ENHANCING THE EFFICIENCY AND RELIABILITY OF RENEWABLE ENERGY SYSTEMS WITH THE INTEGRATION OF INTERNET OF THINGS

Lappeenranta–Lahti University of Technology LUT

Degree Programme in Electrical Engineering, Bachelor’s thesis

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Examiners: Dr. Mehar Ullah

Abstract

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Energy is an essential part of the world today. Energy influences social, economic and technological aspects of society. The efficiency and availability of energy significantly impact the overall well-being and development of both nations and individuals. Renewable energy sources in particular promote environmental sustainability, help to mitigate climate change and enhance energy security.

As we move towards a more connected world and eventually smart cities, we need a smart, reliable and efficient power supply to operate the world seamlessly. By integrating the Internet of Things (IoT) into renewable energy systems, we can meet future energy demands efficiently. The utilization of renewable energy resources already offers various advantages over traditional ones, but the implementation of IoT further enhances the ability to take advantage of these clean energy sources. Additionally, when combined with other cutting-edge technologies such as edge computing and big data, we are able to ensure a future characterized by reliable and clean energy.

Tiivistelmä

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUTin energiajärjestelmien tiedekunta

Sähkötekniikan koulutusohjelma

Yhteistyöyliopisto: Hebei University of Technology

Jenna Pennanen

Uusiutuvien energialähteiden tehokkuuden ja luotettavuuden tehostaminen käyttämällä esineiden internetiä

Kandidaatintyö

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32 sivua ja 6 kuvaa

Tarkastajat: Tohtori Mehar Ullah

Avainsanat: IoT, uusiutuva energia, reunalaskenta, digitaalinen kaksonen

Energia on olennainen osa nykymaailmaa. Se vaikuttaa yhteiskuntaan niin sosiaalisten, taloudellisten kuin teknologistenkin aspektien kautta. Energian tehokkuus ja saatavuus vaikuttavat merkittävästi sekä kansakuntien että yksilöiden yleiseen hyvinvointiin ja kehitykseen. Nimenomaan uusiutuvat energialähteet edistävät ympäristön kestävyyttä ja auttavat hillitsemään ilmastonmuutosta sekä lisäämään energiavarmuutta.

Kun siirrymme kohti yhtenäisempää maailmaa ja lopulta älykaupunkeja, tarvitsemme älykkään, luotettavan ja tehokkaan virtalähteen toimiaksemme maailmassa saumattomasti. Integroimalla esineiden internetin (IoT:n) uusiutuvan energian järjestelmiin pystymme vastaamaan tulevaisuuden energiatarpeisiin tehokkaasti. Uusiutuvien energialähteiden hyödyntäminen tarjoaa jo nyt monia etuja perinteisiin verrattuna, mutta IoT:n käyttöönotto parantaa entisestään kykyä hyödyntää näitä puhtaita energialähteitä. Lisäksi yhdistettynä muihin innovatiivisiin teknologioihin, kuten reunalaskentaan ja massadataan, pystymme varmistamaan tulevaisuuden, jolle on ominaista luotettava ja puhdas energia.

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1 Introduction

The importance of energy is remarkable in today's world. It plays a fundamental role in various aspects of modern life as it supports not only the technological and economic development but also the overall well-being of people. The society we live in would come to an absolute stop without energy, and it is very difficult to come up with cases where energy would not be needed. Energy powers many critical infrastructures and industrial production. It provides electricity and fuels. It supports transportation and global communication. It is needed for healthcare, education, economic growth and global development, and as such it improves the overall quality of life.

The importance, and actually, necessity of renewable energy is also significant. The use of fossil fuels is not sustainable. Not only do they produce greenhouse gas emissions and cause climate change, but they are also finite. Renewable energy sources on the other hand produce minimal harm to ecosystems, reduce the overall carbon footprint, and can be used continuously without running out. By obtaining different energy sources and reducing the dependence on fossil fuels, we can enhance energy security, and thus minimize the vulnerability to geopolitical conflicts and market fluctuations, and also improve the resilience against power outages and natural disasters (Paravantis & Kontoulis, 2020). Because of the current situation in the world, trying to become more independent in covering the nations own energy needs, competing against climate change, and taking into account the considerable rise in the prices of fossil fuels, developing renewable energy sources has become vital.

The adaptation of renewable energy sources requires new technologies, especially when trying to use energy as efficiently as possible. Recent technologies include naturally the development of the renewable energy systems themselves, but also the utilization of internet and data processing. These technologies involve IoT, smart grids, big data, cloud computing, edge computing, digital twins, machine learning and blockchain to name a few. By putting these technologies to use, researchers, companies, policy makers, etc. can improve their decision-making to be more informed as they uncover trends, make predictions and gain more knowledge. We are able to truly unlock the potential of information as we are provided with new ways to understand, analyze and finally capitalize data (Kothari, Ranjan & Singal, 2021).

In recent years the usage of cloud computing has increased as many industries in different fields have started to shift towards it. Cloud computing offers benefits like flexibility and cost savings among others, but because of the rise in usage and therefore the huge amounts of data having to be processed and analysed in the cloud servers, it's bound to create problems. One of the ways this can be dealt with is using edge computing. By processing a lot of the data at the edge of the networks we can speed up the data analysis and decision-making process.

The increasing amounts of generated data has volumes so large and velocities so fast that we can start treating it as big data. Due to the size and diversity of the data, advanced technologies and analytics are required. This sort of big data analytics can be used to further enhance data processing and as so can then be utilized for example in smart grid technologies. Different from a traditional power grid, smart grids use various smart devices and communication and control systems to improve energy production and consumption. More so, with these systems and devices smart grids can be used to increase the production of renewable energy in the electricity grid.

At the center of all of this is IoT, the Internet of Things. It is a system of connected devices that can transmit data over a network without requiring human-to-human or human-to-computer interaction (Ramos & Coronado-Hernández, 2023). IoT systems collect, send and process data from their environment. The variety of purposes for which we can use the aforementioned IoT-related technologies is broad. One of these purposes is to enhance the efficiency and reliability of renewable energy systems.

In this thesis we first briefly tackle the main research questions and methods at hand. In the background section we will clarify what the used terms stand for and how they are handled, specifically in Finland. Then we have the main part where we will delve into the subjects of renewable energy systems and Internet of Things, and how they can come together to create a more reliable and efficient energy structure. After that we will have a discussion section to discuss our findings and finally conclude the thesis.

2 Research

In this chapter we briefly go through the examined research questions and the utilized research methods. We have one main research question and also a few others that complement it. The applied research methods are those of a customary literature review on technology.

2.1 Research questions

The main research question at hand is the integration of Internet of Things into renewable energy systems in order to improve their efficiency and reliability. We go through particular solutions for solar, wind and hydropower. We also delve into other digital technologies which correlate to IoT, such as big data, edge computing and digital twins. In this thesis we highlighted how IoT technologies can be employed to optimize energy harvesting from renewable sources and how IoT devices and smart technologies can be integrated to enable effective management in renewable energy systems. While addressing the reliability of renewable energy systems, we also think about what measures can be implemented to enhance the resilience and security of the systems when integrated with IoT technologies.

2.2 Research methods

When conducting a literature review on technology, we need to systematically examine already existing scientific articles, books and other works to understand what is currently known in a given field. First, we clearly define the research question or objective of the review and also determine the specific characteristics of the technology under study. Next for the selection of relevant literature, we use academic databases, library catalogues and search engines. We use keywords, synonyms and other vocabulary related to the topic, and also create more exact criteria such as publication date, methodology and source type. This study mostly uses LUT Primo and Google Scholar. The used keywords include IoT, renewable energy systems, sustainability, edge computing, big data etc. We have tried to find the recent updated articles from the literature, but we have not set a precise date. After selecting sources we finally summarize their key findings and figure out whether we can somehow reflect on those in our own work. When starting the writing process, we begin by creating a framework organizing our existing and newly gained knowledge to present a clear overview of the research questions.

3 Background

In the background section we explain the relevant themes and technologies associated with the main research question. We address how IoT is defined and what it is comprised of. We also briefly explain the other associated new technologies. We go through renewable energy in more depth, taking into account the situation specifically in Finland.

3.1 Internet of Things

The Internet of Things (IoT) stands for systems based on the automatic data transfer performed by technical devices and the remote monitoring and control of said devices via the Internet. IoT is a network of physical objects that have electronics, software and sensors embedded in them, enabling users to obtain accurate data in real time through services that can exchange data between manufacturers, users or other connected devices (Jaupi, 2017). It can refer to any object that can be assigned an address and an Internet Protocol, and is capable of transmitting data over a network. The devices operate mostly without human intervention, although humans can interact with them for example when setting them up, providing instructions, or accessing the data (Ramos & Coronado-Hernández, 2023).

There are many ways to interpret how exactly IoT is formed, one way being is to break it down into six building blocks; identification, sensing, communication, computation, services and semantic block. The figure 1 showcases these blocks as per Ullah, Nardelli, et al. (2020) has suggested.

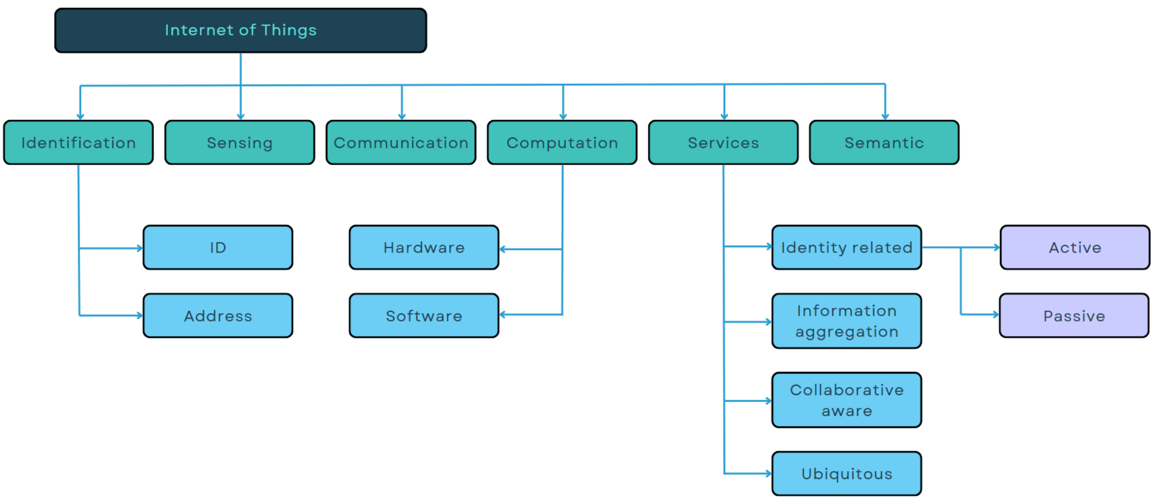

Figure 1: IoT building blocks

In the identification block the devices in the network are identified. Each device has an object ID and an object address with which the devices are identified by. The object ID is the name of the device, while the object address is the location of the device in the communication network. In the sensing block sensors collect data from the network objects and environment. The data then is sent either to the target database or to the cloud where the data gets analyzed. Different kinds of mechanical devices can also be used as hardware; these so-called actuators, such as switches, work in a manner opposite to a sensor (Ullah, Nardelli, et al., 2020).

In the communication block there are many heterogeneous objects that exchange data and services among themselves and with the platform. Objects are connected to the IoT, and the data they generate is sent to the management system using IoT communication protocols such as MQTT, as presented by Ullah, Nardelli, et al. (2020). Sensors among other devices are connected to the Internet using communication technologies such as Zigbee, NFC and Wi-Fi.

The computation block is separated into two parts: hardware and software. There exist many platforms for applications of both, as an example Arduino and Raspberry Pi for the hardware side (Ullah, Nardelli, et al., 2020). For software side the main platform is the operating system that runs continuously during the time the device is active. Software algorithms automate tasks through rules-based analysis and advanced pattern recognition by categorizing historical data to identify subtle variations in what is considered normal operational data. A computational component is also the cloud platform, allowing small objects to send data to the cloud, aiding in the processing of big data in real time and acquiring knowledge from the big data for the end user.

According to Ullah, Nardelli, et al. (2020) the services block has four categories, one of which can be further subdivided into two. Active identity-related services involve the transmission of information and they operate with either continuous power or rely on power from a battery. These services have the ability to send information to other devices. Passive identity-related services do not have a power source and thus require an external device or mechanism to convey their identity. These services are limited to reading information from devices. In information aggregation services data is collected, processed and transferred to an IoT application. Collaborative-aware services utilize the data obtained from information aggregation services to make informed decisions and respond accordingly. Ubiquitous services offer collaborative-aware services to be available at any time to anyone in need, regardless of location.

It can be argued that the semantic block is the brain of the IoT system. IoT needs knowledge in order to provide diverse services, and for obtaining that knowledge in an effective way, a variety of machines is required. The process of collecting knowledge can include for example locating and utilizing resources, modeling information, and identifying and analyzing data in order to make decisions and provide the appropriate service (Ullah, Nardelli, et al., 2020).

3.2 Related technologies

The amount of information that is generated at every moment in today's world is huge. The quantity of data that is collected is so large that the traditional data processing software and techniques struggle to process it. This is where big data comes into play, the collection of unstructured, structured and semi-structured data that is generated by different devices and applications that continuously generate data (Ullah, Nardelli, et al., 2020). Characterized by the 3 Vs – volume, velocity and variety – big data refers to the enormous volume, velocity and variety of information generated in the digitally connected world. Volume signifies the massive amount of data that is too large for the conventional databases to manage and analyze. In this case the data is measured in large units of data, such as terabytes, petabytes, and even exabytes. Velocity is naturally the speed at which the data is generated, processed and transferred in real time. Variety stands for the type that the data is, as to whether it is structured or unstructured.

Cloud computing stands for the delivery of IT services typically via the Internet, as in, "the cloud" and by paying according to usage. Users can access a wide range of services without the need for large-scale local infrastructure. Cloud computing utilizes remote servers and thus differ from conventional computing models which rely heavily on local servers or personal devices. In network computing, applications and documents are stored on a specific server and can only be retrieved through the exact network, while cloud computing involves many servers and networks, allowing global access through an Internet connection (Mirashe & Kalyankar, 2010). Cloud computing is a powerful and intelligent tool that can connect users and information all over the world.

Edge computing allows computations to be performed at the edge of the network, and any computing or networking resource that is between the data source and the cloud can be defined as such. The nodes at the edge of the network reduce traffic from the devices to the cloud by performing many tasks which include data processing, caching, device management and privacy protection (Ullah, Narayanan, et al., 2021). Because of computing happening locally or nearby, edge computing is different from cloud computing which utilizes data processing in remote data centers. By processing data at the edge near devices and sensors that produce said data, edge computing significantly reduces the time it takes for the data to travel between the devices and data centres. This speeds up response times and further improves real-time decision-making.

An additional advantage of utilizing edge computing is the mitigation of failures. In the event of an electricity outage in a specific grid area, the edge computing services in other regions continue to function normally without disruptions. But a dependence only on cloud computing creates a possible vulnerability, as a power supply failure in the cloud infrastructure resulting for example from a natural disaster could lead to a complete network failure (Ullah, Narayanan, et al., 2021).

The smart grid is an electrical grid that uses smart devices. The smart grid creates a widely distributed automated energy delivery network by using two-way electricity and information flows (Fang et al., 2011). The two-way communication between generation and end users enables real-time monitoring, which gives the chance for analysis and response to changes in energy demand and supply. This supports energy saving and cost reduction as the consumers can adjust their energy usage according to the supply and demand. As opposed to a conventional power grid, smart grids delve into digitalization; transforming a conventional one-way electricity grid into a two-way system simply involves the integration of sensors and software (Ahmed Abdulkadir & Al-Turjman, 2021). Smart grids use advanced sensors, and communication and control technologies for better grid management and efficiency.

Digital twin is a precise virtual model of a real-life apparatus. By using a digital twin it is possible to control, change and share information of the apparatus, increasing for example cost efficiency and equipment lifetime. To effectively generate a digital twin, data must be gathered throughout all relevant stages of the product life cycle, a process that is made easier with IoT-enabled sensors. Real-time data, collected through these sensors, can be integrated into models, enhancing the accuracy of predicting the system's behavior in true usage. When this information is digitized, the prediction of possible mechanical failures becomes easier, all the while software tools aid in predicting which component is likely to fail at a specific stage and within a certain timeframe (Hu, 2023). The digital twin can perform simulation, monitoring, prediction, optimization and so on.

Smart meters generate data that can be collected and analysed through IoT to improve energy efficiency. Smart meters provide detailed hourly energy usage data, aiding in balancing power consumption. The information can also be used to adjust prices during specific hours of the day to control peak energy consumption. Smart metering offers a two-way benefit for both the service providers and end users. The main components of a smart meter include analog and digital ports, serial communication, volatile memory, non-volatile memory, a real-time clock and microcontrollers (Ahmed Abdulkadir & Al-Turjman, 2021).

3.3 Renewable energy

Renewable energy is energy that is produced from naturally replenished sources, or in other words energy from sources other than fossils. The reserves of renewable energy sources, when used in a sustainable way, will not decrease in the long term. The main goal of increasing the use of renewable energy is to reduce greenhouse gas emissions and detach from the fossil fuel-based energy system. The use of renewable energy also increases energy self-sufficiency and employment and supports the development of the technology in the field.

Renewable energy sources include hydro and wind power, solar energy, geothermal energy, environmental energy, the biodegradable part of recycled and waste fuels, and wood-based and other plant- and animal-based fuels. Among the renewable forms of energy used in Finland, the most significant ones are bioenergy, wood-based fuels, hydropower, wind power and geothermal energy (Grönlund, 2023). In this thesis I take into consideration solar, hydro and wind energy.

3.3.1 Renewable energy in Finland

Finland is one of the world's leading countries in the utilization of renewable energy sources, especially bioenergy (Grönlund, 2023). Finland ranks among the top EU countries in the use of renewable energy, mainly thanks to the utilization of energy from wood and black liquor from the wood processing industry (*Suomessa käytetään paljon uusiutuvaa energiaa* 2020). The use of renewable energy in Finland is affected by Finland's own energy and climate policies, as well as decisions and directives made in the EU.

In 2020, the share of renewable energy use in the total energy consumption grew larger than that of fossil energy (Alm, 2022). Figure 2 shows a quite steady rise of renewable energy and the recent decline of fossil fuels. It presents the total consumption of energy in terajoules by energy source and year.

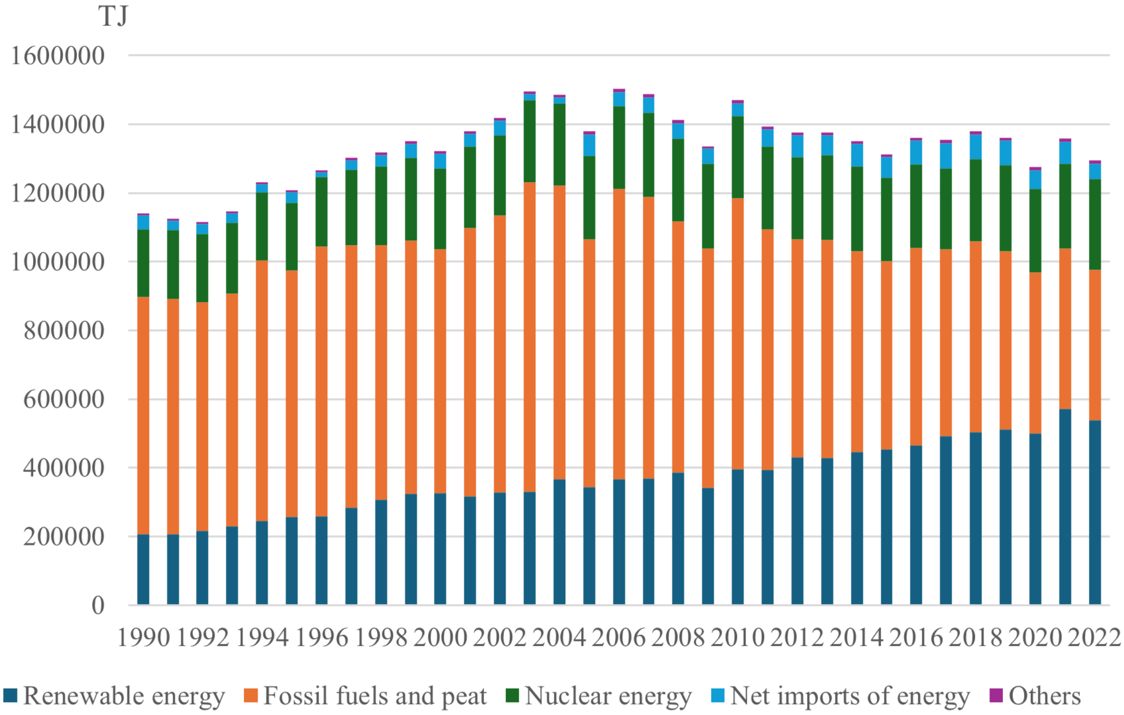

Figure 2: Final consumption of energy in Finland (*Tilastotietokannat* 2023)

In accordance with the national energy and climate strategy aimed at the year 2030, the goal is to increase the use of renewable energy sources so that by the end of 2020s their share in the final energy consumption rises to more than 50 percent from the current approximately 40 percent (Grönlund, 2023). Final energy consumption refers to the consumption of electricity and heat, transport fuels, industrial process fuels and building heating fuels. Total energy consumption on the other hand also takes into account energy transmission and transformation losses (*Uusiutuva energia Suomessa* 2024). Final energy consumption expresses the final amount of energy left to be used by the end users (*Tilastotietokannat* 2023).

Although the use of renewable energy sources has increased in Finland, a considerable amount of fossil fuels like oil, coal and natural gas are still used in our energy production. Finland is committed to reducing greenhouse gas emissions in order to combat climate change and to meet the climate and energy goals set by the EU for 2030 and the carbon neutrality 2035 goal of the government program. In addition, the construction of renewable energy installations increases the share of domestically produced energy and reduces dependence on imports. At the core of a recent strategy by The Finnish Government is the green transition and the current withdrawal from Russian fossil energy since the spring of 2022.

3.3.2 Renewable energy sources

The focus of renewable energy in Finland is clearly on bio-derived recycled fuels and wood. Figure 3 shows the use of different renewable energy sources in Finland in recent years, and wood based fuels clearly take the top spot. The figure 3 presents the total consumption of energy in terajoules by energy source and year. In bioenergy systems, the sun's energy is first bound through photosynthesis with the plant mass and the produced vegetation is then used as an energy source. But when comparing the greenhouse gas emissions during the life cycle of different forms of renewable energy, it turns out that the emissions of biomass are on average significantly higher than those of wind and hydropower and solar and geothermal energy (*Suomessa käytetään paljon uusiutuvaa energiaa* 2020). When plants are burned, they release as much carbon dioxide as they have collected while growing. It is because of this and the fact that it is less suitable for the integration of IoT that we shall not take it into further consideration in this thesis.

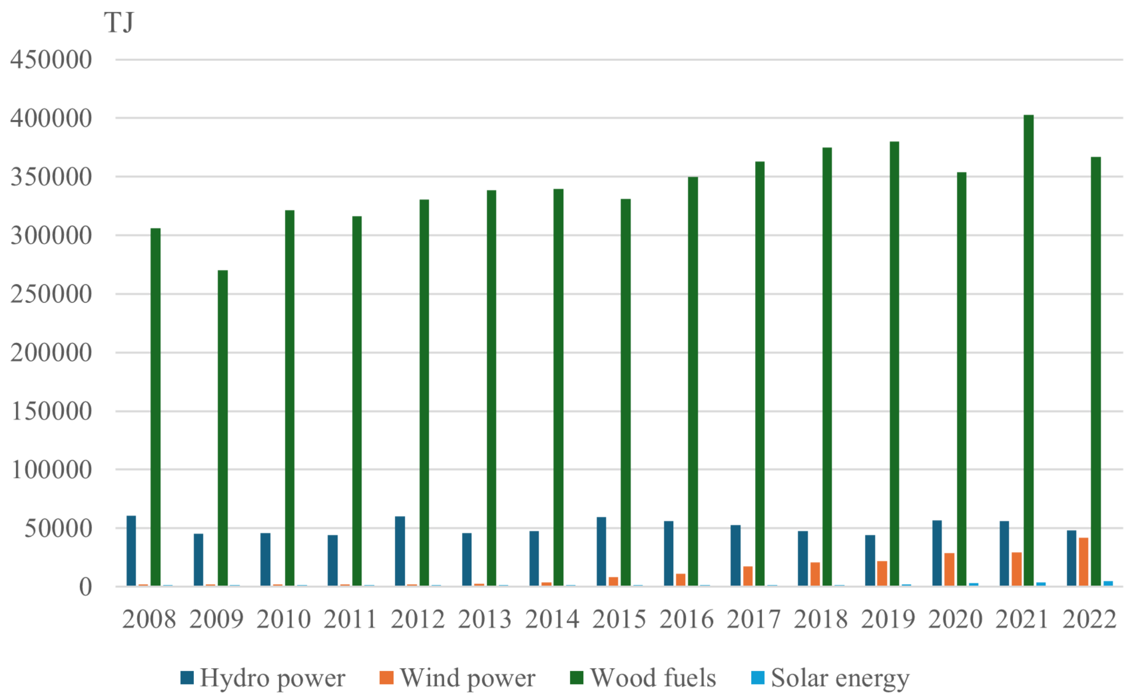

Figure 3: Final consumption of renewable energy in Finland (*Tilastotietokannat* 2023)

Annual wind power production in Finland has been growing quite steadily since 2014 with installed cumulative capacity also increasing every year. During 2023, 212 new wind power plants worth of 1280 megawatts of power were built around Finland. At the end of 2023, Finland's wind power capacity was 6946 megawatts and there were a total of 1601 operating wind turbines (*Toiminnassa olevat & puretut voimalat* 2023). Wind farms can be divided into wind farms located on land or on the coast (on-shore) and marine wind farms (offshore). Offshore wind farms, in particular, are advantageous due to their minimal impact on the landscape and ecology, as well as their access to higher wind speeds at sea. In Europe, the largest wind farms are offshore wind farms.

The kinetic energy of wind is converted into mechanical energy by the rotating wind turbines. The mechanical energy is then used to rotate a generator that produces electrical energy. When comparing the monthly wind levels in Finland, the winter months are especially windy. There are areas well suited for wind power production on coasts, sea areas, fells and in many places also inland (*Tuulivoima Suomessa* 2022). When in the future the wind power plant installations are also built at sea, the size of individual power plants will continue to grow. According to Sandell (2023) there are currently pending offshore wind power projects in the Finnish sea areas that account for about 33 gigawatts, equivalent to 20 Olkiluoto 3 reactors. The power produced by wind power is proportional to the wind speed and if it increases significantly, the wind turbines must be disconnected from the grid so that they are not damaged (Elovaara & Haarla, 2011). In recent years, more and more wind power has been built, even without government subsidies.

When using solar energy, sunlight is converted into usable energy forms. With solar thermal energy technologies the heat from the Sun could also be used but we are concentrating on harnessing the light in order to generate electricity. In Finland the share of solar electricity is increasing, especially in locations where consumer's own production replaces electricity purchased from the grid (Grönlund, 2023). According to *Aurinkosähkön perusteet* (2023) the share of diffuse radiation in total radiation is significant in Finland. In southern Finland, about half of the year's radiation is from it. Diffuse radiation is radiation reflected by the atmosphere and clouds and radiation reflected from the ground. In Finland the utilization of solar energy is limited by the long dark period as solar radiation is strongly concentrated in the summer months, and so our production varies more according to the seasons. The weakness is that the production is lowest in winter, when electricity consumption is the highest.

The use of wind and solar energy has seen a rise in popularity, but hydropower shouldn't be forgotten. As the amount of renewable energy on the grid increases, a constant energy supply might be hard to achieve at all times because of the unsteadiness caused by climatic variations. Hydropower can aid in supporting these intermittencies and load fluctuations. Hydropower plants use the kinetic energy of the water flowing in the plant to create electricity. The kinetic energy is captured when the water flows down through the turbines and it is then converted into electricity in generators. The operation of a hydroelectric power plant is based on the height difference between the upper and lower water reservoirs of the power plant. In Finland, hydroelectric power plants are usually river power plants built in the main channel or the largest branches of large water bodies (Elovaara & Haarla, 2011).

As mentioned, one advantage of hydropower generation is that it can be used to smooth out electricity consumption peaks, as energy can be stored by damming. Hydropower plants are the most reliable part of the electricity production system and they usually take care of the power regulation of the network, i.e. they make sure that production is in instantaneous balance with consumption (Elovaara & Haarla, 2011). Greenhouse gas emissions are not generated in the production of hydropower itself, and with appropriate regulation the other effects on the environment are also minimal. In terms of production costs, hydropower plants are inexpensive due to their long service life. The costs of hydropower plants consist almost exclusively of fixed costs, mainly charged in the construction phase of the plant. The other variable costs are very small, because the fuel itself is free and the plants are tried to be made remotely controlled. According to Elovaara & Haarla (2011) the variable costs are mainly caused by power transmission losses if electricity has to be transferred over long distances. Other advantages of hydropower include for example flood risk management and benefits for recreational use.

Possibilities for additional hydropower construction still exist in Finland, even though the largest sites have already been mostly built. Significant additional construction of a completely new hydropower plant is unlikely due to environmental and nature protection reasons. There are no suitable conditions for wave and tidal energy production in Finland (*Uusiutuva energia Suomessa* 2024).

3.3.3 Renewable energy systems

An energy system is a system whose primary goal is to provide energy services to end users. According to Sorrell, O'Malley, et al. (2004), the goal of an energy system is to minimize energy losses to a level that is insignificant and to ensure that the use of energy is efficient. Renewable energy systems are energy systems that use renewable energy to generate electricity.

Complete renewable energy systems include both supply and demand, and the demand can be further divided into demand and end use. The supply of energy simply consists of the different energy sources and their possible storages. Lund (2014) suggests that the end use of energy is comprised of people's need for energy services such as room temperature, transportation and light, while the demand of energy consists of the demands of consumers such as households and industry, as well as the public and private service sectors. The demand of energy includes the need for heat, electricity and fuel.

4 IoT enhancing efficiency and reliability

There are different ways to determine what reliability exactly is. Renewable energy is reliable in the sense that there are no limits to the amount of power that the earth provides. As the name suggests, they are renewable, and as such can be used continuously without running out. But renewable energy sources, wind and solar in particular, struggle with reliability as their production cannot be precisely known in advance, only forecasted. This unpredictability is one of the issues of renewable energy. They produce energy only at certain times at specific conditions and thus the electricity production does not correspond to peak demand hours. There is instability in both production and load and so they cannot provide a continuous on-demand power supply, which is a problem as there still is a lack of power storage at an affordable price.

If there is a lot of wind or solar power in the system, there should also be reserves that generate electricity when needed, for example in calm or cloudy weather. Even though these energy sources do not pollute and cause greenhouse emissions, the power plants acting as their reserve may do so. It is also better that the same power system has plenty of wind or solar power in different places, because in larger areas the weather conditions vary more and thus the fluctuations in power production can be evened out. However according to Elovaara & Haarla (2011), it must be remembered that examining the electrical system only in terms of the produced power and frequency is not sufficient, but also the transmission in the network must be taken into account. If changes between two areas would require the power transfer to be increased beyond the permitted limit, reserves must be created where the electricity is transferred too much, maintaining reliability of operation. With hydropower the problem of fluctuating weather conditions is not as apparent as its production can be better controlled.

Uncertainty, too, leads to the unreliability of the system. The uncertain parameters of renewable energy sources, as suggested by Kumar et al. (2020) include technical and economical parameters. Technical parameters are operational parameters such as wind generation, and topological parameters such as outage of system components. Economical parameters can also be divided into two, macroeconomic parameters like inflation and interest rates, and microeconomic parameters such as electricity price, operational costs and investment costs.

Many things affect the efficiency of a renewable energy source. The different factors include power usage, cost, ease of installation and maintenance, regional weather conditions, environmental impacts and the availability of energy storage. The intended usage and geographical location also have an impact. When installing a new energy supply these factors should be taken into account. Traditional electricity production methods usually involve electricity being produced in centralized, large power plants. Different distributed forms of production are emerging, especially when using renewable energy, allowing electricity generation even on a small scale. The electricity produced in this way can also be fed into the grid, if the facility meets the technical requirements set for connecting to the grid.

4.1 Transportation of data

Generating and collecting the data from various sources enhance the grid reliability and contribute to the overall robustness of the grid. Figure 4 as mentioned by Ullah, Narayanan, et al. (2021) describes how the different technologies come together to transport data across the network. Data is first collected from the renewable energy sources and then further distributed with the help of Internet of Things.

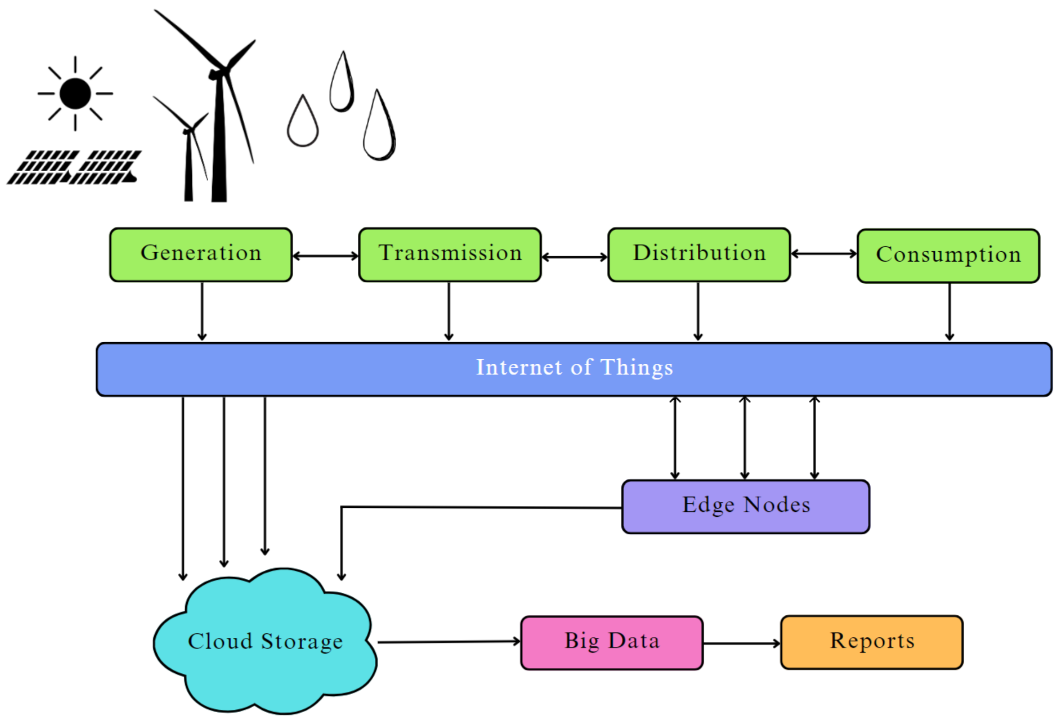

Figure 4: IoT, Edge Computing and Big Data transporting data

The figure shows the lifecycle of the data, spanning from data generation to its eventual use in data analytics. The data is produced by various smart meters, sensors and digital devices, while the sources of the data include not only the generation plants themselves but also transmission and distribution networks and different customer types such as residential homes, electric vehicles and commercial buildings. Additionally, environmental data like weather, humidity, temperature and pressure can be gathered. The generated data is then transferred to the IoT network through IoT devices like sensors and actuators, using various network technologies such as 3G/4G/5G, Wi-Fi and Bluetooth (Ullah, Narayanan, et al., 2021).

The important data is then handled by edge nodes. The nodes are situated close to the data collection points, thus demanding minimal latency. The latency is however influenced not only by the distance between the data collection point and the edge processing server but also by factors such as the processing power of the edge server, computational complexity of tasks and edge traffic, resulting in not having guaranteed benefits. Ullah, Narayanan, et al. (2021) mentions that when designing the edge network, it is required to take into consideration aspects such as task complexity, server processing power and the employed network topology in order to efficiently fulfil the latency requirements. Edge computing helps reduce data traffic by distributing data across various edge servers for computational workloads, resulting in a smaller volume of data that needs to be transmitted to the cloud, finally improving the data transfer capability of the network. This is also achieved by the collaboration between cloud and edge computing since the data is transmitted to the cloud server if the capacity of the edge servers is surpassed.

The data from IoT devices can be processed and analysed by the edge nodes or it can be directly routed to cloud storage, and the data can then be stored in the cloud or in another database (Ullah, Narayanan, et al., 2021). Preprocessing of the data might be required given that it is gathered from different devices with varying formats and information. This preprocessing phase also involves managing inaccurate and incomplete data. The data is then analysed in different ways and finally the information is visualized and shared using various platforms such as graphs or reports.

4.2 IoT across the renewable energy systems

The integration of IoT in renewable energy not only presents significant opportunities for companies but also offers notable benefits to individual consumers. Individuals can generate energy to fulfil their own domestic needs. With the assistance of IoT devices, customers can combine their different appliances into a unified system, and furthermore integrate their system to the whole grid. By using an application, the user can oversee the functioning of their electrical devices. They can also install smart devices for the ability to measure the power consumption of individual devices, and then this information can be used to identify inefficiencies and power-intensive appliances (Joshi, 2019). Furthermore, additional IoT devices like thermostats can automatically optimize their operation based on environmental conditions, contributing to reduced energy consumption.

In both commercial and residential settings, the utilization of smart grid is increasing, and energy companies need to make changes to adapt to this. In addition to overseeing their primary generators, they now also need to manage a growing number of small generators scattered throughout the grid. To efficiently monitor all of these, IoT comes in handy. Sensors that are strategically placed at multiple points enable the monitoring of numerous stages in production and transmission. And in response to fluctuating energy demands, the sensors autonomously adapt to changes, providing operators with accurate information to precisely manage demand (Joshi, 2019). This not only betters the efficiency and decreases losses, but also strengthens the reliability by offering constant power and not getting affected by for example grid overload.

An example of incorporating automation using IoT devices in renewable energy involves their application in monitoring and optimizing the performance of wind turbines and solar panels. According to the data generated by the IoT sensors, the direction of the wind turbines and solar panels can be adjusted to maximize efficiency. By implementing automated controls, the power plant operates with increased efficiency, leading to a significant improvement in power output and a reduction in operating costs (Joshi, 2019). In recent years, both wind and solar energy sectors have made significant advancements and it so happens that these two sectors also have the most widespread adoption of IoT (Koon, 2020).

IoT also helps to improve cost efficiency as it provides tools for monitoring power consumption. This allows for electricity suppliers and other utility companies to make data-driven decisions by gaining valuable insights. Power distribution companies can analyse the power consumption patterns of different users, allowing them to balance supply based on consumer demands, and eventually leading to a reduction in electricity wastage and significant cost savings. These monitoring tools can also be of aid to the consumers if they generate some of their own electricity. Power usage data can also be used as a foundation for load forecasting, aiding in the management of overloads along transmission lines and ensuring that all generation plants meet the requirements for frequency and voltage control (Joshi, 2019). The data can even assist companies in deciding whether to upgrade existing infrastructure or construct new ones (and where).

All in all IoT proves to be useful when using renewable energy systems. There exist many different devices and technologies which are a by-product of IoT, and thus its implementation across a network is broad. Figure 5 showcases the generation, transmission, distribution and consumption of energy and how different IoT technologies are scattered throughout (Singh, Gao & Massarelli, 2022). Edge computing, cloud computing and big data is also showcased. The signals represent infrastructure for IoT, regardless of what kind of devices they are.

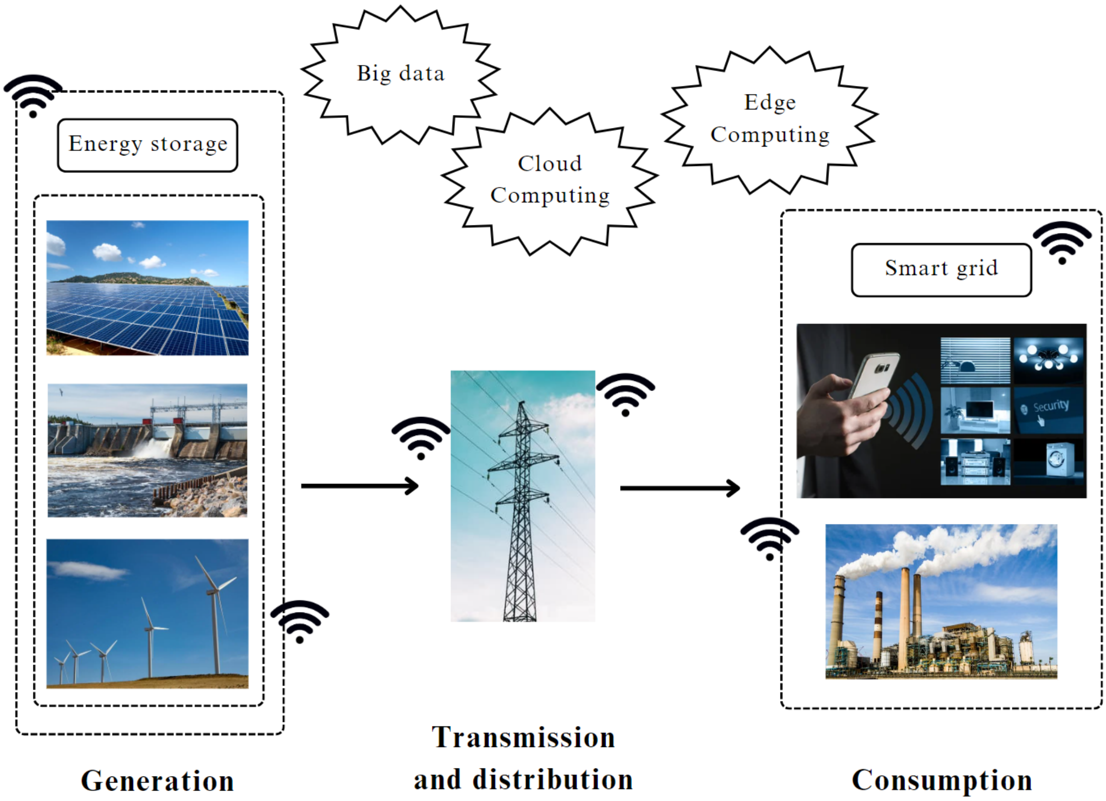

Figure 5: Distribution of IoT technologies across energy generation and consumption

Another IoT related technology that is not mentioned in the figure 5 is the digital twin. Digital twins support the digital design and testing of infrastructure before entering production. This not only saves valuable time and costs but also enhances engineering quality. The digital twin enables the simulation of the critical phase before commissioning, while also ensuring a secure implementation. Additionally, maintenance personnel can undergo thorough training prior to the actual commissioning phase. Also after commission, maintaining a digital twin is crucial for optimizing operations to achieve high performance, reliability and quality. Failures can lead to dangerous situations and costly shutdowns. Employing a digital representation enables the analysis and prediction of potential failures, allowing for proactive intervention. By anticipating and addressing issues before they escalate, hazards and shutdowns can be averted, explains Hu (2023).

IoT can be also used in safety measures. Sure, placing sensors at substations and along distribution lines enables companies to collect real-time power consumption data which can be used to make informed decisions regarding voltage control, load switching and network configuration. But these sensors can also alert about outages, the real-time data enabling quick response and thus preventing extra damage to the lines and even potential cases of electrocution, wildfires, or other hazards. Additionally, in the event of an outage, there could be implemented smart switches that can autonomously isolate problem areas, and IoT devices that can automatically reroute power to restore lighting swiftly. This would not only save time but also minimize the need for human resources (Joshi, 2019). Beyond monitoring system performance, IoT sensors can be used as tools to address theft and vandalism, particularly in rural areas. For example, sensors connected within solar panels can identify suspicious movement or attempts at dismantling units, triggering alarms even before the perpetrator makes physical contact. The enhanced IoT sensors have advanced security features, equipped to defend against malicious attacks, ensuring the security of the systems. In addition to physical safety, cyber security can be enhanced by using for example edge computing, ensuring a secure network by reducing the distances of data travel and by not relying only on one storage.

When IoT devices are integrated with energy systems, continuous collection of information on energy production, consumption trends and environmental factors takes place (Akshay, 2023). The data can be analysed to detect patterns, anomalies and areas for improvement, enabling efficient use of energy. Energy managers, through real-time data analysis, can gain comprehensive insights into energy output, distribution and consumption. By leveraging this information, they can identify inefficiencies, pinpoint potential issues or malfunctions, and implement targeted strategies to enhance energy efficiency. The benefit of implementing IoT could be summarised to three aspects: efficient grid management, load balancing and demand response.

Akshay (2023) expresses that efficient grid management can be achieved with the deployment of IoT devices and sensors across the grid, as utility companies gain valuable real-time insights into the network's condition, including details on energy production, consumption trends and grid performance. With this information, operators can identify and address issues such as equipment breakdowns or power outages in advance, thereby minimizing downtime and increasing overall grid reliability. To achieve load balancing, the grid management system can anticipate the time periods for peak demand and efficiently distribute the load by analysing power usage trends from connected devices. For example, the system might prioritize critical facilities such as hospitals during times of high-power demand. Simultaneously, it can adjust and even temporarily suspend power to non-essential devices, optimizing energy distribution and preventing overload situations. For demand response IoT offers effective mechanisms in the form of smart grids. Before energy suppliers couldn't really affect consumer demand, but with IoT-enabled smart grids, utility providers can engage with end consumers, encouraging them to adjust their power usage patterns during peak hours in order to maintain a balance between supply and demand. Through real-time data monitoring, consumers can receive notifications or even automate their devices to consume less energy during peak periods. This demand response capability plays an important role in stabilizing the grid, reducing energy waste, and enhancing overall system efficiency.

4.3 The particular energy sources using IoT

Currently, the role of IoT in renewable energy is most seen in the solar and wind sectors. These sectors, being among the larger subsectors in renewable energy and experiencing rapid growth, particularly benefit from IoT integration. Wind turbines and solar panels, characterized by their expensive and complicated constructions often installed in remote and challenging environments, rely on IoT for crucial functions (Koon, 2020). IoT plays a vital role in assisting managers in operating, adjusting, monitoring and maintaining equipment, as well as contributing to cost reduction and optimizing energy production and distribution.

Renewable energy power plants are often spread across various locations, but the integration of IoT enables remote asset management. It also makes it easier to adapt to unpredictable and challenging environments, thus decreasing equipment breakdowns and losses. Continuous data collection by IoT sensors aids managers in identifying and implementing optimal production and distribution strategies. Utilizing IoT data analytics allows for predictive maintenance, preventing expensive downtimes. IoT helps the operating costs for renewable energy power plants to be reduced through the optimization of production and control, as well as the minimization of repair expenses (Koon, 2020). Figure 6 shows examples of how IoT can be utilized in renewable energy systems. It presents different uses of IoT and how they affect the efficiency and reliability of the system.

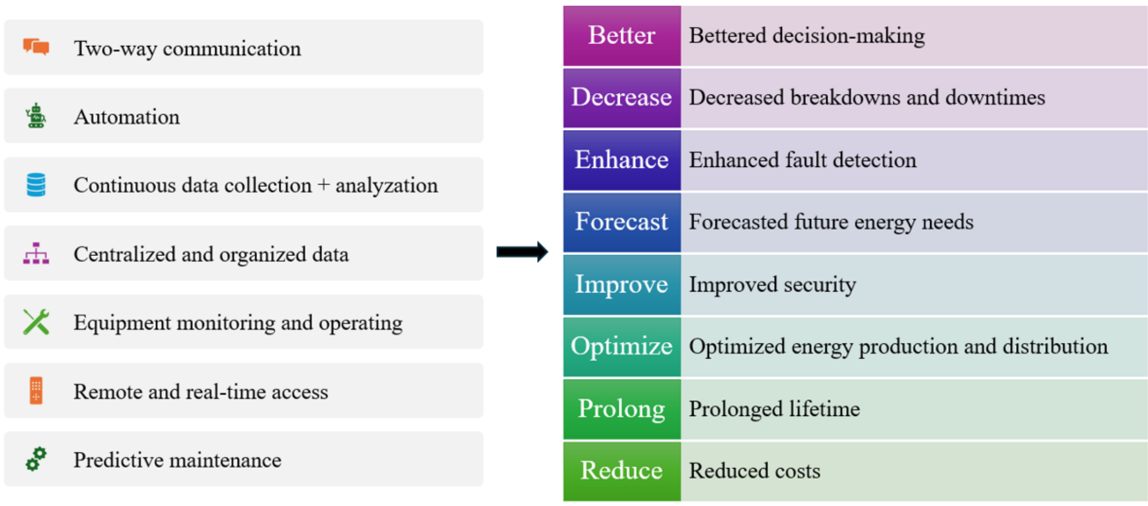

Figure 6: Benefits for renewables by using IoT

According to *IoT for Renewables* (2021) the obstacles faced by solar energy systems include the complex process of installing and operating them which demands significant time and resources, and even though the solar technology is quite mature, there still remains unpredictability. Some weather elements like temperature and solar radiation affect variations and instability on the output. When trying to ensure consistent power supply, the burden on control systems intensifies. In the absence of continuous environmental monitoring, there's a risk that controllers may inaccurately adjust power generation parameters in response to physical changes. Beyond the reliance on external conditions, each panel is expected to operate at its peak capacity in order for the entire solar system to achieve optimal efficiency. While meters can easily measure total power output, it gets more difficult when attempting to monitor individual module activities. These challenges are further amplified in solar farms with numerous on-field PV panels. Consequently, even if network-level faults and inefficiencies are identified, operators often struggle with the challenge of tracing their root causes and implementing timely repair and maintenance measures.

The remote sensors on solar panels enable the collection of a variety of data, including solar radiation, temperature, malfunctions, air particulates and energy outputs. With the help of IoT the sensors can transmit the data to a unified platform, providing operators with a comprehensive real-time perspective on critical parameters as they change. When analyzing the data, it can be observed how variations in the relevant parameters impact the performance and output of individual panels and make precise adjustments accordingly. Functions like tilt-tracking can even be automated through direct interfaces between sensors and actuators (*IoT for Renewables* 2021). When responding to the variables accurately, solar panel efficiency can be enhanced, ensuring optimal output and minimizing operational costs. What might have been a challenge before for remotely or otherwise inaccessibly located solar panel installations, can now be accessed with IoT and the smart operation of solar energy farms. Through the application of machine learning technologies, we can take it one step further by analysing the data collected by the IoT driven smart meters and forecasting future energy needs (Sutaria, 2023).

When using IoT for panel-specific monitoring and observing the outputs of individual panels, underperforming units can be identified more easily, thus reducing the time required for solving the issue. Furthermore, when integrating sensors with end-user devices, the monitoring systems can notify technicians at once when the system parameters deviate from acceptable ranges, enhancing the efficiency of fault detection and the reliability of the systems. The real-time IoT monitoring also enhances routine maintenance procedures. The collected data can be used to create inspection and maintenance schedules, and even to decide whether to prioritize high-performing panels for maximum overall output or struggling panels for minimum efficiency losses, or adopt a balanced approach (*IoT for Renewables* 2021). Sensors which are installed for monitoring, provide information on current location, health status, operational condition, damages, anticipated challenges and upcoming maintenance needs. This thorough operation that is automated by using IoT technology helps prevent faults that could cause delays and require human intervention (Sutaria, 2023).

In addition to managing faults, IoT can be used to forecast demand, ensuring a more reliable power supply. *IoT for Renewables* (2021) suggests that data analytics and predictive models could be utilized to gain insight into the correlation between output and different variables like weather conditions, maintenance schedules and even the brands of the panels. When understanding how these factors influence system performance, the expected solar energy production for a specific time period could be predicted, making it possible to precisely adjust other available energy sources to maintain a balanced relationship between demand and supply.

With the escalating dependence on wind energy, there is a growing requirement for larger wind turbines. This is because when the diameter of wind turbines doubles, the potential capacity quadruples, leading to a substantial enhancement in efficiency (Hu, 2023). The increase in size has led to offshore and even floating installations, as they cannot be accommodated on land, presenting new challenges for both design and operation. The necessity for increased capacity causes the design of wind turbines to be more difficult, as conventional validation methods like testing, physical prototyping and certifications become impractical.

IoT is a key factor in enhancing especially offshore wind turbine performance, extending their lifespan and decreasing overall costs. IoT can be used to establish an advanced analytics network, aiding in understanding the real-time operation of components, ultimately contributing to the maximization of turbine lifespan and the reduction of operation and maintenance costs. This will result in an improvement in reliability, leading to a reduction in both the number of failures and the downtime. Additionally, it increases lifetime of crucial components and decreases operation and maintenance costs by minimizing the resources required for inspections. For offshore wind farms this holds particular significance since their operation and maintenance costs are typically higher due to factors like the long distance to the coast or challenging weather conditions (Taylor-Smith, 2020). The operation and maintenance costs can also be reduced by minimising both inspections and unexpected major corrective actions and by trying to transition from a calendar-based, corrective maintenance agenda to a proactive schedule based on the real-time behaviour analysis.

According to Taylor-Smith (2020) traditional maintenance strategies rely on maintenance that is planned in advance, carried out at predefined intervals or in response to identified issues. This approach doesn't take into account the real-time status of components, leading to potentially inefficient resource usage. In contrast, condition-based maintenance focuses on repairing components or equipment only when certain indicators signal a decrease in performance or detect an upcoming failure. This enables maintenance to be executed when it is truly needed, optimizing activity planning, reducing logistical and material costs, and increasing overall availability. Moreover, it cuts costs by minimizing the occurrence of severe faults. Monitoring should also be tried to be done remotely as it enhances the operations and maintenance of offshore wind turbines. Remote monitoring aids in cost reduction, heightened reliability of access, and the improvement of health and safety standards for repair workers.

In contrast to other renewable energy sources, hydropower is a more established and widely adopted technology. The likelihood of new investments in hydropower projects is low. The hydro sectors have been slow to embrace the latest technology for operation and maintenance. Despite these challenges, IoT can be used to enhance the efficiency, adaptability, flexibility and competitiveness of hydroelectric facilities. Hydro plants, more than other power facilities, face issues related to aging equipment, leading to costly and unexpected breakdowns. Using IoT for scheduling predictive maintenance enables plant owners to reduce the expenses associated with such breakdowns. Moreover, IoT can be utilized in the automation of plant operations, thus decreasing labour costs (Koon, 2020).

IoT helps in reducing data storage requirements by adding localized sensors. A typical hydro plant transmits data for quantitative analysis, covering parameters like temperature, pressure, water level, power output, turbine rotation and vibration (Koon, 2020). The storing of data in isolated systems poses challenges in integrating the data for decision-making. IoT sensors enable continuous data collection, allowing for more detailed, accurate and real-time analysis, addressing this challenge. As hydropower is the most established and mature sector, the application of IoT will primarily focus on management and maintenance areas.

Maintenance schedules are often created based on historical inspections, and maintenance activities are carried out on a predetermined cycle. On one hand the practice of repairing or replacing components after a fixed amount of time is often unnecessary and leads to the underutilization of equipment life, and on the other hand it creates a risk of not noticing possible breakdowns early enough. Skidmore, Shivakumar & Ward (2019) suggests that the first step to involve IoT in hydropower plants is to collect data continuously, allowing plant operators to analyze the sensor data and make informed decisions. An advantage of incorporating IoT to the system is the ability to combine data that was previously separated and put it into a centralized and organized location through software applications.

Applications of IoT on the hydro sector include for example acoustical analysis, as presented by Skidmore, Shivakumar & Ward (2019). Microphones, replacing technicians who previously listened for abnormal noises, generate machine-specific sound profiles. They trigger an alarm whenever there is a deviation from normal sound levels, having the ability to detect abnormalities, such as headwater level changes and generator unbalance. Another example involves assessing the modifying existing equipment in contrast to installing new equipment, enabling operators to determine the most efficient use of their budget for optimal performance, and a third one involves monitoring environmental factors like weather forecasts or wildlife health when deciding when adjustments should be made.

5 Discussion & Conclusions

The transition towards renewable energy is vital for not only addressing environmental challenges, but also promoting economic and social well-being and sustainable development. Relying on renewable energy sources reduces dependence on imported fossil fuels, contributing to national and energy independence, and a consistent and dependable energy supply encourages economic growth. The aim is to increase the use of renewable energy in accordance with the goals of the energy and climate strategy and the government program. Finland has committed to reducing emissions and since 2014, Finland has exceeded the EU's target for the share of renewable energy in final energy consumption (Grönlund, 2023).

During the research we managed to answer the wanted research questions, and thus the used methodology was successful. We found particular solutions for solar, wind and hydropower but also common results for all of them. We could find many examples from previously done research on how to integrate IoT to renewable energy sources. Multiple sources used similar approaches on how to improve the production of renewable energy by using IoT. We also found other recent advancements in IoT-related technologies and how they might be incorporated as well. We especially took into consideration the reliability and efficiency aspects of renewables, while also addressing the management and security aspects. In the future my research could be used as a coherent reference on the subject.

The importance of renewable energy systems has grown due to their environmental benefits and basically infinite resources. By using IoT it is possible to enhance their utilization even further. With especially the large rise of acquiring wind turbines and solar panels in recent years, we need to make sure that they are used as efficiently as possible. For the more established hydropower technology, IoT could be of aid above all on the maintenance side. But regardless of the application, IoT can help different sectors achieve the common goals of improving efficiency and reliability. Also utilizing other technologies such as edge computing, big data, digital twin and smart grid, data analysis can be done more efficiently in order for the data to become useful information.

IoT helps to make informed, quicker and more efficient decisions based on data. It improves real-time monitoring, problem diagnostics, continuous data collection and analytical processes. IoT can be used to optimise the operation and maintenance, maximise the lifetime and enhance the knowledge about the real performance of systems. The integration of IoT aids in identifying trends and insights from both historical and real-time data (Skidmore, Shivakumar & Ward, 2019). IoT helps in making monitoring, decisions and controls automated, which in some cases is more efficient than when relying on human intervention.

Iot can detect, diagnose and predict faults. It can improve safety and minimize risks, schedule repair and maintenance tasks, and enhance incident management and emergency response capabilities (Taylor-Smith, 2020). IoT helps in minimizing costly and unexpected breakdowns and optimizing maintenance schedules. It enables analysis and operational assessment to be made remotely in real time, providing the ability to react quickly from anywhere if the system doesn't operate optimally. IoT aids in maintaining the health of the power plants and reacting to the environment around them while minimizing wastage.

IoT improves the overall grid management, while also integrating more and more systems into the grid. The use of IoT helps monitor these multiple distributed systems easily. IoT even enables devices that aren't traditionally connected to the internet to be able to communicate and be remotely monitored and controlled. Furthermore, with the ability to interact, appliances can act as a unified system rather than working separately (Ahmed Abdulkadir & Al-Turjman, 2021). Power distribution companies and consumers alike can balance the supply and demand based on the data they gain. An IoT device itself can identify optimal conditions for energy production, adjusting the equipment to achieve maximum output. The possible excess energy produced by consumers can be utilized locally or sold and transferred to the national electricity grid (Ramos & Coronado-Hernández, 2023).

What might be considered a challenge with IoT is the initial investment cost, as various sensors, monitoring devices and data storage need to be integrated to the grid. We also need a reliable electricity source for the systems to function seamlessly, but with the integration of IoT we get exactly that. The primary concern however is probably cybersecurity. When connected to a network without sufficient protection the systems become vulnerable to cybercrimes. We need to improve network security by using for example edge computing and blockchain technologies, and then we can truly achieve an efficient and reliable energy system. In the future, more research should be done in order to ensure a safe, continuous and sustainable energy generation.

The transition from traditional nuclear and fossil fuel–based systems to renewable energy systems involves many changes and challenges, to some of which IoT could be of help. Investing in renewable energy not only encourages technological advancements and innovation but also results in enhanced efficiency, reduced costs and the emergence of new clean energy technologies. By using the Internet of things, we are able to move towards a future of sustainability.

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