consuming.

For IoT systems, a top-down approach is recommended, since it is often a new solution. It is recommended to start with layer 7 and specify the demands of the system. The value creating logic must be clear before taking the next step. Where to continue after that is not as clear. There might be a need to study the workings of the sensors and actuators in layer 1. Or if knowledge of sensors is thorough, focus on visualization and data abstraction in layers 5 and 6. It is hard to give directions, since every project has different challenges and different people with different knowledge. (CIO Story, 2019) (The Internet of Things Business Show, 2018)

To summarize: if it is a completely new solution, use top-down. Once the technology is mature and well-tested, use bottom-up.

2.7 Creating value with IoT

This part will focus on real life implementations of IoT in energy and traffic to give an idea of how many different solutions IoT can be used for.

Duke Energy, an American utility company with over 60 power plants, decided to monitor their turbines in operation and run predictive analysis. If any measured values were abnormal, they would be investigated. One day it was noticed that a turbine bearing was hotter than usual, although the planned maintenance date was still far ahead. It was decided to stop the turbine to investigate the issue and a propagating crack in the turbine shaft was found. The estimated savings using early failure recognition was 5 million dollars. (The Internet of Things Business Show, 2018)

The Finnish utility company Fortum have developed a service called Fortum Fiksu Energiaseuranta, which allows homeowners to monitor their electricity consumption and remotely control the temperature of their water tank, with the possibility to heat the water mainly when there is cheap electricity available instead of every water heater heating at the same time, which creates an energy peak. This also allows for energy storage when the electricity mix consists of an increasing amount of volatile production methods, such as wind and solar. The heating demand will be evenly spread throughout the day, since every homeowner have their own preferences. There are less energy peaks throughout the day and that leads to less demand for peak-shaving production, like coal. The service requires a modest hardware investment and a configuration of the remote-controlled technology. The homeowner pays a monthly fee for the service. The service is aimed to those who have direct electricity heating and it has saved an equivalent of 57,000 litres of oil a month. (Fortum, 2019a) (Fortum, 2019b)

Joachim Lindborg, CTO of Sustainable Innovations AB that conduct development projects for an energy and resource-efficient society, is currently working on a project regarding the lack of capacity in the electrical grid and peak management and was thus interviewed for this thesis. He and his team have connected several heat pumps to a system that monitors grid load and predict when a demand peak will come. When the demand peak is predicted to come, the heat pumps react by lowering their energy consumption in advance. Lindborg further explains what variables should control the pumps, which he argues should not be the electricity price, since he fears a scenario where all pumps simultaneously discover that the electricity is cheap, start operating at maximum capacity, creating a peak in demand and electricity prices increase. (Lindborg, 2019)

As urbanization grows globally, cities around the world have been implementing IoT to monitor the quality of life for citizens and offering new services as a result of new technology. For example, in Barcelona smart energy units have been deployed to monitor and control streetlights. The LED streetlights are equipped with a motion sensor and illumination is increased in an individual light once someone is walking by. Cost savings in energy consumption are reported to be 30%. (Ravindra, 2018)

Apart from connected cars described in chapter 2.4, IoT can also be used for smart parking. It works by mounting an electromagnetic sensor (Figure 20) to a parking spot and it detects whether a car is present or not and publishes its status to an application, saving the driver time and effort to find a free parking space, ultimately improving urban traffic fluency. (The IoT Marketplace, 2019)

Figure 20. Libelium-Yazamtec SmartParking sensor (The IoT Marketplace, 2019)

As described in these previous examples, the common denominator for energy and traffic implementations seem to be a more efficient use of resources and predicting the future based data from real-time operations.

2.8 Criticism towards IoT

As more device are being connected to the internet, concern is being raised about the risks that this involves. A denial of service (DDoS) attack happened in October 2016 in east USA, leaving millions of people without internet. The hackers scanned millions of IoT devices, such as baby monitors and security cameras and got access to them by trying a variety of pre-set usernames and passwords. The hackers used the hacked devices to form a network of bots that targeted Dyn, an internet service provider, with millions of attacks until their servers went offline. The code used by the hackers was released on the internet before the attacks began, meaning there is now a dangerous code on the internet that exploits unprotected IoT devices that the ordinary owner might not realize needs to be protected with strong identification. (Fruhlinger, 2018)

For this thesis Joachim Lindborg, the CTO of Sustainable Innovations AB, was interviewed regarding his ideas on IoT and what role he thinks it will have on our future. He says IoT is critical for a more sustainable future. With IoT, resources can be monitored and efficiently used.

Lindborg criticizes the technology sector for having a narrow mindset regarding their IT-systems. There is a silent understanding that IT-systems need to be able to interact with each other. However, every branch is now forming their own branch specific alliances and not collaborating with other branches. This so-called silo mentality slows down innovation, he claims.

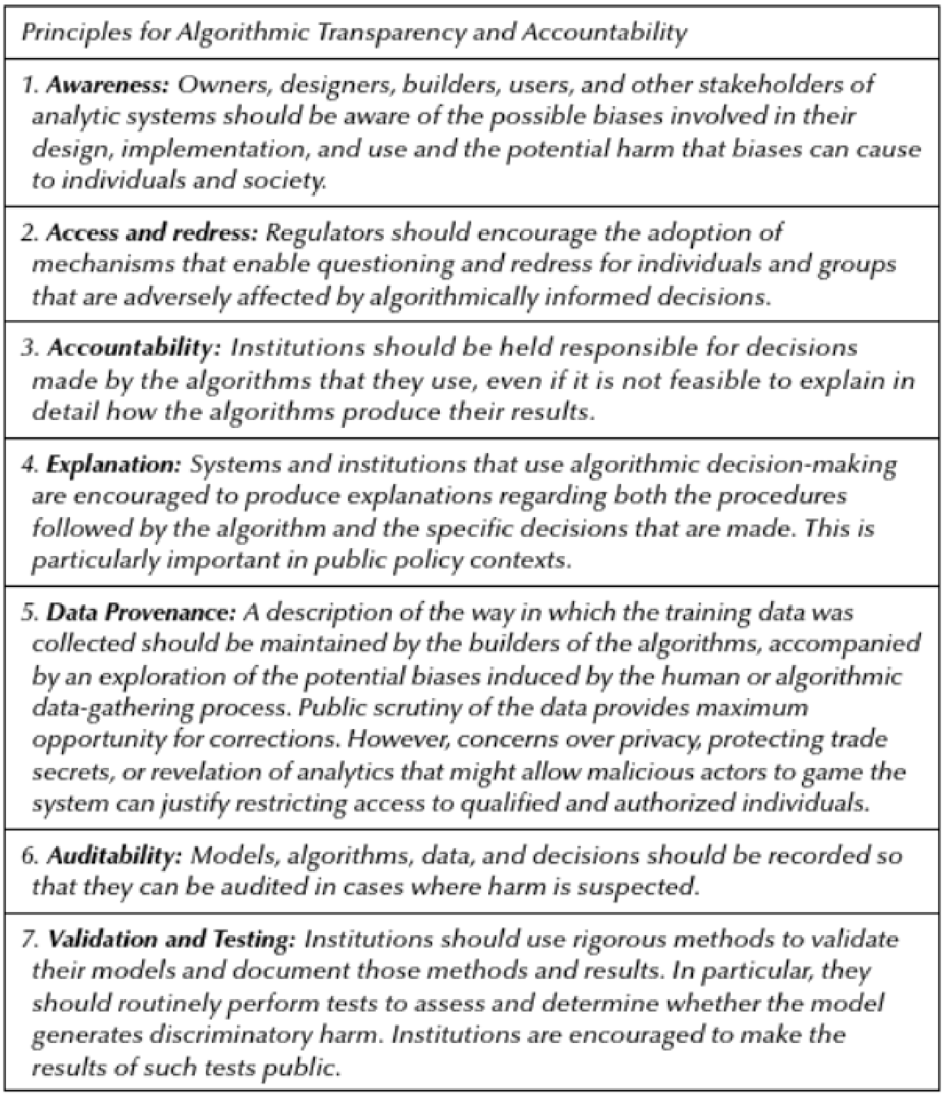
Lindborg calls for increased modularization of IoT products. He explains that if a small part of an IoT product fails, an entirely new product must be bought instead of changing the faulty component. He says to look at the automotive industry for ideas to implement modularization in electronics. Lindborg also calls for focusing on the customer experience when designing IoT applications, as applications should be easy and intuitive to use.

On the issue of autonomous energy grids Lindborg is concerned with applying them on a large scale. He argues that it can lead to the wealthy going of the grid, leaving cities and people of low socio-economic status on the grid. Lindborg calls for regulation that make it beneficial to stay on the grid regardless of technological advances. (Lindborg, 2019)

In his book Internet of Things, for Things and by Things, Abhik Chaudhuri (2018) devotes a chapter to exploring the philosophical aspects of IoT and its possible impact on society. Chaudhuri sees a lot of potential in a world where an increasing number of people and things are interconnected. However, he is concerned about uncritically interconnecting everyone and everything might lead to a disaster if basic ethics and human decency are forgotten.

Chaudhuri describes five philosophical dimensions of IoT that need to be met for IoT to be implemented and trusted on a large scale: ontology, phenomenology, epistemology, logic and digital ethics. Ontology is the basic understanding of what IoT is, discussed in chapter 2.1. Phenomenology is the study of how we experience IoT and how we realize the value of it, based on our experiences. Epistemology asks the question: can the knowledge be trusted? Knowledge can be based on facts or biases or both. Trust in IoT is built by two factors: trust in the technology itself and trust in the social surroundings of the technology. The trust in the social surroundings of the technology can be improved by people accepting the technology as a part of their daily lives, then interact with other users and form a helping community where knowledge is shared. Logic asks the question: how should IoT be reasoned with? When a user uses an IoT device, they have a subjective experience and then contemplate how this experience was possible to occur. The user’s technical expertise, trust in technology and the experience outcome itself will influence how IoT is reasoned with. Digital ethics defines concepts for right and wrong uses of IoT.

Chaudhuri argues that system designers, legislators and end users must have a dialog on issues such as IoT reliability, security and privacy. The author offers some possible ethical guidelines. Given the experimental state of the IoT market, every individual partaking in IoT business should ask themselves these philosophical questions, Chaudhuri argues.



Principles for Algorithmic Transparency and Accountability
1. ***Awareness:*** *Owners, designers, builders, users, and other stakeholders of analytic systems should be aware of the possible biases involved in their design, implementation, and use and the potential harm that biases can cause to individuals and society.*
2. ***Access and redress:*** *Regulators should encourage the adoption of mechanisms that enable questioning and redress for individuals and groups that are adversely affected by algorithmically informed decisions.*
3. ***Accountability:*** *Institutions should be held responsible for decisions made by the algorithms that they use, even if it is not feasible to explain in detail how the algorithms produce their results.*
4. ***Explanation:*** *Systems and institutions that use algorithmic decision-making are encouraged to produce explanations regarding both the procedures followed by the algorithm and the specific decisions that are made. This is particularly important in public policy contexts.*
5. ***Data Provenance:*** *A description of the way in which the training data was collected should be maintained by the builders of the algorithms, accompanied by an exploration of the potential biases induced by the human or algorithmic data-gathering process. Public scrutiny of the data provides maximum opportunity for corrections. However, concerns over privacy, protecting trade secrets, or revelation of analytics that might allow malicious actors to game the system can justify restricting access to qualified and authorized individuals.*
6. ***Auditability:*** *Models, algorithms, data, and decisions should be recorded so that they can be audited in cases where harm is suspected.*
7. ***Validation and Testing:*** *Institutions should use rigorous methods to validate their models and document those methods and results. In particular, they should routinely perform tests to assess and determine whether the model generates discriminatory harm. Institutions are encouraged to make the results of such tests public.*

Figure 21. Principles for Algorithmic Transparency and Accountability as proposed by U.S. Association for Computational Mechanics (Chaudhuri, 2018)

In Figure 21 Chaudhuri (2018) quotes the U.S. Association for Computing Machinery's principles for algorithm transparency and accountability. Chaudhuri argues that these principles are adequate guidelines when trying to implement IoT products and services in real life. For IoT technology to be accepted on a large scale, the population will need to see positive experiences repeatedly and any inconveniences must be accounted for. This will over time build a positive reputation for IoT, he argues. Furthermore, Chaudhuri urges for discussion on transparency in system design, data gathering practises and data spread over complex ecosystems and its impact on personal integrity.

2.9 Summary of rationale

IoT can be explained by interconnected devices that transmit data about real-time events and by storing and analysing data, more information-based decisions and predictions can be made. As for an energy system, the article by Groscurth, Bruckner & Kümmel (1995) shows the various value-producing streams that can be monitored, regulated and optimized with various mathematical models. Using the findings of Groscurth, Bruckner & Kümmel, different energy management schemes with a varying degree of autonominty and centralization can be implemented, as described by Shakerighadi, Vasquez, Anvari-Moghaddam, & Guererro (2018).

The most prominent use for IoT in traffic is self-driving vehicles. Gerla, Lee, Pau, & Lee (2014) describe the infrastructure needed, while Krasniqi & Hajrizi (2016) list advantages and disadvantages with autonomous vehicles. The advantages are better and more socially equal mobility, an improved traffic fluency, an elimination of the human factor on the road, causing irrational behaviour and a decreased need for parking in urban areas. The disadvantages are possible increase in traffic volumes and increasing car ownership costs. Syrjärinne (2016) describes how IoT helped the city of Tampere pinpoint the performance of the public transportation network by installing sensors on buses, gathering data about their speed and location to determine traffic fluency.

The possibility to create value with IoT has a broad spectrum. From predictive maintenance (The Internet of Things Business Show, 2018), managing heating water (Fortum, 2019b) and heat pumps (Lindborg, 2019) to controlling city infrastructure, like streetlights (Ravindra, 2018) and parking space availability (The IoT Marketplace, 2019). The common denominator for these IoT implementations is to use resources more efficiently.

Criticism has also risen towards IoT. DDos attacks were executed in 2016 as IoT devices with the default identification were hacked. Millions of Americans were left without access to internet (Fruhlinger, 2018). Chaudhuri (2018) describes the ethical guidelines, which every IoT actor should be aware of regarding privacy, algorithm transparency and accountability. Lindborg (2019) challenges the technology sector to cooperation, rather than the “silo mindset” he experiences in the development of the IoT market.

The IoT Reference model proposed by Cisco in chapter 2.5 is evaluated, using the four case studies, in chapter 6.

3 FOUR CASE STUDIES

This thesis includes four case studies. Two of them are briefly explained in this chapter, while the other two are presented more thoroughly in chapter 4. The reason for this is that some case studies do not have an academic result to present, because the hardware has just been installed and tested briefly, while the other two case studies have results which show how IoT can be implemented in energy and traffic. In chapter 6, all four case studies are reviewed with the IoT Reference Model introduced in chapter 2.5. Ideas for further development are discussed in chapter 7.

The case studies were part of a project called IoT in Energy Systems, a collaboration between Åbo Akademi University and Novia University of Applied Sciences. The aim of the project was to strengthen energy technology research collaboration between universities, while simultaneously developing regional knowledge about IoT in general, and especially in energy systems, in order to be prepared for global technological changes. Based on the case studies, a demonstration environment was planned in Technobothnia, a research laboratory mutually owned by Vaasa University, VAMK University of Applied Sciences and Novia University of Applied Sciences.

The IoT Project Design Reference Model was discovered and explored while the case studies had progressed significantly. Hence, the reference model was not used to plan the case studies. The goal is not to point out the technological choices that do not exactly comply with the reference model. A more constructive approach is to explore the potential of the reference model with functioning case studies and acquire better knowledge for future projects.

3.1 Detached house

The detached house case study was located at an old school that had been renovated to a residential house for a family of three. As a part of the renovation, the old oil heater was replaced with a downhole heat exchanger, which means that a hole is drilled in the ground, typically 200 m deep, and a liquid that withstands sub-zero temperatures is circulating in a closed loop. The groundwater temperature is considered stable throughout the year, so it can be used to cool the liquid after it has circulated through a heat exchanger.

The goal of this case study was to monitor the heat consumption, the electricity consumption, the coefficient of performance (COP) and the seasonal performance factor (SPF). COP is a ratio between produced heating or cooling power and the input electricity. SPF is basically COP, but during a longer time span. Since the COP varies throughout the year, SPF is the ratio between annual heat production and annual electricity consumption.

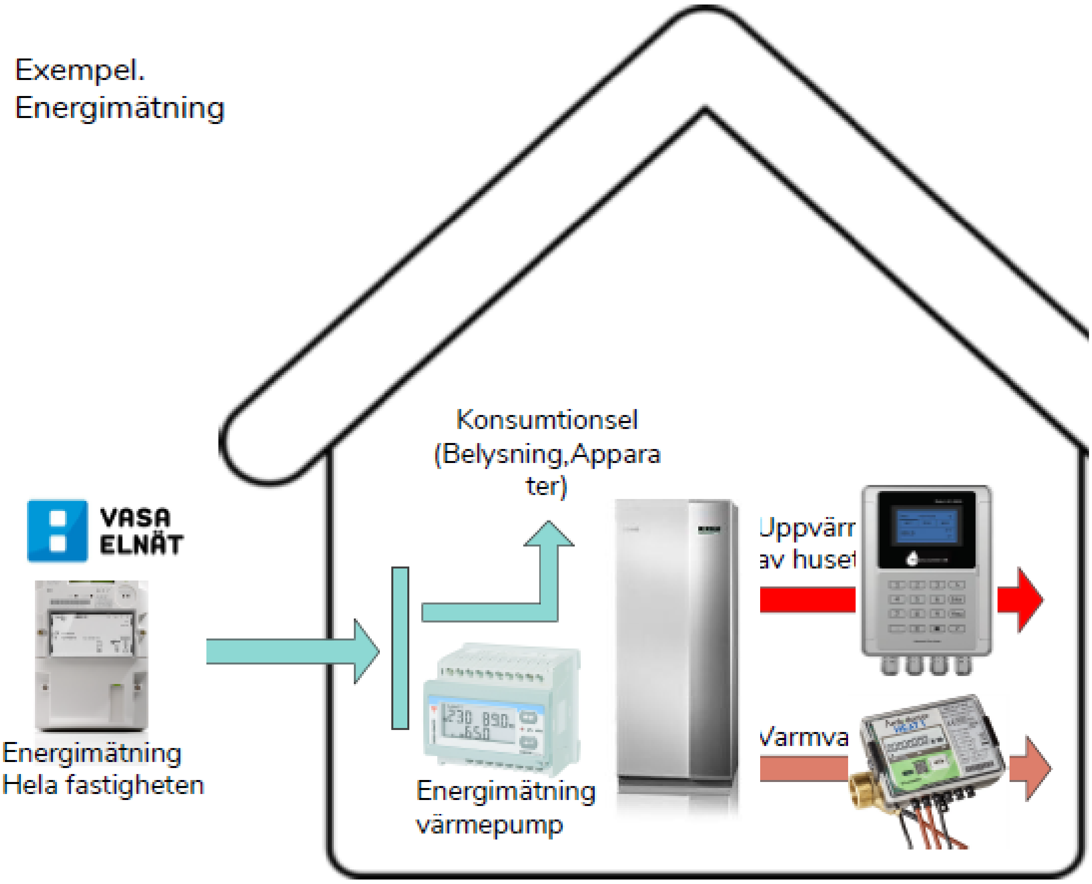


Figure 22. Schematic of detached house energy system (Högväg & Andersson, 2019a)

In Figure 22, the energy system of the detached house is described. Parameters being measured are electricity consumption of the downhole heat exchanger (energimätning värmepump), energy in the heating water (uppvärmning av huset), energy in the warm water used for showering etc (varmvatten) and total electricity consumption of the house (energimätning hela fastigheten). The electricity consumption of the house was measured with a meter provided by the local utility company. The electricity consumption of the heat exchanger was measured with an external energy meter, heat exchanger parameters were measured via a Modbus interface, the heating water energy content was measured using LRF 3000S ultrasonic sensors and the warm water energy content was measured with a Qalsonic HEAT2 ultrasonic sensor. The technology is similar to that described in chapter 3.2. Measuring the energy content in the liquid circulating in the bore hole was agreed to be left out of the scope of the case study due to late installation.

The detached house case study resulted in the electricity consumption of the downhole heat exchanger, the energy in heating water, the energy in warm water (used for showering etc), and the total electricity consumption of the house being successfully measured and logged. The house owner noticed that the heat exchanger responded too slowly to temperature decrease in the heating water, so the regulator was modified to respond faster, resulting in a more consistent water temperature. Data is being stored both in a server owned by Novia University of Applied Sciences and a Google cloud service. For visualization, Grafana was used to plot the energy consumption and heat exchanger parameters.

3.2 Housing

The housing case was conducted in a house with eight apartments and two business facilities, comprising a total floor area of approximately 500 m^2. The housing company was interested in monitoring the consumption of drinking water, warm water, heating water, electricity and district heating on a more detailed level. The status quo was that consumption data were presented in housing board meetings and presented for a long period of time, for example the consumption for the past year. With more detailed data, the company could faster react to abnormal consumption patterns, such as a water leak or a window left open while the resident is away. The idea of a living laboratory environment in Technobothnia including data from the housing was discussed. Data gathered from the housing could be implemented in research or education at Technobothnia. However, this led to concern about privacy issues and was not yet implemented.

This IoT system has four different consumptions that are measured: electricity, heating water, drinking water and district heating. To form a systematic overview of the system, layers 1 and 2 are described separately, since a gateway is used at layer 3, linking together all components.

3.2.1 Electricity

To measure the electricity consumption, the local utility company had to be involved. They were in the process of testing a new electricity meter with remote monitoring capabilities and were positive to co-operate in this case study. The meter is layer 1.

The electricity meter operates with Mbus, as is common for these types of meters. The meter is wired to a Raspberry Pi gateway.

3.2.2 Heating water

- För fast installation på vägg eller i skåp
- Skyddsklass: IP65, sensorer IP68
- Utgångar: 4-20mA, puls, relä och Modbus RS485
- Kommunikation Modbus RS485 som standard
- Värmemängdsmätning 2*Pt1000(option)
- Temperaturkompensering
- Universella sensorer för rör DN25-1200
- Temperaturområde -40 – 80°C (option 130°C)
- Matningsspänning: 10-36VDC och 90-265VAC
- Stor och tydlig Display
- 2 st analoga ingångar 4-20mA för externa givare

Figure 23. Ultrasonic flow meter LRF3000S (Process Center AB, 2019)

To measure energy flow in water-carried heating systems, the flow and temperature of the water must be known. Figure 23 shows the ultrasonic flow and temperature meter used in this case study. The meter also has some built-in energy calculations, so in a way edge computing is computed at layer 1. The meter has Modbus RS485 capabilities and is wired (layer 2) to the Raspberry Pi gateway.

3.2.3 District heat

Figure 24. Kamstrup MULTICAL 601 district heat meter (Indexterm, 2019)

Figure 24 shows the meter used for measuring district heat. It has two measuring probes, one for the incoming water and one for the return water as well as ultrasonic sensors for flow measuring. As for the heating water meter, this meter also has calculation capabilities, so edge computing is executed at layer 1. It operates with Modbus and is wired to the gateway.

3.2.4 Warm water

Figure 25. Qalcosonic HEAT2 warm water meter (Ambiductor AB, 2019)

Warm water for showering etc was measured with Qalcosonic HEAT2. It has temperature probes and ultrasonic sensors. Unlike the meter in chapter 3.2.2, the ultrasonic measuring device is installed between pipes instead of sensors being mounted outside the pipe, as seen in the picture of the different installations below.

Figure 26. Left: LRS 3000S, right: Qalcosonic HEAT 2 ultrasonic sensors

The Qalcosonic HEAT 2 uses Modbus and is wired to the Raspberry Pi gateway.

3.2.5 Drinking water

No suitable drinking water meter was found within the project’s deadline, so it had to be neglected. The situation when writing this thesis is that an old-fashioned water meter with manual consumption reading is used, but no data are logged in this project. There are some meter models with electronic impulse output which could be tested nd was proposed for future development.

3.2.6 The technology of layers 3–6

As mentioned earlier, all sensors are connected to a gateway (Raspberry Pi), which labels the data. No edge computing apart from this is executed. Data are stored on a server owned by Novia University of Applied Sciences as well as in the cloud (IBM Watson). The reason for choosing both is purely experimental. IBM’s Watson service wanted to be evaluated and compared to the alternative of having a university-owned server. No data abstraction was used. For visualization, Grafana was explored, but no final solution was implemented.

The results in this case study can be concluded as the hardware being installed and a better understanding of what should be considered when retrofitting an IoT system into an existing heating system as well as valuable insights about ultrasonic measuring.

Due to time and resource constraints, as well as many different parties being involved (housing company, water company, utility company, plumbing fitters and sensor manufacturer technical support), the case study was concluded with the result that the sensors are installed and are collecting data for storage.

The goal of the case study was to monitor district heating, heating water, drinking water and electricity consumption. All but the drinking water and warm water are successfully being monitored. The issue with the drinking water meter was explained in chapter 3.2.5 and the warm water meter gave inconsistent data. Upon investigation it was discovered that the warm water meter was installed incorrectly due to poor knowledge about ultrasonic measurements and the intricate workings and placing of the sensor.

As mentioned before, visualization of data was tested in Grafana, but a digital dashboard or reporting tool requires further development.

The case studies Meteoria and Energy Consumption in Transport are presented in the next chapter.

4 MATERIAL AND METHODS

4.1 Meteoria

Meteoria is a visitor center located at one of Europe's biggest meteor craters at Söderfjärden, 13 km from Vaasa city center. When the visit center was built, it would have been very costly to acquire electricity from the grid because of the remote location. It was decided that Meteoria will produce its own electricity off-grid.

Meteoria consists of an exhibition hall with an astronomy observatory and a meeting room. The observatory has electrical radiators while the meeting room is heated with a heat pump. The non-profit organization operating the visitor center wanted to be able to keep the heating to a minimum when there is no activity at the premises and remotely turn on the heating for upcoming events.

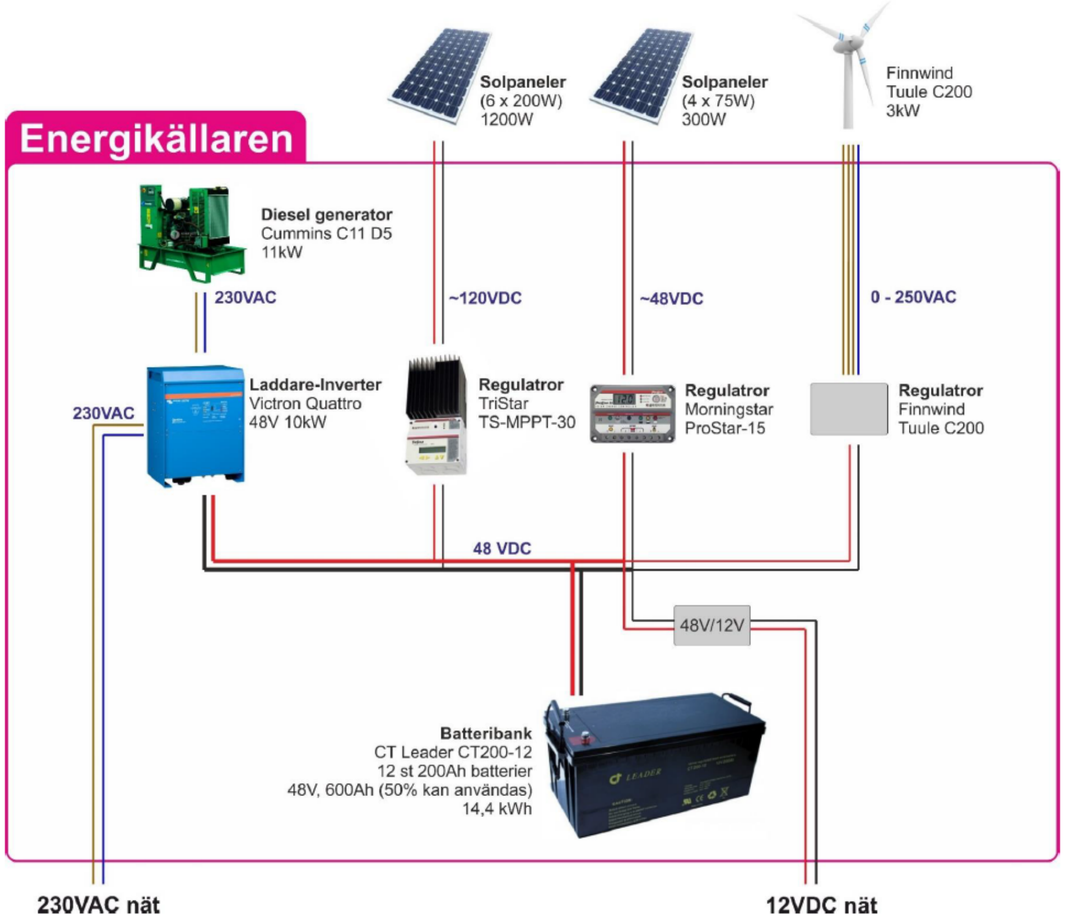


Figure 27. Meteorian energy system (Lindén, 2019)

As seen in Figure 27, Meteoria has three energy sources: a wind turbine (Finnwind Tuule C200), solar panels (solpaneler) and a backup diesel generator as well as a stack of batteries (batteribank) for energy storage. The goal of the case study is to monitor the energy generation, storage capacity and consumption. The weather conditions are also monitored. The goal is to achieve a fully autonomous energy system, where the diesel generator starts as soon as the battery capacity is too low. Furthermore, the feasibility to use the data captured from Meteoria in energy technology education is evaluated.

Table 1. Parameters in the Meteoria energy system. M are measured values, C are calculated values and R are reported values reported every 24 hours

Measurement	Type
Date	M
Hour	M
Minute	M
Wind speed avg (m/s)	M
Wind speed max (m/s)	M
Relative humidity (%)	M
Air pressure (mBar)	M
Wind direction min (deg)	M
Wind direction avg (deg)	M
Wind direction max (deg)	M
Air temperature (degC)	M
Internal temperature (degC)	M
Heating temperature (degC)	M
Rain accumulation (mm)	M
Rain duration (s)	M
Rain intensity (mm/h)	M
Rain peak intensity (mm/h)	M
Hail accumulation (hits/cm^2)	M
Hail duration (s)	M
Hail intensity (hits/cm^2*h)	M
Hail peak intensity (hits/cm^2*h)	M
sun[3013] raw data (2).Sun altitude (deg)	M
sun[3013] raw data (2).Solar radiation (W/m^2)	M
sun[3013] raw data (2).Solar radiation/sin(Sun altitude)	C
victron[3012] raw data.Battery voltage (V)	M
victron[3012] raw data.Battery current (A)	M
victron[3012] raw data.Battery capacity (%)	C
victron[3012] raw data.Inverter status	M
victron[3012] raw data.Battery indicator	M
victron[3012] raw data.Inverter current (A)	M
victron[3012] raw data.Power out, inverter (W)	C
victron[3012] raw data.Power out, external meter (W)	M
victron[3012] raw data.Power from generator to inverter (W)	M
victron[3012] raw data.Power from windmill to regulator (W)	M
victron[3012] raw data.Current from wind to batteries (A)	M
victron[3012] raw data.Power from wind regulator to battery (W)	C
victron[3012] raw data.Current from solar regulator to batteries (A)	M
victron[3012] raw data.Power from solar regulator to batteries (W)	C
victron[3012] raw data.Energy from solar to batteries (Wh)	R

data-24h[3011] raw data.Wind charge regulator to battery (Wh)	R
data-24h[3011] raw data.Solar charge regulator to battery (Wh)	R
data-24h[3011] raw data.Wind charge to regulator (Wh)	R
data-24h[3011] raw data.Genset charge to battery (Wh)	R
data-24h[3011] raw data.Inverter consumtion (Wh)	R
data-24h[3011] raw data.Inverter discharge (Ah)	R
data-24h[3011] raw data.Battery charge (%)	C
barn - cut[3017] raw data.Heat pump on/off	M
barn - cut[3017] raw data.Heat pump mode	M
barn - cut[3017] raw data.Set point (degC)	M
barn - cut[3017] raw data.Heat pump temperature (degC)	M
barn - cut[3017] raw data.Heat pump power consumtion (W)	M
barn - cut[3017] raw data.Barn temperature, new sensor (degC)	M
barn - cut[3017] raw data.Relative humidity (%)	M

In Table 1 all Meteoria energy system parameters are listed and categorized based on whether they are measured, calculated or reported every 24 hours.

4.1.1 Weather measurements

The weather station is a Vaisala WXT520. It measures wind speed (average and maximum), relative humidity, air pressure, wind direction (minimum, average and maximum), air temperature, meter internal temperature, meter heating temperature, rain accumulation, rain duration, rain intensity, rain peak intensity, hail accumulation, hail duration, hail intensity and hail peak intensity.

A pyranometer measures sun altitude, solar radiation and calculates the actual solar radiation relative to a flat surface.

4.1.2 Wind power

The wind turbine is a Finnwind Tuule C200 with a rated power of 3kW. It produces 0-250 VAC. A regulator is located between the wind turbine and the battery pack since the battery pack is operating at 48V. Parameters measured in the wind power energy system are power from wind turbine to regulator and power from regulator to batteries.

4.1.3 Solar power

There are two types of solar panels. The first type has a rated power output of 200W and produces 120VDC. There are six of these, so the nominal rated power is 1,200W. The other type is rated 75W and produces 48VDC, there are four of these, so the rated nominal power is 300W. The total rated nominal power is 1.5kW. As for the wind turbine, the solar panels also have regulators that work in the same way. They regulate the voltage to both 48V for charging the batteries and feeding to the inverter as well as 12V for smaller electrical appliances, as seen in Figure 27. The parameter measured in the solar energy system is power from solar regulator to batteries.

4.1.4 Diesel generator

The diesel generator functions as a backup energy source when neither wind nor solar energy can be produced and battery levels are running low. The diesel generator has a rated power of 11kW and produces 230VAC. Parameters being measured are power from generator to regulator and fuel tank level.

4.1.5 Batteries

The battery pack consists of 12 batteries with 200Ah each. They operate at 48V and have a total power rating of 28.8kW, but it has been determined that only half of the capacity can be used due to old age, so the rated power is 14.4kW.

4.1.6 Heat pump

The heat pump is a Mitsubishi FH35 with a rated heating power of 6.6kW and rated cooling power of 4kW. The energy consumption is measured with an external energy meter. The temperature inside the meeting room is measured with a temperature sensor which gives feedback to the heat pump and compares the ambient temperature to a desired value and makes necessary adjustments. This feedback loop is not part of the case study, but the ambient temperature and set-point temperature are monitored.

4.2 Energy consumption in transport

According to BP Energy Outlook, traffic accounts for 20% of the global energy consumption. In October 2016, the so-called Paris agreement was signed by 197 countries with the aim to limit global warming to 1.5°C above the pre-industrial level. These insights and global frameworks encourage an increased focus on energy efficiency in the transport sector. (BP, 2018) (United Nations Framework Convention on Climate Change, 2015)

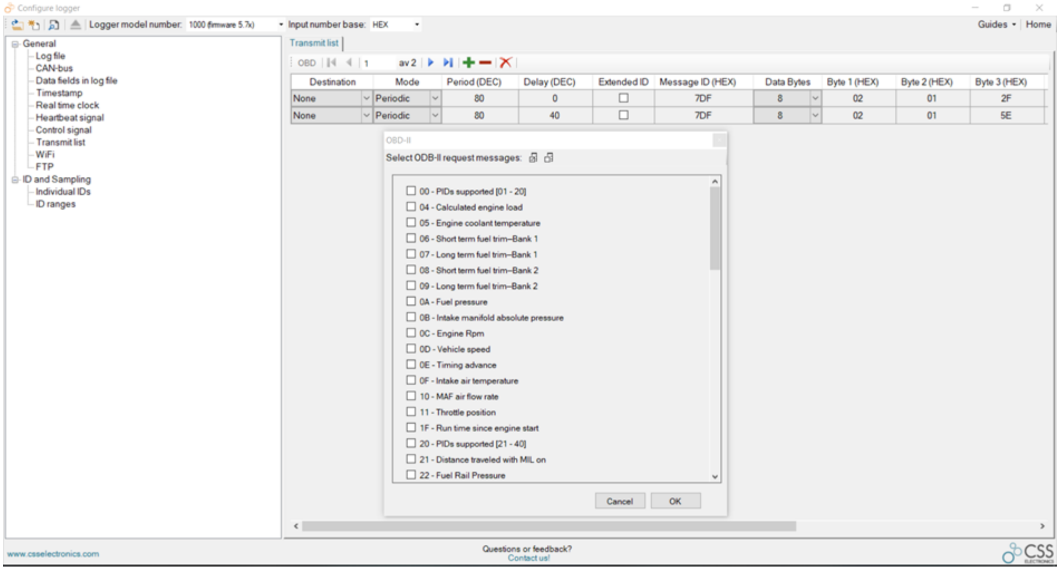
When investigating energy efficiency in, for example, a biomass production chain, the primary focus of measurements is often on the power plant itself, while fuel transport is being estimated by theoretical models such as LIPASTO by VTT. Can one be certain that these estimations are correct? In order to measure energy efficiency in transport one needs: a way to measure fuel consumption and location tracking, a way to combine these two and as knowledge about different fuels and their energy content. This technology is of interest as it can be used for large vehicle fleets as well as individual drivers to study how, for example, road conditions, driving behavior, vehicle age etc. influence the fuel consumption.

4.2.1 Fuel consumption

To measure fuel consumption, an OBD2 data logger was purchased. OBD2 is a CAN-bus protocol that is standard in every car in the EU since 2003. With the data logger connected to the vehicle, one can access various parameters, including fuel tank level (parameter ID 2F) and engine fuel rate (parameter ID 5E) (CSS Electronics, 2019). The data logger is configured using the manufacturer’s software, called Canvas.

Relating back to the IoT Reference Model described in chapter 2.5, this is layer 1. A picture of the data logger and the software is found below.

Figure 28. CL3000 OBD2 data logger (CSS Electronics, 2019)



Logger model number: 1000 (firmware 5.7x)
Input number base: HEX

Destination	Mode	Period (DEC)	Delay (DEC)	Extended ID	Message ID (HEX)	Data Bytes	Byte 1 (HEX)	Byte 2 (HEX)	Byte 3 (HEX)
None	Periodic	80	0	☐	7DF	8	02	01	2F
None	Periodic	80	40	☐	7DF	8	02	01	5E

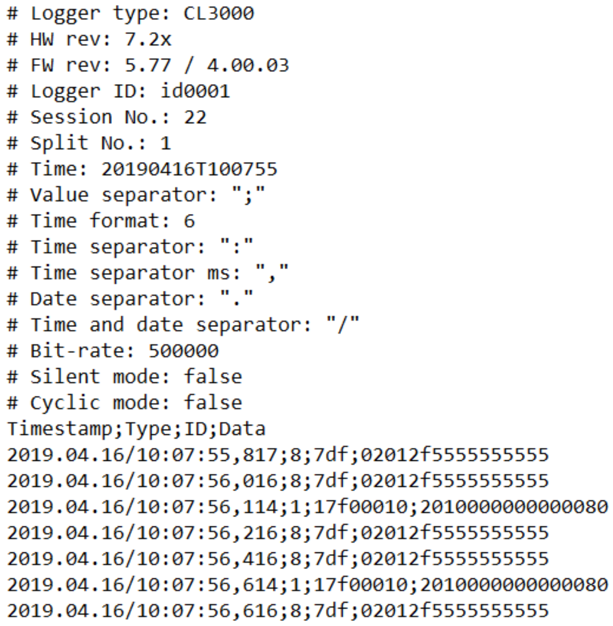
Select ODB-II request messages:

- ☐ 00 - PIDs supported [01 - 20]
- ☐ 04 - Calculated engine load
- ☐ 05 - Engine coolant temperature
- ☐ 06 - Short term fuel trim–Bank 1
- ☐ 07 - Long term fuel trim–Bank 1
- ☐ 08 - Short term fuel trim–Bank 2
- ☐ 09 - Long term fuel trim–Bank 2
- ☐ 0A - Fuel pressure
- ☐ 0B - Intake manifold absolute pressure
- ☐ 0C - Engine Rpm
- ☐ 0D - Vehicle speed
- ☐ 0E - Timing advance
- ☐ 0F - Intake air temperature
- ☐ 10 - MAF air flow rate
- ☐ 11 - Throttle position
- ☐ 1F - Run time since engine start
- ☐ 20 - PIDs supported [21 - 40]
- ☐ 21 - Distance traveled with MIL on
- ☐ 22 - Fuel Rail Pressure

Figure 29. Screenshot from configuration in Canvas

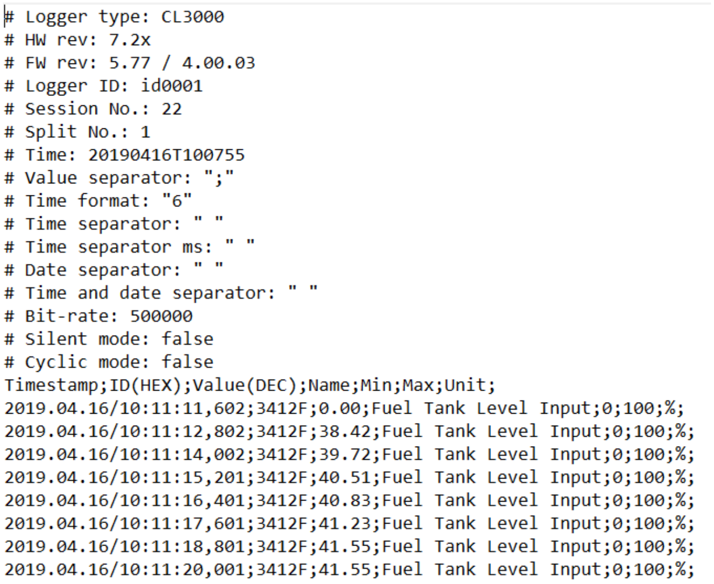
In Canvas there is also a possibility to define a WiFi-network and an FTP-server. When the vehicle is in range of the known WiFi-network, it uploads its data to the FTP-server for storage. This accounts for layers 2 and 4. Layer 3, edge computing, is not possible with this technology.

When OBD2 data is logged, the values are in hexadecimal form. In order to convert them to human-readable form, Canvas must be used. Examples are seen in the figures below.



```
# Logger type: CL3000
# HW rev: 7.2x
# FW rev: 5.77 / 4.00.03
# Logger ID: id0001
# Session No.: 22
# Split No.: 1
# Time: 20190416T100755
# Value separator: ";"
# Time format: 6
# Time separator: ":"
# Time separator ms: ","
# Date separator: "."
# Time and date separator: "/"
# Bit-rate: 500000
# Silent mode: false
# Cyclic mode: false
Timestamp;Type;ID;Data
2019.04.16/10:07:55,817;8;7df;02012f5555555555
2019.04.16/10:07:56,016;8;7df;02012f5555555555
2019.04.16/10:07:56,114;1;17f00010;2010000000000080
2019.04.16/10:07:56,216;8;7df;02012f5555555555
2019.04.16/10:07:56,416;8;7df;02012f5555555555
2019.04.16/10:07:56,614;1;17f00010;2010000000000080
2019.04.16/10:07:56,616;8;7df;02012f5555555555
```

Figure 30. OBD2 data in hexadecimal form



```
# Logger type: CL3000
# HW rev: 7.2x
# FW rev: 5.77 / 4.00.03
# Logger ID: id0001
# Session No.: 22
# Split No.: 1
# Time: 20190416T100755
# Value separator: ";"
# Time format: "6"
# Time separator: " "
# Time separator ms: " "
# Date separator: " "
# Time and date separator: " "
# Bit-rate: 500000
# Silent mode: false
# Cyclic mode: false
Timestamp;ID(HEX);Value(DEC);Name;Min;Max;Unit;
2019.04.16/10:11:11,602;3412F;0.00;Fuel Tank Level Input;0;100;%;
2019.04.16/10:11:12,802;3412F;38.42;Fuel Tank Level Input;0;100;%;
2019.04.16/10:11:14,002;3412F;39.72;Fuel Tank Level Input;0;100;%;
2019.04.16/10:11:15,201;3412F;40.51;Fuel Tank Level Input;0;100;%;
2019.04.16/10:11:16,401;3412F;40.83;Fuel Tank Level Input;0;100;%;
2019.04.16/10:11:17,601;3412F;41.23;Fuel Tank Level Input;0;100;%;
2019.04.16/10:11:18,801;3412F;41.55;Fuel Tank Level Input;0;100;%;
2019.04.16/10:11:20,001;3412F;41.55;Fuel Tank Level Input;0;100;%;
```

Figure 31. OBD2 data converted

4.2.2 Location tracking

For location tracking, a smartphone and the application Owntracks were chosen. These are layer 1. To retrieve data from the Owntracks application, an MQTT broker is needed. The MQTT protocol works by having a publisher publish messages to an MQTT broker and one or several subscribers subscribe to the messages. Owntracks publishes coordinates of the device, CloudMQTT is the message broker and a subscriber was created in Node Red, a graphical programming interface. This arrangement accounts for layer 2.

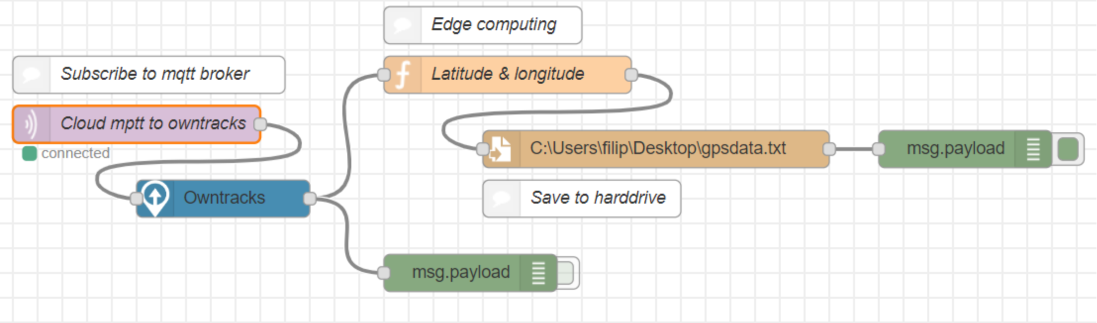


Figure 32. Layers 3 and 4 in position tracking

Layer 3, edge computing, was executed using Node Red. The Owntracks application publishes a long message with several parameters that are of no interest in this case. After edge computing, the message is reduced to the form name, year, month, day, hour, minute, second, latitude, longitude. Due to the small scale of the experiment, data storage on a laptop was chosen, which constitutes layer 4. A screenshot from Node Red is seen in Figure 32.

4.2.3 Mathematical model

Now that the technological capabilities of the hardware are known, a mathematical model can be introduced. For the fuel consumption there are two different models, since the two parameters mentioned measure different units.

Method 1 uses parameter 2F, fuel tank level input:

$$Q_{tot} = V_{tank} * (Level_{start} - Level_{end}) * E_{fuel}$$

Where:

$$Q_{tot} = The\ total\ energy\ consumtion\ (MJ)$$

$$V_{tank} = Fuel\ tank\ volume\ (l)$$

$$Level_{start} = Level\ in\ the\ tank\ at\ the\ start\ of\ the\ journey\ (\%)$$

$$Level_{end} = Level\ in\ the\ tank\ at\ the\ end\ of\ the\ journey\ (\%)$$

$$E_{fuel} = The\ energy\ content\ of\ the\ fuel\ \left(\frac{MJ}{l}\right)$$

Method 2 uses parameter 5E, engine fuel rate:

$$Q_n = \frac{q * E_{fuel}}{t}$$

$$Q_{tot} = \sum Q_n$$

Where:

$Q_n = The\ momentary\ fuel\ consumtion\ (MJ)$

$q = Flow\ of\ fuel\ \left(\frac{l}{h}\right)$

$t = Sample\ time\ (h)$

In order to calculate the distance travelled, the following equations are needed:

$$\Delta Lat = R_1 * (Lat_n - Lat_{n-1})$$

$$\Delta Lon = R_2 * (Lon_n - Lon_{n-1}), R_2 = R_1 * \cos(Lat_n)$$

$$x_n = \sqrt{(\Delta Lat^2 + \Delta Lon^2)}$$

$$x_{tot} = \sum x_n * 10^{-3}$$

Where:

$\Delta Lat = Change\ in\ latitude\ (°)$

$Lat_n = Current\ latitude\ (°)$

$Lat_{n-1} = The\ previous\ latitude\ (°)$

$R_1 = 6370000\ m, constant\ (m)$

$\Delta Lon = Change\ in\ longitude\ (°)$

$Lon_n = Current\ longitude\ (°)$

$Lon_{n-1} = Previous\ longitude\ (°)$

$x_n = The\ distance\ between\ two\ points\ (m)$

$x_{tot} = The\ total\ distance\ travelled\ (km)$

(Syrjärinne, 2016)

Furthermore, CO2 emissions can be calculated using:

$$CO_{2,e} = CO_{2,f} * Q_{tot}$$

Where:

$CO_{2,e} = CO2\ emissions\ [g]$

$CO_{2,f} = \ Fuel\ specific\ CO_2\ emission\ constant\ \left[\frac{g}{MJ}\right]$

$Q_{tot} = Total\ energy\ consumtion\ [MJ]$

The mathematical models presented were calculated with Excel, which is layer 5.

In order to have something to compare the results to, the energy consumption was estimated with VTT's LIPASTO. The test vehicle was a 2017 Volkswagen Golf and the distance travelled was measured. This gave:

$x_{tot} = 65\ km$

$$Fuel\ consumtion = \ 5{,}4\frac{l}{100\ km} * 0{,}65 * 100\ km = 3{,}51\ l$$

$$Energy\ consumtion = 1{,}7\frac{MJ}{km} * 65\ km = 110{,}5\ MJ$$

5 RESULTS

5.1 Meteoria

This case was very successful. The energy system is autonomous in the sense that the diesel generator automatically starts producing electricity if neither sun nor wind is producing electricity. The only human interaction needed is to fill the fuel tank, which users are notified about when the level is low. Every parameter in Table 1 is being measured and stored at an own server. A dashboard was made for monitoring the energy production and consumption on a 24-hour timespan and start the diesel generator manually, if needed.

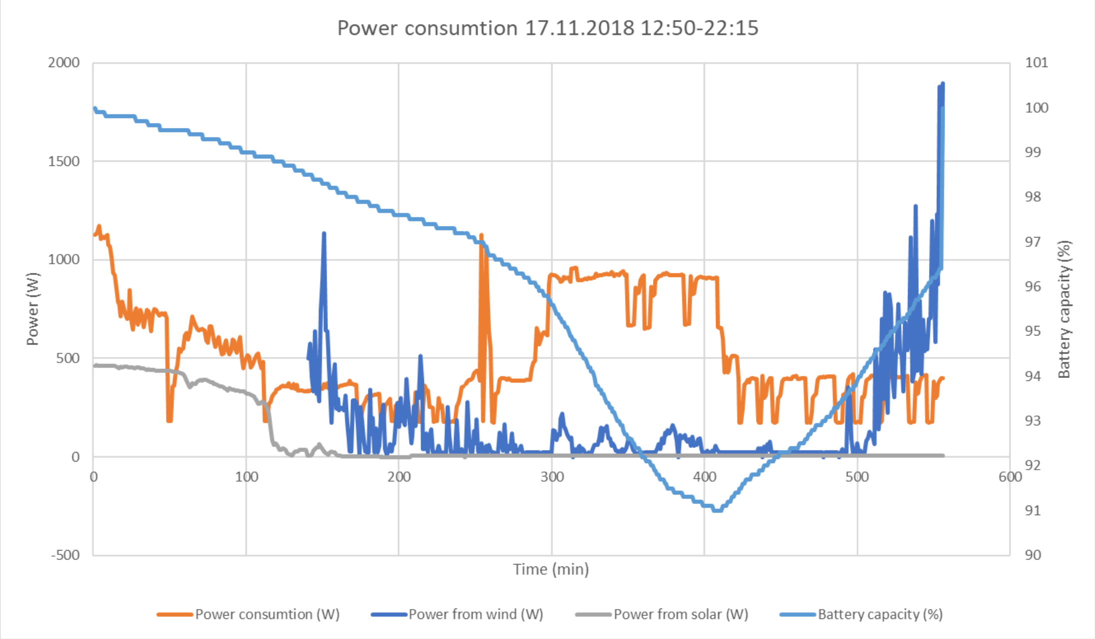


Figure 33. Example of measurements at Meteoria

Figure 33 presents an example of the dynamics of the Meteoria energy system. It can be seen, that when neither wind nor solar is producing electricity the battery capacity decreases. At around minute 400 the battery is recharged when the diesel generator is engaged. The graph for the diesel generator cannot be seen here, because the energy meter was broken. This graph still gives an idea of what conditions are required for it to start, and as mentioned the generator now starts automatically.

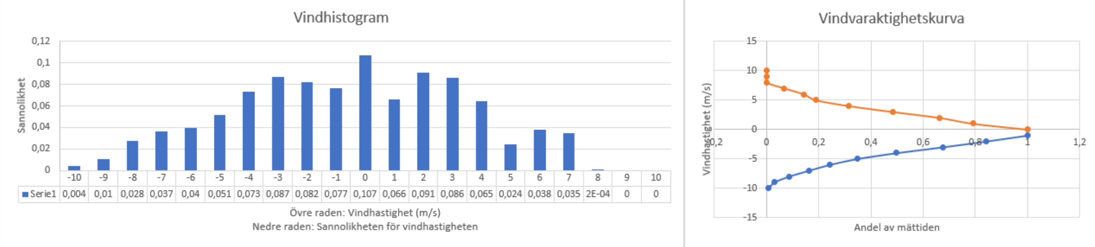


Figure 34. Wind histogram and wind duration curve made with data from Meteoria

The acquired data can result in many different applications. Figure 34 shows a wind histogram and wind duration curve based on acquired data from Meteoria. This is just one example of the various uses the Meteoria data could have in energy technology education. By measuring and logging different parameters, different aspects of the energy system can be investigated by combining data streams.

Analyzing why this case was successful, it can be concluded that the right knowledge about the technology and proper time management led to satisfying results. The right technology, in this case, means knowledge about the Modbus-protocol. Most of the power sources were equipped with Modbus-compatible meters and thus relatively easy to acquire data from.

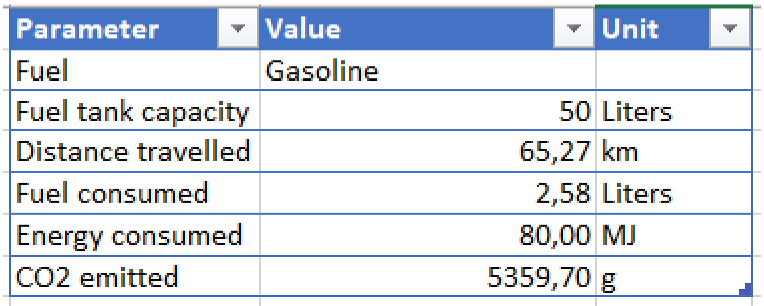
Commenting the time management aspect, it can be concluded that the hardware installations were more time-consuming than expected. This is a fact that is sometimes neglected, but in this case, the person responsible for this case had enough time to overcome this obstacle.

5.2 Energy consumption in transport

The estimated values using LIPASTO were:

$$Fuel\ consumtion = 5{,}4\frac{l}{100\ km} * 0{,}65 * 100\ km = 3{,}51\ l$$

$$Energy\ consumtion = 1{,}7\frac{MJ}{km} * 65\ km = 110{,}5\ MJ$$



Parameter	Value	Unit
Fuel	Gasoline	
Fuel tank capacity	50	Liters
Distance travelled	65,27	km
Fuel consumed	2,58	Liters
Energy consumed	80,00	MJ
CO2 emitted	5359,70	g

Figure 35. Results from measured values

As seen in Figure 35 the measured energy consumption (2,58 l and 80 MJ) differs from the assumptions. This suggests that LIPASTO over-estimates the energy consumption and does not consider economical driving behaviour. However, no such conclusions can be made from one test.

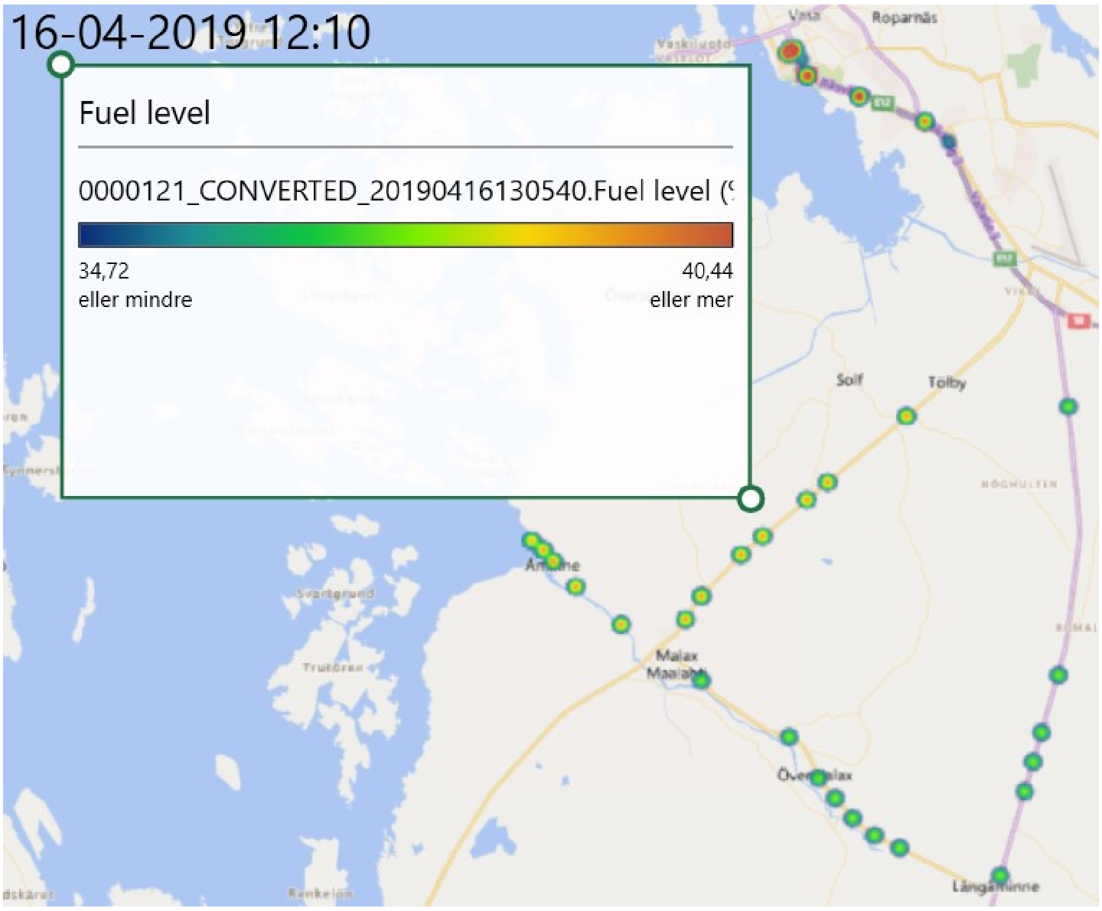


Figure 36. Route and fuel tank level visualized

Figure 36 shows the route with the fuel tank level visualized. The route starts from Vaasa city centre, goes south on the E12, turns to road 673 and then road 6792 until reaching the shore. The route back to Vaasa starts on road 6792, taking road 679 and E8 until reaching the city centre. The position of the dots on the map are generated by GPS coordinates and the colour is determined by the fuel tank level, the darker the dot the lower the fuel level. The visualization was made in Microsoft Excel.

6 EVALUATION OF RESULTS AND THE IOT ASPECT

When evaluating the results using the IoT Reference Model, it was decided to color code the progress of each layer and component. Green means that the component in that layer is tested and works automatically. Yellow means the component has not been tested, but should work automatically. Red means that it does not work automatically. The reason for choosing this scale is because IoT’s main idea is to automize manual data transmission.

6.1 Meteorian

Evaluating the progress from an IoT reference model point of view it can be said that the case was successful.

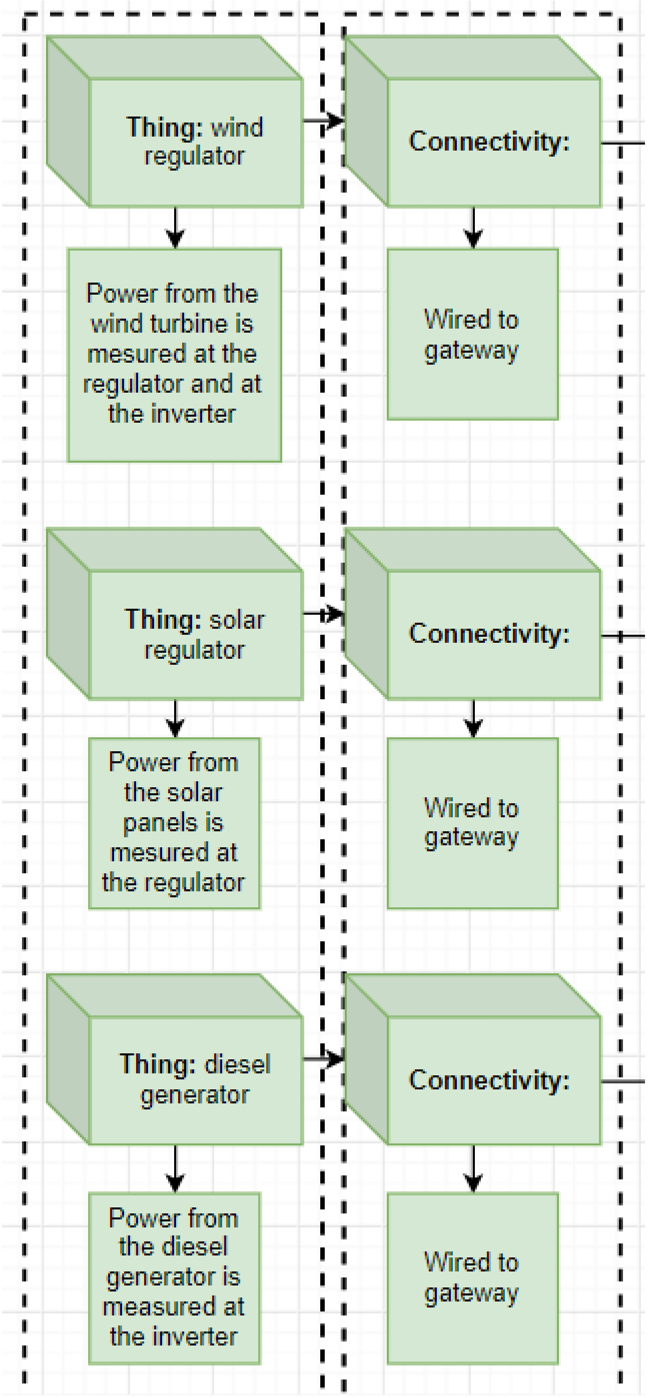


Figure 37. Meteoria layers 1 & 2, part 1

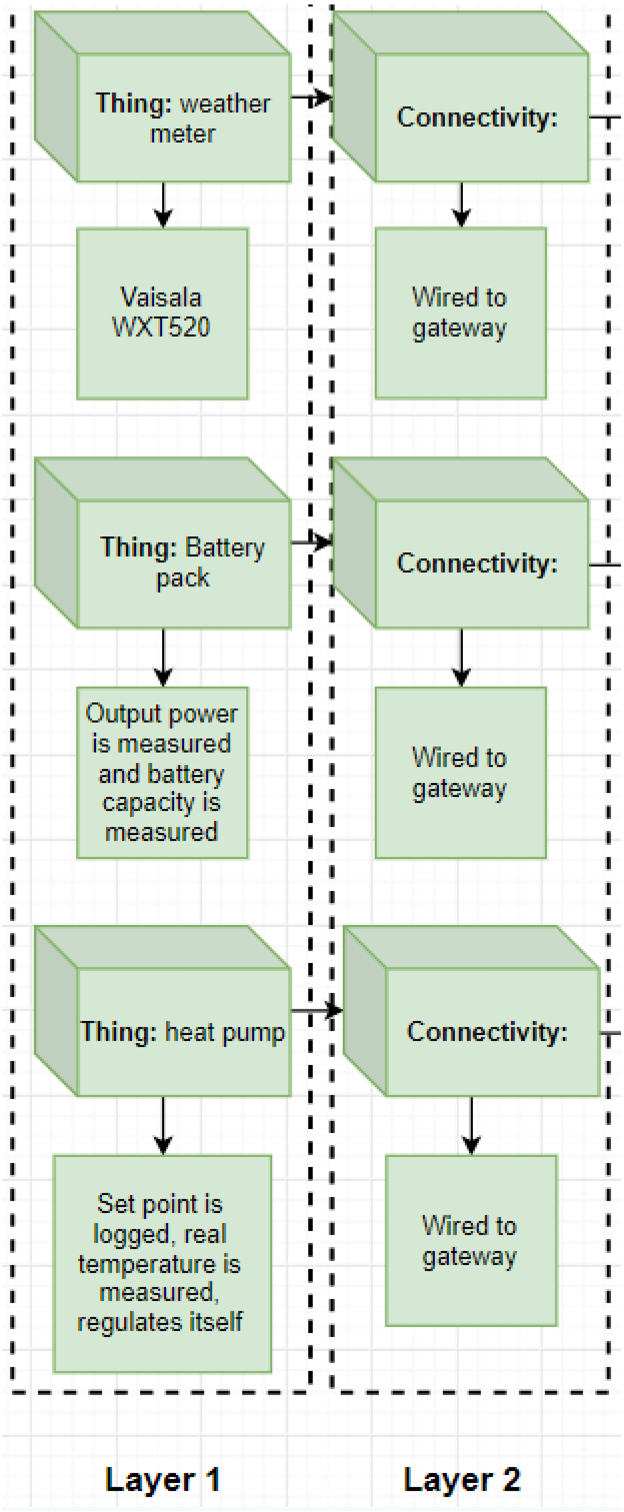


Figure 38. Meteoria layers 1 & 2, part 2

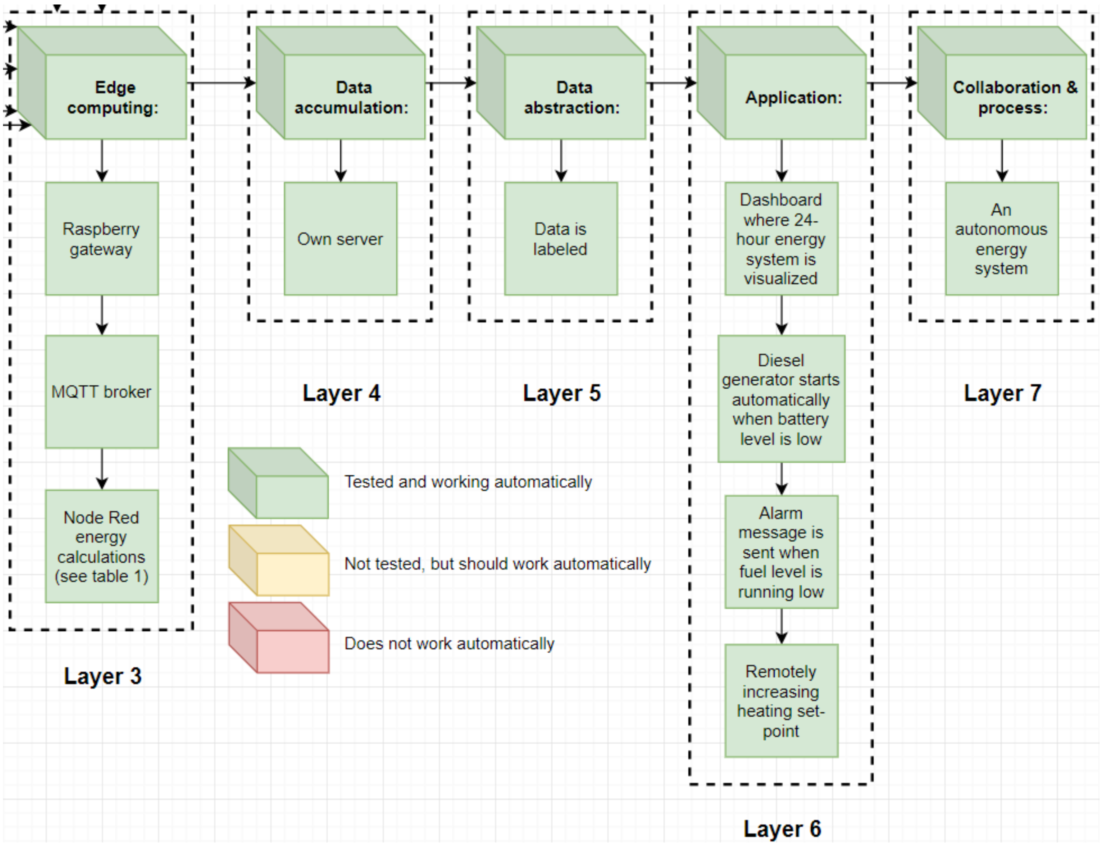


Figure 39. Meteoria layers 3–7

As seen in Figure 37, Figure 38 and Figure 39 the system meets its set targets.

Some comments about the different layers. The functions of layer 1 have been described previously in chapter 4.1. Layer 2 can be described as acquiring Modbus-data from the devices and wiring them to a Raspberry Pi.

Layer 3 uses an MQTT-broker, in this case Cloud MQTT, to transmit data to the programming environment Node Red. In Node Red, some energy calculations are made, as described in Table 1. The calculations will not be described in detail, but the basic equation is:

$$P = U * I$$

Where P is the power (W), U is the voltage (V) and I is the current (A).

The data is stored in a server owned by Novia University of Applied Sciences and is planned to be made available for educational purposes. Data is abstracted by labelling the different data streams. A dashboard with an overview of the real-time consumption as well as a 24-hour historical visualization were made. The diesel generator starts automatically when the battery capacity is low, and the systems alerts the users when the generator fuel tank level is running low. It is also possible to alter the set-point temperature for the heating remotely, which is convenient when there is an exhibition coming up at the premises. As concluded in layer 7, this is as close to an autonomous energy system one can get without constructing fuel pipelines to the diesel generator fuel tank.

6.2 Detached house

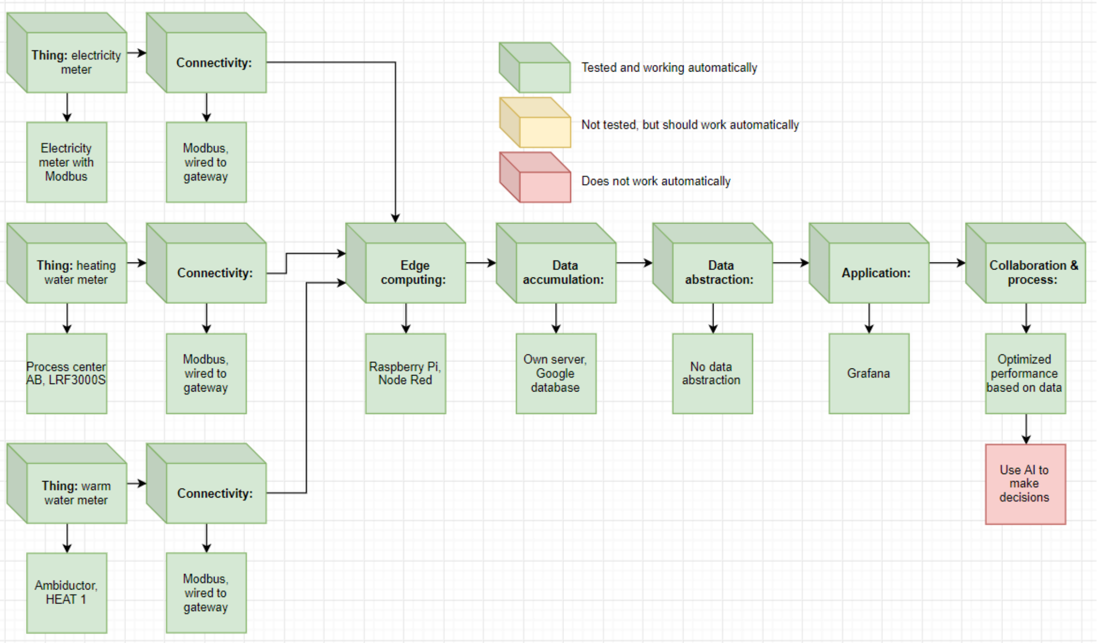


Figure 40. Detached house according to the IoT reference model

As seen in Figure 40, the detached house case study was successful. Layer 1 was described in chapter 3.1. Connectivity in layer 2 is enabled with wiring the meters to a Raspberry Pi gateway. Layer 3 does some minor edge computing in Node Red. Data is being stored both at a university-owned server and a Google cloud service. No data abstraction is conducted, other than labelling. The data is visualized in Grafana, an open source software for time series analytics. This led to optimization of the bore hole heat exchanger. In the future, AI could be used to make heating decisions using historical data, which is being stored for future training the AI.

6.3 Housing

Evaluating the progress of the housing case study with the IoT reference model concludes that some sensors are not functioning and development needs are found in layers 6 and 7.

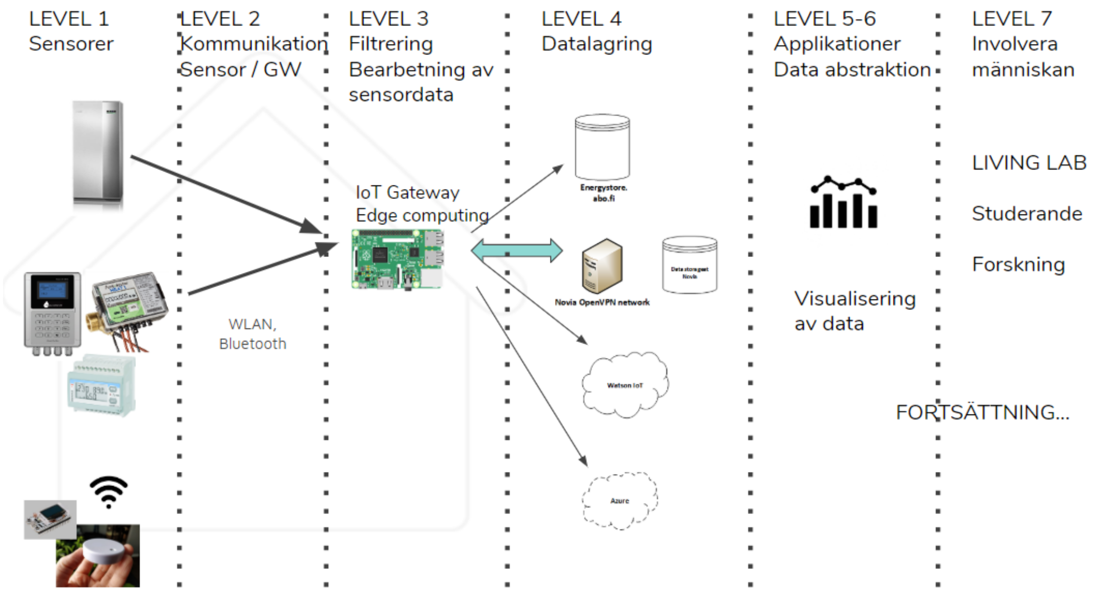


Figure 41. Case housing visualized

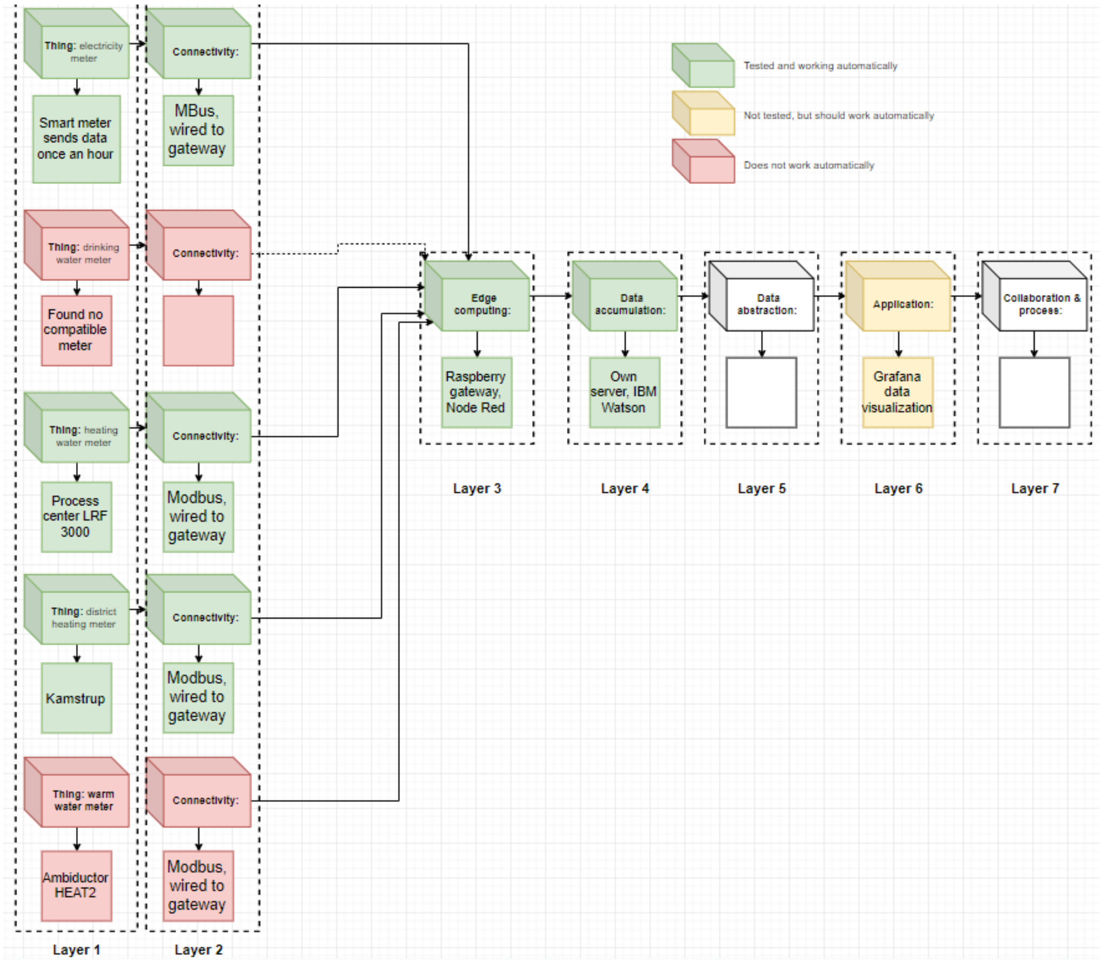
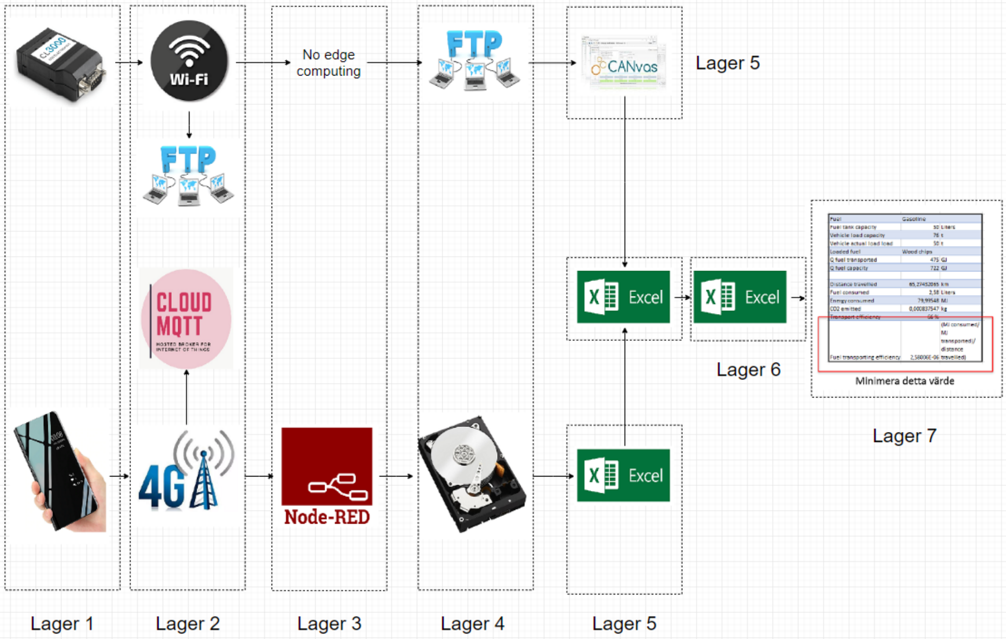


Figure 42. Case housing according to the IoT reference model

As Figure 42 suggests, most of the sensors work and data is being stored. As mentioned earlier, no suitable water meter was available, and the warm water meter gives inconsistent data due to poor installation.

6.4 Energy consumption in transport

Evaluating the technological choices using the IoT reference model, it can be said that the solution is halfway finished.



Fuel	Gasoline	
Fuel tank capacity	50	Liters
Vehicle load capacity	76	t
Vehicle actual load load	50	t
Loaded fuel	Wood chips	
Q fuel transported	475	GJ
Q fuel capacity	722	GJ
Distance travelled	65,27432065	km
Fuel consumed	2,58	Liters
Energy consumed	79,99548	MJ
CO2 emitted	0,000837547	kg
Transport efficiency	66 %	
Fuel transporting efficiency	2,58000E-06	(MJ consumed/ MJ transported)/ distance travelled)

Figure 43. Case energy consumption in transport visualized

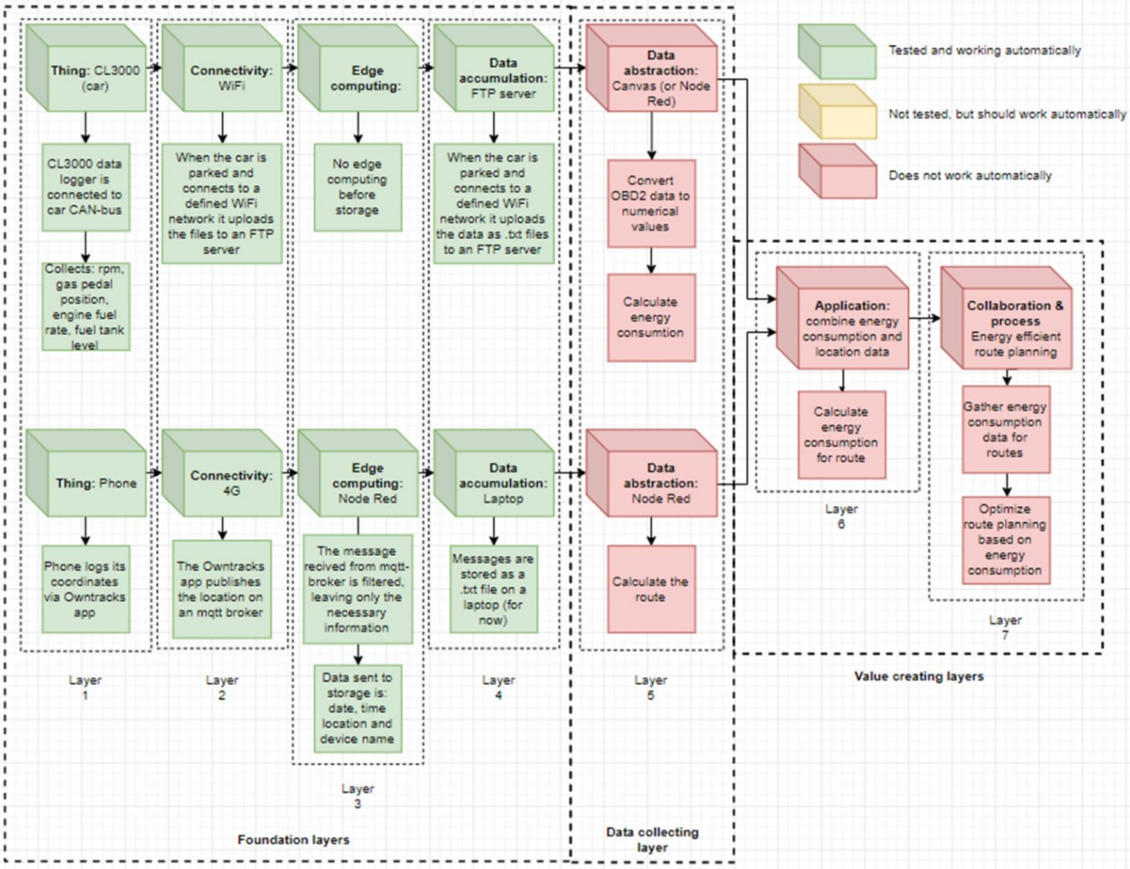


Figure 44. Case energy consumption in transport according to the IoT reference model

Figure 43 shows a visualization of the technology used. Figure 44 shows how well each layer is fulfilled, with green boxes being fully automated and red boxes being not working automatically. Challenges arise in layer 5, where the OBD2 data must be manually converted using the data logger's software called Canvas. The route calculation could be automated, but the problem is to index the incoming values in order to calculate the change between points and the total distance travelled. Due to time constraints, Microsoft Excel was chosen as a tool for presenting the results. As shown in chapter 5.2, results can be presented, but require manual work in Microsoft Excel.

A few reflections on the technology that was used. The CL3000 OBD2 data logger was easy to use. The Canvas software was intuitive once familiarizing oneself with the different parameters to measure. The downside was the need for manual conversion of the measured values. The file transfer to the FTP server was slow. It took several hours to transfer data. Whether it was due to slow WiFi or bad coverage is left unknown. One model for measuring fuel consumption, the one using engine fuel rate, did not work and therefore was not used. While inspecting the raw data from the measurements, it was noted that the fuel tank level is measured four times a second. This is unnecessary, since the points of interest are at the beginning and the end of the journey.

The position tracking worked fairly well, considering it was a free mobile application. However, at the beginning of the journey coordinates were updated roughly every 30 seconds, but soon the interval increased to several minutes. This causes trouble when trying to pair coordinates with fuel tank level. A consistent timing would have made it easier to pair values. Microsoft Excel has tools for issues like this and in the end, it was not difficult since the data were well structured. In this case, well-structured data meant having year, month, day, hour, minute and second in separate columns and using queries to join the measurements together. The timestamps that did not have a corresponding value were neglected. After some correspondence with the OBD2 data logger manufacturer, I was told they are soon launching a logger with built-in GPS, which could solve the problem with data inconsistence.

7 FURTHER DEVELOPMENT AND CONCLUSIONS

7.1 Meteoria

As mentioned before, Meteoria was a highly successful case study. Its goal was to be an autonomous energy system with remote accessibility, and the goal was reached. A part of the project was to introduce ways to implement the Meteoria data in energy technology education as a living laboratory where different aspects of the energy system are explored. One idea for further development would be to estimate the renewable power production based on weather forecasts and comparing that to historical data. Historical weather data could be used to determine the potential for solar and wind power, battery storage dynamics could be explained with a functioning example, new hardware investments could be modeled and examined beforehand, new hardware investments could be attributed with a cost parameter as described in chapter 2.2, to determine when the investments have paid themselves back and so on. Only the imagination sets boundaries for implementing data from the case study into energy technology education.

7.2 Detached house

The detached house case study was very successful both in terms of a well-executed installation and implementing IoT to create value for the stakeholder, in this case the house owner. As mentioned before, the house owner was able to optimize the heat exchanger, which he did in close co-operation with the manufacturer. A funny side note is that the heat exchanger manufacturer was not able to explain why the slower, original controlling algorithm was chosen, and were impressed with the adjustments. Perhaps the manufacturer could benefit from IoT as well?

The future for this case study will involve measuring the energy content in the closed loop circuit as well as proposing an algorithm that could control the system more efficiently. In my opinion, this is also an ideal case to implement in energy technology education as a part of the living laboratory concept. Opposed to the housing case study, there is only one resident, which makes privacy issues easier to agree upon, since the house owner is very fond of education and innovation.

7.3 Housing

The housing case study was very challenging from various points of view. The most challenging technological obstacle were the ultrasonic measuring devices that had to be retrofitted onto an existing heat system. For the devices to work properly, they need a certain amount of linear piping before and after the device, something that was unknown before the meters were purchased. Therefore, some measurements were obsolete.

Retrofitting onto an existing system caused its own problems. Another layer of difficulty was the fact that there were residents present at all times and businesses operating in the house, making the retrofitting inconvenient. No one wants to have their water supply cut off. With proper planning and an open dialog with all parties involved, inconveniences were minimized.

When working with external partners, one should prepare for surprises. One might think that the own project is priority number one, but an external partner might have other priorities. Good communication skills and proper project planning is crucial when working with external partners.

With the technology in place, creating value for the housing company will be developed further. Automatically generated consumption reports and abnormal consumption detection have been discussed so far.

7.4 Energy consumption in transport

The results suggest that estimations may not project the reality when it comes to energy consumption in traffic. However, this is one measurement and it is too early to draw any conclusions. The case study offers a technology that is easy to use for further investigation. One could also expand the case study to measure actual fuel transports in order to gather data about fuel efficiency in real-life situations. As the technology is easy to use and already available at Åbo Akademi University, it could be implemented in some courses regarding energy systems.

Regarding IoT development, a good starting point is layer 5, as Figure 44 suggests. The OBD2 data should be converted automatically, possibly using Node Red. The GPS data needs a solution for indexing messages before using the calculations based on the mathematical model presented in chapter 4.2. Furthermore, options for visualization could be explored.

If the efficiency of the transportation is to be determined, different factors must be determined. For example, in the case where a truck is transporting fuel, the desired outcome is to transport as much fuel using the least amount of energy. For transporting other goods other factors may be of interest, such as CO_2-emissions, delivery time or value of goods.

7.5 The IoT Project Design Reference Model

The IoT reference model proved to be useful for describing IoT systems. It can divide large and complex systems to manageable pieces and the color coding can be used for an overview of the project. However, this model was applied when the case studies were already finished or well progressed. The next evaluation would be to plan a project from the beginning using the reference model. Only then can one see how well the model handles unpredicted events and insights. My estimate is, that layering each part of the IoT system will predict the project better, since better hardware purchases, for example, can be made.

Another aspect could be to combine the IoT reference model with traditional project management tools like time management, change management and cost management. It could help finishing projects faster while controlling risks better.

7.6 Final statements

In this thesis I have tried to enlighten just how wide the potential of IoT is in energy and traffic. I have given recommendations for each of the case studies, where some are already useful for the stakeholders, some can be used in energy technology education and some need further improvements. I have also introduced a method to use when planning IoT projects, but it needs further testing to prove its usefulness.

It is estimated that there will be 3.5 billion cellular IoT devices in 2023 (Ericsson, 2018). Whether that number turns out to be true or not I believe IoT will be an increasing part of our daily lives. I base my prediction on the fact that IoT devices are convenient and people tend to like convenient things. But as Chaudhuri in cited in chapter 2.8, the success or failure of any IoT device does not only depend on the product itself, it depends on how people perceive it and interact with it. With news about hacker attacks and data leaks, people may develop an increasing concern about their privacy and thus be reluctant to more devices gathering data. As Chaudhuri points out, ethical guidelines are needed, since the upsides of IoT devices and AI are increased productivity and better resource planning, which are welcome assets in our battle against global warming and an increasing population.

SVENSK SAMMANFATTNING

SAKERNAS INTERNET I ENERGI OCH TRANSPORT

De senaste åren har sakernas internet (Internet of Things, förkortat IoT) figurerat i teknologinyheter och ses som en av de betydande teknologitrenderna. Med IoT avses fysiska objekt som länkas samman i ett digitalt nätverk för att samla data om omvärlden. Dessa data analyseras sedan och på basis av det kan en människa eller algoritm fatta bättre informationsbaserade beslut. I denna avhandling ges med hjälp av litteraturstudier och fyra fallstudier svar på tre frågor: hur kan IoT vara till nytta när energi- och transportsektorn strävar efter hållbarhet? Finns det en projektledningsmodell för planering av IoT-tillämpningar som tar i beaktande olika teknologier? Hur kan IoT införas i undervisningen?

Forskningresultat om IoT i energisektorn förutspår att framtidens energimarknad kommer att vara allt mer decentraliserad eftersom konsumenten i framtidens energimarknad kan vara både konsument och producent. På grund av bl.a. solpaneler och energilagringslösningar måste en faktor som tidigare inte fanns i energisystemet introduceras: kommunikation. När energiproducenterna blir allt mer decentraliserade är det svårt för ett enskilt kraftverks styrsystem att veta hur mycket el och värme det ska producera utan att veta ifall mindre producenter också producerar eller har lager med energi som de använder. IoT kunde vara till hjälp genom att bygga upp ett nätverk där alla parter kommunicerar med varandra för att balansera utbud med efterfrågan. Exempel på lyckade IoT-tillämpningar i energisektorn är förutseende underhåll av ångturbiner, smarta värmepumpar och vattenvärmare samt självreglerande gatubelysning.

Den främsta tillämpningen av IoT i trafik är självkörande bilar. I de självkörande fordonens nätverk är varje enskilt fordon utrustat med sensorer och nätverksanslutning som ständigt sänder och tar emot data från andra fordon för att få information om vilka rutter de andra ämnar köra, eventuella trafikstockningar osv. Till de potentiella fördelarna hör ökad trafiksäkerhet, ökad mobilitet, ökad bränsleeffektivitet, smidigare trafikflöde samt mindre efterfrågan på parkeringsplatser i tätorter. Med hjälp av IoT har Tammerfors stad kunnat kartlägga flaskhalsar i trafiken genom att placera sensorer i alla sina bussar som rapporterar deras hastighet och position. Till nackdelarna hör ekonomiska risker då vissa företagsmodeller blir föråldrade, risk för ökade trafikmängder ifall efterfrågan på kollektivtrafik minskar samt ökade kostnader för den enskilda bilisten då bilarna ökar i pris.

Vid planeringen av nya IoT-tillämpningar har ingen vedertagen metodik fått gehör inom branschen. En klar metodik för planeringen skulle ge en överblick över den teknologiska komplexitet som IoT-tillämpningar ofta utgör. Företaget Ciscos referensmodell för IoT kan användas för att planera IoT-tillämpningar och har evaluerats i denna avhandling med hjälp av fallstudierna. Modellen består av sju lager:

Lager 1 är fysiska enheter eller datakällor. Det innefattar allt som producerar data eller styrs av data. Producenter av data innefattar oftast sensorer av olika slag. Saker som styrs av data är i industriella sammanhang t.ex. pumpar och ventiler.

Lager 2 är kommunikation. De samlade data måste transporteras vidare till förvaring och då ska lämplig kommunikation väljas. Faktorer som påverkar val av kommunikation är t.ex. räckvidd, hastighet, pris och tillgänglig teknologi. Exempel på vanlig kommunikation som används inom IoT är Bluetooth, ZigBee och WiFi.

Lager 3 är gränsfiltrering av data. Ibland kan det vara nödvändigt att på förhand minska mängden överförda data. Detta kan man göra genom att t.ex. omvandla enheter eller räkna medelvärden för en tidsperiod. Fördelen är att överföringshastigheten blir snabbare och lagringskapaciteten kan minskas.

Lager 4 är datalagring. Vid val av datalagring bör man avväga vilken kapacitet man behöver. Man måste beakta hur snabbt datamängden växer, hur stora datapaket man tar emot samt om man ska lagra på egen server eller använda någon molntjänst.

Lager 5 är abstraktion av data. När man hanterar stora dataflöden är det i planeringsskedet nödvändigt att namnge dataflödena i processen och inte endast se på vilket numeriskt värde de har. Abstraktion av data handlar också om att sammanlänka data från olika källor och tidpunkter, indexering och normalisering.

Lager 6 är tillämpning. Det är vanligt att man vill visualisera data på något vis. Det kan handla om automatisk rapportering, grafer över mätvärden eller en digital kontrollpanel.

Lager 7 är samverkan. Den mest fundamentala aspekten av IoT är vad all insamlade data ska leda till för förändring. Att samla data och generera automatiska rapporter är enkelt. Det är viktigare att veta vad den rapporten ska användas till.

IoT har kritiserats främst för brister i personlig integritet vad gäller privatpersoners data. Vidare kan oskyddade IoT-apparater leda till att hackare enkelt kan använda apparaterna i en överbelastningsattack.

För att undersöka vilken nytta IoT kunde göra inom energi och transport gjordes fyra fallstudier inom ramen för ett forskningsprojekt i samarbete mellan Åbo Akademi och Yrkeshögskolan Novia. De fyra fallstudierna heter Meteoria, Egnahemshus, Bostadshus med lägenheter och Energiförbrukning i transportsträckor. Jag har arbetat i projektet som forskningsassistent och haft ansvar för fallstudien Energiförbrukning i transportsträckor.

Meteoria är beläget vid Söderfjärden 13 km utanför Vasa centrum mitt i en av Europas största meteoritkratrar. Där finns en utställningshall som berättar om kratern, ett mötesrum samt ett observatorium för astronomer. På grund av dess svårtillgängliga läge har föreningen som driver Meteoria beslutat att inte ansluta sig till elnätet, utan producera all el själv med hjälp av solpaneler, vindkraft och en dieselgenerator samt lagra energi i batterier. Syftet med studien var att använda IoT för att kunna övervaka och kontrollera energisystemet vid Meteoria och att göra systemet autonomt, dvs med så litet behov av mänsklig interaktion som möjligt.

Vid Meteoria finns tre energikällor och energilagring. Energin går åt till en luftvärmepump, elektriska värmeelement, belysning och annan kringutrustning. Det finns även en väderstation som mäter väderförhållanden. Vind- och solkraft har var sin regulator som omvandlar inkommande spänningar till 48 VDC. Spänningen styrs till en inverter som antingen laddar batterierna eller omvandlar spänningen till användbar 230 VAC. Från invertern går strömmen till luftvärmepumpen och annan kringutrustning. Totalt mäts och loggas 53 parametrar såsom inkommande energi, batterikapacitet, energiförbrukning för luftvärmepump och väderförhållanden.

Resultatet från fallstudien Meteoria var mycket tillfredställande. Meteorias energisystem är så autonomt som det kan bli. En nivåmätare installerades i dieselgeneratorns bränsletank och den skickar ett meddelande till inblandade parter när bränslenivån är låg. Vidare gjordes en kontrollpanel där en dygnsrapport över energisystemet visas. Via kontrollpanelen kan man bl.a. starta generatorn manuellt och ställa in vilken temperatur man vill ha i mötesrummet. Luftvärmepumpens interna reglersystem sköter resten.

Betraktar man Meteorias energisystem med hjälp av referensmodellen för IoT kan man konstatera att även denna aspekt lyckades bra. Lager 1 beskrevs ovan. Lager 2 sköts uteslutande av att diverse mätare är kopplade till en Raspberry Pi gateway. Gatewayn skickar samtliga data till en MQTT broker och vidare till gränsfiltrering i Node Red där vissa beräkningar och förenklingar utförs. Data lagras på en egen server och i lager 5 görs data abstrakt genom att namnge de olika dataflödena. I lager 6 sammanställs data i en digital kontrollpanel med tidigare nämnda egenskaper och lager 7 resulterar i ett (så gott som) autonomt energisystem.

Mitt förslag till fortsatt forskning i denna fallstudie är att utnyttja data från Meteoria i undervisningen för att t.ex. studera potential för vind- och solkraft regionalt samt studera batteriernas roll i ett decentraliserat energisystem. Den stora tillgången till data gör att antalet möjliga fallstudier är stort.

Fallstudien Egnahemshus ägde rum i en nedlagd byskola som omvandlats till ett hem för en familj med tre personer. När huset renoverades byttes den gamla oljepannan ut mot bergvärme. Husägaren var intresserad av att kunna följa med energi- och elförbrukningen, vilket gjorde att en elmätare, energimätare för bergsvärmepumpen, ultraljudsmätare för uppvärmningsvattnet och bruksvattnet installerades. Via en Modbusanslutning till bergvärmepumpen kunde även pumpens inre parametrar loggas. Målet med fallstudien var att övervaka el- och energiförbrukningen samt att beräkna COP- och SPF-värde.

De uppsatta målen för egnahemshuset uppnåddes. En visualiseringspanel gjordes i Grafana där man kunde välja vilka av de loggade parametrarna man är intresserad av och en dygnsrapport över dem visas. Husägaren kunde med hjälp av pumpens interna parametrar optimera systemet för att ytterligare spara energi, vilket skulle kräva mera forskning. Värmepumpens funktion kunde vara intressant att implementera i utbildningen för olika konsekvensanalyser.

Ur ett IoT-perspektiv var fallstudien också lyckad. Mätarna i lager 1 är kopplade till en Raspberry Pi gateway (lager 2) som skickar data vidare för gränsfiltrering i Node Red (lager 3). Data lagras på egen server och Googles molntjänst (lager 4). Ingen abstraktion av data görs (lager 5). Data presenteras i Grafana (lager 6) och allt detta har gjort det möjligt att optimera bergvärmepumpen (lager7). Husägaren är i framtiden intresserad av att styra energisystemet med artificiell intelligens för att få ett ännu mer optimerat system.

Fallstudien Bostadshus med lägenheter utfördes i ett hus med åtta lägenheter och två företagsutrymmen med en total boyta på ca 500 m^2. Bostadsbolaget var intresserade av att följa konsumtionen av el, fjärrvärme, vatten för uppvärmning samt dricksvatten mera detaljerat än de årliga rapporterna som används nu. En digital el- och fjärrvärmemätare lånades från det lokala elbolaget och ultraljudsmätare med temperatursensorer köptes för att mäta energiinnehållet i det varma vattnet. Någon lämplig dricksvattenmätare hittades inte.

Resultatet blev att konsumtionen av el, fjärrvärme och ingående vatten för uppvärmning kan mätas och loggas. Snabba försök med visualisering av data i Grafana testades. Returvattnet från uppvärmningen kunde inte mätas eftersom mätaren hade installerats felaktigt och gav därför inga mätvärden. Projektgruppen lärde sig därför en hel del om ultraljudsmätning som den inte visste förut. Det bör även poängteras att en del överraskningar uppkom i och med att mätarna skulle installeras på ett existerande värmesystem, där det inte fanns det utrymme som mätarna krävde och mätarna hade en del tekniska fel. Det stora antalet involverade samarbetspartner gjorde också att vår tidtabell fick revideras några gånger.

Ur ett IoT perspektiv är fallstudien halvfärdig. De mätare som är rätt installerade fungerar bra. De är kopplade till en Raspberry Pi gateway (lager 2) som skickar data vidare för gränsfiltrering i Node Red (lager 3). Data lagras på en egen server och i IBM Watsons molntjänst (lager 4). Ingen abstraktion av data görs (lager 5) och endast snabba tester med visualiseringsprogrammet Grafana gjordes (lager 6).

Mitt förslag till fortsatt forskning i fallstudien Bostadshus är att automatiskt göra rapporter för husets konsumtion av vatten och energi samt att undersöka möjliga modeller för att upptäcka avvikande konsumtionsmönster.

Det fanns ett behov för fallstudien Energiförbrukning i transportsträckor eftersom då man undersöker ett energisystem för ett kraftverk mäter man oftast bränslekonsumtionen i själva kraftverket, medan bränsletransporternas energikonsumtion beräknas teoretiskt, t.ex. med VTT:s LIPASTO. Fallstudien undersöker vilken teknologi som kunde användas för att få mer tillförlitliga värden än de teoretiska beräkningarna.

För att mäta bränslekonsumtionen för ett fordon på en viss rutt måste man mäta själva bränslekonsumtionen via fordonets dator och veta vilka koordinater fordonet rört sig på. Bränslekonsumtionen mäts via fordonets inbyggda dator med hjälp av en OBD2-logger. OBD2-protokollet har ett antal olika standardiserade parametrar som kan mätas, i detta fall valdes parameter 2F (nivå i bränsletanken) och parameter 5E (bränsleflödet). GPS-koordinaterna mäts genom en mobilapplikation kallad Owntracks. Owntracks publicerar data till en MQTT broker där data kan vidarebefordras för ytterligare databehandling. Genom en matematisk modell för den momentana bränslekonsumtionen och sträckan mellan två koordinater kan den totala bränslekonsumtionen för hela sträckan beräknas. Som referens beräknades med hjälp av LIPASTO hur mycket testfordonet teoretiskt sett förbrukar på en 65 km sträcka.

Fallstudien visade att det finns belägg för att värden beräknade med LIPASTO kanske inte stämmer. Då LIPASTO uppskattade förbrukningen till 3,51 liter och 110,5 MJ var den uppmätta förbrukningen 2,58 liter och 80 MJ. Man ska dock inte dra slutsatser av ett enda test. Sträckan och bränsleförbrukningen visualiserades i Excel 3D Maps. Det visade sig att det går att mäta bränsleförbrukning hos ett fordon på en sträcka. Baserat på de utförda mätningarna är det troligt att de teoretiska beräkningarna inte stämmer, men det behövs flera tester för att verifiera detta.

Den använda tekniken utgjorde vissa problem. Det visade sig att parameter 5E (bränsleflöde) inte fungerade på testfordonet, så testet kördes med parameter 2F (bränslenivå i tanken). OBD2-loggern mäter nivån i bränsletanken fyra gånger i sekunden, vilket är onödigt då det skulle räcka med nivån i början och i slutet. GPS-applikationen gav nog ut koordinater, men den gjorde det med ojämna intervall. Vissa gånger var intervallet 30 sekunder, ibland flera minuter.

Ur ett IoT perspektiv fungerar lagren 1 till 4 som de ska. Problem uppstår i lager 5 där data ska konverteras till användbar form. OBD2-loggern ger mätvärden i hexadecimal form och dessa måste via ett dataprogram omvandlas till decimalform. GPS-koordinaterna var svåra att indexera. Detta behövs för att kunna räkna skillnaden mellan två koordinater och således den erlagda sträckan. Löser man dessa problem kunde man undvika manuell databehandling.

Mitt förslag till fortsatt forskning i fallstudie Energiförbrukning i transportsträckor är att undersöka om det finns ett sätt att bestämma ett fordons verkningsgrad på en given rutt. Med en verkningsgrad kunde man uppmuntra förare att använda den rutt som förbrukar minst bränsle.

Vad beträffar referensmodellen för IoT kan man utifrån fallstudierna dra slutsatsen att den är nyttig då man vill ha en helhetsbild över systemet. Det bör dock påpekas att referensmodellen upptäcktes när fallstudierna redan var långt gångna vilket betyder att alla fallstudier har granskats med modellen i efterhand. Det kan antas att den, kombinerat med traditionella projektledningsverktyg, kunde ge mervärde när nya IoT-tillämpningar utvecklas. Genom att använda modellen kan man undvika att inte samla data bara för samlandets skull, utan man har en klar vision över vad datainsamlingen ska resultera i och hur den är tänkt att äga rum så man kan planera den på förhand. Referensmodellen kunde studeras ytterligare med en ny fallstudie där man använder referensmodellen redan i början av planeringen.

REFERENCES

Ambiductor AB. (2019, May 23). *Qalcosonic E2*. Retrieved from https://www.ambiductor.se/produkter/energimatare/kompakta-energimatare/qalcosonic-e2#support

BP. (2018). *BP Statistical Review of World Energy.* BP. Retrieved from https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf

Chaudhuri, A. (2018). *Internet of Things, for Things, and by Things* (1:st ed.). Boca Raton: CRC Press.

CIO Story. (2019, May 10). *Enterprise IoT: Top-down > Bottom-up*. Retrieved from CIO Story: https://ciostory.com/cxo-perspective/enterprise-iot-top-down-bottom-up/

Cisco. (2013). *Building the Internet of Things*. Retrieved from https://www.cisco.com/c/dam/global/en_ph/assets/ciscoconnect/pdf/bigdata/jim_green_cisco_connect.pdf

CSS Electronics. (2019, August 21). Canvas (software).

CSS Electronics. (2019, August 20). *CL3000 CAN BUS logger*. Retrieved from https://www.csselectronics.com/screen/product/can-bus-logger-canlogger3000/language/en

electronicshub.org. (2017, November 8). *Different types of sensors*. Retrieved from electronicshub.org: https://www.electronicshub.org/different-types-sensors/

Ericsson. (2018). *Ericsson Mobility Report.* Ericsson. Retrieved from https://www.ericsson.com/assets/local/mobility-report/documents/2018/ericsson-mobility-report-june-2018.pdf

Fortum. (2019a, May 16). *Energiasuranta Ympäristöraportti*. Retrieved from https://energianseuranta.fortum.fi/raportti

Fortum. (2019b, May 16). *Fortum Fiksu Energiaseuranta*. Retrieved from https://www.fortum.fi/kotiasiakkaille/fiksu-koti/energianseuranta

Fruhlinger, J. (2018, March 9). The Mirai botnet explained: How teen scammers and CCTV cameras almost brought down the internet. Retrieved from https://www.csoonline.com/article/3258748/the-mirai-botnet-explained-how-teen-scammers-and-cctv-cameras-almost-brought-down-the-internet.html

Gerla, M., Lee, E.-K., Pau, G., & Lee, U. (2014). *Internet of vehicles: From intelligent grid to autonomous cars and vehicular clouds.* IEEE. Retrieved from https://ieeexplore.ieee.org/document/6803166

Groscurth, H.-M., Bruckner, T., & Kümmel, R. (1995). Modeling of energy-services supply systems. *Energy : the international journal, 20*(9), 941-958. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/036054429500067Q

GSMA. (2019, August 13). *NarrowBand - Internet of Things (NB-IoT)*. Retrieved from NarrowBand - Internet of Things (NB-IoT): https://www.gsma.com/iot/narrow-band-internet-of-things-nb-iot/

Guillemin, P., Berens, F., Vermesan, O., Friess, P., Carugi, M., & Percivall, G. (2015). *Internet of Things: Position Paper on Standardization for IoT technologies.* Brussels: European Research Cluster on the Internet of Things. Retrieved from http://www.internet-of-things-research.eu/pdf/IERC_Position_Paper_IoT_Standardization_Final.pdf

Holodowsky, J., Mahto, M., Raynor, M. E., & Cotteleer, M. (2015, August 21). *Inside* *the Internet of Things*. Retrieved from https://www2.deloitte.com/insights/us/en/focus/internet-of-things/iot-primer-iot-technologies-applications.html

Högväg, J., & Andersson, S. (2019a, April 25). Case Malax bergsvärme.

Indexterm. (2019, May 23). *MULTICAL 601 HEAT METER*. Retrieved from https://indexterm.all.biz/en/multical-601-heat-meter-g82061

Krasniqi, X., & Hajrizi, E. (2016). *Use of IoT Technology to Drive the Automotive Industry from Connected to Full Autonomous Vehicles*. IFAC-PapersOnLine. Retrieved from https://pdf.sciencedirectassets.com/313346/1-s2.0-S2405896316X00298/1-s2.0-S2405896316325162/main.pdf?x-amz-security-token=AgoJb3JpZ2luX2VjEMH%2F%2F%2F%2F%2F%2F%2F%2F%2F%2FwEaCXVzLWVhc3QtMSJHMEUCIQDZdfFBHWz5Pg4gWGG%2B6X21zx1%2FcMLTWrBXg%2F9VHm%2FGeAIgHEXi

Lindborg, J. (2019, January 24). Sustainable Innovations AB and IoT. (F. Slotte, Interviewer)

Lindén, H. (2019, April 25). Case Meteoria.

Lowe, M. (2013, November 1). *Bottom(s)-up or is the Top-down? A Working Definition of Systems Engineering*. Retrieved from engineering.com: https://www.engineering.com/DesignSoftware/DesignSoftwareArticles/ArticleID/6576/Bottoms-up-or-is-the-Top-down-A-Working-Definition-of-Systems-Engineering.aspx

Oxford Living Dictionaries. (2019, April 15). *Oxford Living Dictionaries*. Retrieved from https://en.oxforddictionaries.com/definition/self-driving

Process Center AB. (2019, May 23). *Flödesmätare Ultraljud (Energi) LRF3000S*. Retrieved from http://www.processcenter.se/produkter/flodesmatare/flodesmatare-ultraljud/flodesmatare-ultraljudenergi-lrf-3000s/

Ravindra, S. (2018, July 5). *The Transformation That Barcelona Had Undergone To Become A Smart City*. Retrieved from http://www.barcinno.com/barcelona-smart-city-technologies/

SAE International. (2014, January). *Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems*. Retrieved from https://www.sae.org/standards/content/j3016_201401/preview/

Shakerighadi, B., Vasquez, J., Anvari-Moghaddam, A., & Guererro, J. M. (2018, May 14). Internet of Things for Modern Energy Systems: State-of-the-Art, Challenges and Open Issues. *Energies*, p. 23. Retrieved from https://www.researchgate.net/publication/325129909_Internet_of_Things_for_Modern_Energy_Systems_State-of-the-Art_Challenges_and_Open_Issues

Srinivas, S. (2013, October 16). *What is meant by Data Abstraction*. Retrieved from https://www.youtube.com/watch?v=GSTvJujN4kw

Syrjärinne, P. (2016). *Urban Traffic Analysis*. Tampere: Tampere University Press. Retrieved from http://tampub.uta.fi/bitstream/handle/10024/98613/978-952-03-0069-2.pdf?sequence=1&isAllowed=y

Teodorescu, M. (2016, August 24). *10 considerations when choosing the right sensor for hazardous environments*. Retrieved May 8, 2019, from electronicproducts.com: https://www.electronicproducts.com/Sensors_and_Transducers/Sensors/10_considerations_when_choosing_the_right_sensor_for_hazardous_environments.aspx

The Internet of Things Business Show. (2018, June 29). The IoT Playbook - Schneider Electric is All In. (B. Sinclair, Ed.) The IoT Inc Business Show. Retrieved from https://www.iot-inc.com/iot-playbook-schneider-electric-podcast/

The Internet of Things Business Show. (2018, February 21). Top-down Design with Bottom-up IoT Tech. (B. Sinclair, Ed.) The Internet of Things Business Show. Retrieved from https://www.iot-inc.com/top-down-internet-of-things-design-podcast/

The Internet of Things Business Show. (2019, March 15). To be or not to be a Data Hoarder. (B. Sinclair, Ed.) Retrieved from https://www.iot-inc.com/iot-big-data-management-storage-podcast/

The IoT Marketplace. (2019, May 17). *Smart Parking: The IoT Marketplace*. Retrieved from https://www.the-iot-marketplace.com/libelium-yazamtec-smartparking-sigfox-solution-kit

United Nations Framework Convention on Climate Change. (2015). *Paris agreement.* Paris: United Nations Framework Convention on Climate Change. Retrieved from https://unfccc.int/process/the-paris-agreement/status-of-ratification

wikipedia.org. (2015). *Narrowband IoT*. Retrieved May 15, 2019, from https://en.wikipedia.org/wiki/Narrowband_IoT

Wortmann, F., & Fluchter, K. (2015). Internet of Things: Technology and Value Added. *Business & Information Systems Engineering, 57*(3), 221-224.