CO_2 CAPTURE AND STORAGE IN ENERGY PRODUCTION

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Abstract

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Abstract

Carbon Dioxide (CO_2) – a major participant in the greenhouse effect process. Carbon Dioxide is a blanket, retaining heat on our planet, which would otherwise escape. The amount of CO_2 in the atmosphere and heat are proportional – when the former increases, the latter does the same. For the last few decades the amount of CO_2 in the atmosphere has increased globally by approximately 60% and continues rising by 3,2% per year.

To deal with the problem of climate change, countries should decrease the amount of CO_2 emissions released globally by using renewable energy in housing, transportation, and energy providing. Also, new environmental solutions and technologies should be developed in order to protect the world from the rapidly increasing temperature which will cause more frequent natural disasters, raising in the sea level and can bring harm to the human health.

Carbon Capture and Storage is a technology which is used to capture big emissions of Carbon Dioxide (CO_2) released into the atmosphere from stationary point sources such as power plants and energy intensive industrial processes (pulp and paper, steel and oil refineries, etc.). The technology can be integrated into the combustion of fossil fuels during energy generation, where CO_2 is captured and transported to the “storage bank” in order to isolate it from the atmosphere. The main goal of CCS is the “struggle” against global warming and climate change. The researches and examples of existing CCS systems show the benefits in establishing this technology as it may reduce up to 90% of Carbon Dioxide emitted into the atmosphere from the power generation and other industries. Hovewer, many limitations and barriers exist to implement and develop CCS in the world. The limitations are associated mainly with costs, lack of knowledge and government policies, as well as general public unawareness.

The development of the system is too slow to capture the green market due to the high risks of leakages and human mitakes, lack of governmental supply, policies and financing. The future goals include the distribution of CCS projects all other the world and accordingly the reduction of costs of the interacting the system into the plant. The Savonia student awareness research showed great diversifications in the opinions concerning the necessity and the capability of CCS which is relevant to the current global situation. The analysis is based on the discussions and the answers to question during the Sustainability and Engineering course. The 62% out of 29 students have accepted the CCS system and consider it to be a great and innovative solution for the reduction of CO_2 emissions in the nearest future. Only 28% of all students decided that the technology is too risky and has no future development.

Keywords
Environmental Technology, CCS, Carbon Capture and Storage, Carbon Dioxide, Climate Change, Analysis, Student Awareness, Energy Production, Technologies, Greenhouse Effect, Atmosphere, Intergovernmental Panel on Climate Change, International Energy Agency

CONTENTS

1 INTRODUCTION

Carbon Capture and Storage (hereafter CCS) is a technology which is used to capture big emissions of Carbon Dioxide (CO_2) released into the atmosphere from stationary point sources such as power plants and energy intensive industrial processes (pulp and paper, steel and oil refineries etc). It consists of 3 phases:

- Capturing CO_2 produced by fossil fuel used by industries,
- Compressing it into liquid form for the transportation into geological formations,
- The long term storage and monitoring of CO_2.

For the last few years the amount of CO_2 in the atmosphere has been rising largely and it has caused greenhouse effect on the Earth. To address this problem, new technologies must be created and developed. Institutions of International climate change experts such as the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) have both indicated that CO_2 emissions must be reduced to a reasonable level to limit global temperature approximately by 2 °C to save our planet. This is crucial in creating a sustainable society cause most of our economic activities relies on environmental life supporting systems such land, water and natural resources. Carbon Capture and Storage (hereafter CCS) has emerged as part of the low-carbon technologies for fighting climate change. Unfortunately, because of the lack of adequate knowledge of this technology from the wider population including some policy makers, the implementation of the system is almost impossible because of public opposition.

1.1 Implementation of the thesis project and research method

The theoretical part of the project was implemented by analysing and gathering data from various sources, for example books, scientific reports, journals and internet. The analysis of future effects on the energy is based on the comparison of opinions and information available. The method for analysing the perception of Savonia students is a qualitative, interview-based research. Open-ended interview questions as data collection strategy were used to assess Savonia students' perceptions on carbon capture and storage technologies in the world. Two main research questions were motivating this research:

- What do students in Savonia University of Applied Sciences think about carbon capture and storage technology when the technology is first presented to them? In other words, what are the student's spontaneous reactions to the technology?
- How do their opinions change when provided with more information on CCS and the problem of climate change and energy security?

Data from students was collected as part of Sustainability Engineering and Business course taught by Eric Buah in Varkaus campus. Engineering students were the main respondents in this thesis.

1.2 Skills and knowledge required

The implementation of the thesis required relevant knowledge and information in the fields of:

- Environmental technologies,
- Influence of Carbon Dioxide on the atmosphere,
- Environmental change issues,
- Green energy technologies,
- The theory of CCS and its components.

2 HUMAN DEVELOPMENT AND CLIMATE CHANGE

2.1 Greenhouse effect and human activities

One of the biggest concerns for humanity in today's world is an efficient use of resources. Environmental changes and exhausts of natural reserves have an influence on every person. Annual increase in temperature, overall decrease in health level, difficult relationships among governments, soil erosion are only some causes of climate fluctuations. Main reasons for destructive changes are human activities, for example huge amount of agricultural waste, emissions from transport usage, manufacturing processes, etc. The increase in Carbon Dioxide emissions during significant reductions in forest areas led to the greenhouse effect. (EPA, 2014)

The greenhouse effect is one of the biggest global ecological issues nowadays. Energy the Earth gets from the Sun is absorbed and some of it is radiated back to the space. Though certain types of gases – "greenhouse gases" hold some amount of energy from the Earth in the lower atmosphere and warm our planet. Without the greenhouse effect the possible mean temperature of the Earth would be -15°C. (IPCC, 2012)Thus, the process of absorbing the energy by greenhouse gases is crucial for humans and influences the weather and climate.

The most significant greenhouse gases that absorb the Earth's radiation are water vapour (H_2O), Carbon Dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O) and other gases the impact of which on Earth is not so important. The description of main greenhouse gases and their impact on our planet are listed below. (Live Science, 2016)

Water vapour (H_2O) – natural greenhouse gas which is considered to be most significant for the formation of greenhouse effect. Over a period of years, scientists have debated about the importance of the influence of H_2O on the Earth's temperature. The growth in the amount of water vapour in the atmosphere directly corresponds to the temperature increase. In that case, if temperature changes are caused, for example, by CO_2 emissions – H_2O greenhouse gas evaporates even more causing the heat rise. This regularity seems to be cyclic with no possible end in the nearest future. (NASA, 2008)

Carbon Dioxide (CO_2) – a major participant in the greenhouse effect process. From the beginning of industrialization, for about a period of 200 years a huge rise of Carbon Dioxide emissions was noted by scientists. Besides natural process of CO_2 origin, for example, soil decay, breathing of humans and animals, plant respiration, evaporation from the ocean, different human activities have had a great effect on Carbon Dioxide emissions. The burning process of fossil fuels, increase in the usage of transport modes, manufacturing processes of plants have an inconvertible influence on our planet which has led us to the dangerous level of emissions in the atmosphere. (What's YOUR Impact?, 2015)

Methane (CH_4) – the next gas the emissions of which are the base for the appearance of the greenhouse effect. Same as with Carbon Dioxide, Methane is emitted by natural processes and human activities. Methane is an inherent part of oil and natural gas, so it is generated from all the supply chain processes of natural resources: manufacturing, transportation, storage, distribution, etc. Moreover, landfill is one of the biggest producer of CH_4 emissions, so every person influences the climatic conditions of our planet. (EPA, 2014)

Nitrous Oxide (N_2O) – is not a gas of great influence on the temperature change but still it takes an important part in the greenhouse process. N_2O is mostly created by natural processes, such as chemical reactions in the atmosphere, ocean evaporations and soil vegetation. Human activities that influence the increase of greenhouse effect with Nitrous Oxide are biomass and fossil fuels combustion, farming and transportation. (EPA, 2014)

Nowadays, it is obvious that human activities significantly influence the rise and development of greenhouse effect. The progress of transportation modes and rapidly increasing use of them, industrial processes in different areas, inappropriate waste disposal and agriculture are the main leverage of the climate change on Earth. Nevertheless, all the medium size and big corporations nowadays tend to achieve sustainable use of natural resources in the manufacturing processes in order to produce less emissions. Also, the development of environmental-friendly transport and proper distribution of waste for future recycling offers us a hope for future green world.

2.2 Evidence of global warming

Global warming is one of the most discussed environmental questions. Every day scientists set up a new hypothesis about this issue and refute old ones. Rapidly increasing temperature gives the concern to the population about the future of our planet and people is health. In spite of contradicting information, strong evidence of global warming exists – for the last century the mean temperature has increased by about 0.8 °C, which is a significant change. The definition of global warming and substantial proof of its existence and development are discussed below.

Global warming is a gradual temperature increase which is probably impossible to notice for an ordinary person, although statistics for the last few years demonstrate a clear picture of climate change. Historical sources, meteorological observations, measurements of glaciers' melting speed, other controls and analysis are only some of the instruments which help to identify evidence of global warming.

The first and obvious sign of climate change is the decreasing amount of Arctic Sea Ice and snow cover on mountains. The size of arctic ice covering sea is 13% lower compared to average statistics from 1979 till 2000. (Liberty voice, 2014)

Second factor is the general temperature increase all over the world. As mentioned in the previous chapter, the main reason for changes in climate and accordingly for the rise of mean temperature is greenhouse effect. (Liberty voice, 2014)

Finally, annual tide-gauge measurements give evidence of the existence of global warming. On average, sea levels rise yearly by almost 1.7 millimeters. It is unnecessary to be scientist to understand how huge the change is. Moreover, if the progress will be the same continuously, it will lead to the submersion of most costal cities, for example: New York, London, Miami, etc. (Liberty voice, 2014)

Nowadays, no one doubts the existence of global warming. News cover all the evidence of climate change from temperature increase to the comparison of historic and present-day data. All the information concerning the rapid increase of temperature and global warming process is an alarm for every person to take an action toward the "green" and better world.

2.3 Future effects of climate change

Climate change will greatly affect humans' lives and can cause grave and irreversible consequences. Droughts, hurricanes, significant temperature increase – this is not even a full list of present after-effects of global warming. (EPA, 2014) Nowadays it is only possible to assume what kind of world we will have because of the climate change. According to the former chapter the main circumstances of global warming are:

- natural disasters: more frequent and stronger hurricanes,
- frost-free seasons in agricultural sector: productivity slowdown in tropical and subtropical climates,

- sea level rise: floods of many small islands and coastal territories, migration from flooded areas and "ecological refugees",
- Arctic Sea Ice thaw: significant increase of the World Ocean level, desalination of water,
- harm to the human health: water famine, diffusion of pestilent diseases, increase in number of deaths because of natural disasters and droughts. (Global Climate Change, 2014)

Global warming will have a great effect on lives of some animals, for example, polar bears and penguins will be forced to change the habitat because of disappearance of the ice. Besides, plenty of species of plants and animals will be at the point of extinction because of inability to adapt to rapidly changing climate.

Forthcoming global warming and its circumstances are a huge issue of human survival in the future, so the cooperation of different countries and input of every person are needed. Industrialized countries have a great responsibility for the appearance of climate change process while poor and developing countries suffer from consequences (droughts and natural disasters) because they do not have enough funds to recover or resist it. The spreading of information is an important influencing factor. Unfortunately, most people do not recognise the size of the problem, so, the better delivery of data through news, websites, and newspapers probably will lead to action.

To sum up, the expected climate change will affect human health and the way of life, migration processes and agricultural sector in many countries. Nowadays, there is enough evidence that global warming will cause significant changes in the world in the nearest future.

3 CARBON DIOXIDE AND ITS EFFECT ON GLOBAL CLIMATE

3.1 Carbon Dioxide: background information and definition

Carbon Dioxide (CO_2) is the colourless and flavourless gas which is continually generated in the nature by combustion of organic matters: decomposition of animal and plant remains, respiration, and fuel burning. Gas is an important component of all types of biological resources. According to the available data, the concentration of CO_2 in the Earth's atmosphere nowadays is approximately 0,04%. (Global Climate Change, 2016)

Carbon cycle in the biosphere is a complex chain of reactions. Carbon is literally exchanged between living beings and an inorganic world from one corner of our planet to another. CO_2 moves from the atmosphere and water sphere to organisms of plants and animals, and then back into the air, water or soil. CO_2 is absorbed with plants for photosynthesis. During the photosynthesis part of Carbon Dioxide becomes sugar molecules which are broken up during respiration of a plant and bringing it energy, some – is returned back into the atmosphere. Moreover, Carbon dioxide is emitted by the decay of animals and plants and later used again by plants for the photosynthesis. Human intervention into the Carbon Cycle process leads to excessive gathering of CO_2 in the atmosphere which plants or forests simply do not manage to absorb. So, for this reason a deforestation is too destructive in the modern world. (Earth System Research Laboratory, 2012)

Carbon Dioxide is a blanket, retaining the heat on our planet, which would otherwise escape. The amount of CO_2 in the atmosphere and the heat are proportional – when the former increases, the latter does the same.

Nevertheless, the process of Carbon Dioxide isolation into the atmosphere is not only generated by the natural processes. A breach of Carbon Cycle started from the era of industrialization. Huge amounts of CO_2 are produced as a consequence of human activities. Primary sources of Carbon Dioxide emissions are production, transportation, processing and consuming of fossil fuels. Moreover, an approximate period of gas in the Earth's atmosphere is 50 – 200 years. Accordingly, the sooner actions concerning the CO_2 concentration in the atmosphere will be taken, the better for the future planet and people.

3.2 The way human activities release CO_2

Human activities often lead to the pollution of the environment. Moreover, industrial processes and other activities can increase the level of Carbon Dioxide in the atmosphere and decrease the content of Oxygen. In most developed countries the quality of the air is extremely poor. It is one of the most important environmental problems, which does not only cause the greenhouse effect, but influences locally humans' health and ecosystem of the world. High density of Carbon Dioxide acts as a glass – under the action of sun the atmosphere gets warmer than usual. Besides natural isolation of CO_2, some human activities also contribute as the heating driving force of the atmosphere. (Science, 2016)

CO_2 emissions during the combustion of fossil fuels and cement production are 87% of all carbon output produced by the human intervention. Fossil fuels, such as coal, natural gas, petroleum, are fuels which are composed by decomposition and turned into electricity, heat or power for transportation while burning. All fossil fuels contain carbon to a greater or smaller extent. According to this fact, during the combustion CO_2 is produced as a co-product. As a result, the content of Oxygen in the atmosphere decreases while concentration of Carbon Dioxide rises. (What's YOUR Impact?, 2015)

Heat and electricity are the fields where the greatest amount of Carbon Dioxide is generated. The main fossil fuel used for the sector of electricity is coal – brown or black fuel which mostly consists of carbon and can be found in 50 countries all over the world. Nowadays about 70% of developed countries are provided with the electricity from the burning of fossil fuels, for example coal, petroleum. The industries which mostly consume electricity are paper, pulp, aluminum and cement production. Although people should not forget that electricity is also used for their own needs like heating, lightning, air conditioning, etc. (What's YOUR Impact?, 2015)

Another category of fossil fuel production is transportation. This type of sector uses oil and products refined from it as energy sources. With the increase of transportation, the world's emissions associated with logistics are rapidly increasing year by year. The greatest impact produced on the atmosphere is by road vehicles – about 72% of all transport Carbon Dioxide emissions. The transportation emissions are divided into two groups: direct and indirect emissions. Direct emissions can be controlled by people as normally they choose the distance and the method of transportation. Indirect emissions usually belong to the logistics where it is impossible for consumers to regulate the transportation of goods. Although new electrical modes of transportation are developed, the amount of emissions is still too high. (What's YOUR Impact?, 2015)

The industrial area also has an enormous contribution into CO_2 and other greenhouse gases released by human activities. Manufacturing, mining and agriculture are only some industrial processes which produce Carbon Dioxide in huge amounts. (What's YOUR Impact?, 2015)

Deforestation – the process of cutting down forests in a large scale – is the significant cause of CO_2 emissions. It doesn't only influence extinction of animal species, but the climate change as well. First of all, forests are one of the main absorbers of CO_2 in the Carbon Cycle. Secondly, it considerably increases the level of decomposition, which leads to greater CO_2 emissions. (EPA, 2014)

Unfortunately, the human influence on the climate change is enormous. Evolution led to the industrialization – people burn tonnes of coal, oil and gas in order to get energy, roads are full of cars and so on. The release of excessive amounts of greenhouse gases is the consequences of human activities.

3.3 CO_2 emissions in Finland

Finland is a country in Europe with an area of 338,424 km^2 and population of 5,5 million people. In spite of the quite small size of the country, the economy is highly developed because of a great number of small and large scale enterprises and international trade. The main fields of the Finnish economy are services, manufacturing and primary sector. In Finland there are a lot of industrial organisations which release a significant number of CO_2 and other emissions during the working process. Moreover, for keeping a position in the market, many companies increase outputs which leads to greater emissions. (Statistics Finland, 2015)

The total emissions of Finland in 2013 were 63,2 million tones of CO_2. The greatest share of them belonged to energy production (35%) and consumption during domestic transportation (19%), heating and lightning of buildings, agriculture, forestry industries (all are 9%) and industrial production and construction (14%).

All the industries in Finland demand for huge energy consumption. The biggest amount of energy goes to industries, heating of buildings and transportation. Moreover, nowadays Finland provides various energy systems including oil (23,1%), nuclear energy (18%), natural gas (7,8%), coal (11%) and also high share of renewable energy, for example wood fuels (24,7%) and hydro and wind power (3,5%).

The emissions from domestic transportation mostly consist of road traffic (89%) that includes passenger cars (53%) and transport by trucks and vans (31%). Domestic transportation by rail, air or waterways is not so significant. International transportation is not taken into the account because it is not monitored officially. International air and road carriages significantly increase the level of transport emissions.

Another large sector of energy consumption is housing. About 50% of it is relative to heating and another half – to lightning (30%) and water (20%).

Emissions released from agricultural processes are 10% of all emissions released in Finland. The main actors and processes where agricultural emissions appear from are soil, liming and controlled burning and fuel consumption. (Statistics Finland, 2015)

In today's world many governments are concerned about the process of climate change. New politics and climate policies are developed by World and European Union environmental Organisations. Nowadays Finland has a significant role in climate policies.

One of the main international agreements concerning the decreasing of countries emissions is Kyoto Protocol concluded and brought to enforce on 16th of February in 2005. According to this agreement the EU should decrease the amount of emissions by 8%. Moreover, countries are allowed to release only some amount of gases, if they exceed that level it is possible to "buy emissions" from the countries which have not achieved the maximum allowed amount. Finland is one of the countries in the European Union which took the responsibility to take part in Kyoto Protocol. By the year 2050 Finland is planning to decrease greenhouse gas emissions by 80%. It should be reached by the increasing share of renewable energy and improving energy efficiency. Already now 80% of renewable energy in Finland is provided by bioenergy which comes from energy plants, firewood, biowaste, manure and so on. (Ministry of the Environment, 2013) The area of development in transportation sector is the usage of electricity, hydrogen, biogas or renewable diesel instead of common petrol and diesel. In the housing area new and sustainable energy efficient communities are developed. New houses are built in developed districts in order to decrease transportation emissions and produce the energy locally. Some of already existing green houses in Finland are Zero Energy House, Kantaatti, Villa ISOVER, Tikkurila Commercial Centre Dixi, and future projects examples – Helsinki New Horizons: Viikki, Myllypuro, Kalasatama, etc. (Green Building Council Finland, 2015)

Finland already has experience of introduction of renewable energy into industries and ordinary human lives. Climate policy of the country opens the new opportunities of international cooperation with countries and possible business coordination of sharing the experience and green and innovative technologies. (Ministry of Employment and the Economy 2015, 2015)

4 CARBON CAPTURE AND STORAGE TECHNOLOGY

4.1 Understanding the CCS Supply Chain

Carbon Capture and Storage is the technology of capturing up to the 90% of the Carbon dioxide (CO_2) emissions released by industrial processes of producing energy, for example fossil fuel combustion, and transporting them to the "storage bank" in order to isolate from the atmosphere. (Carbon Capture & Storage Association, 2011) The main goal of CCS is the "struggle" against global warming and climate change.

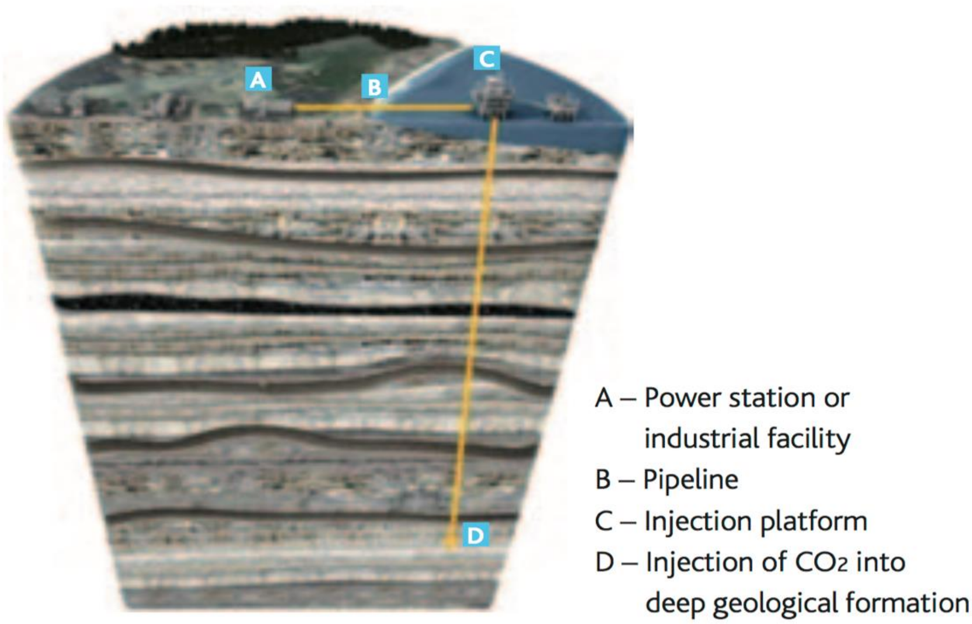

FIGURE 1. Carbon Capture and Storage Process (Global CCS Institute, 2015)

CCS technology involves three main steps:

- Capturing,
- Transportation,
- Storage.

The capture of Carbon Dioxide is implemented during the process of combustion of fossil fuels. Industries in which the possibility of capturing is high are cement, steel, chemicals and other processes that have a great contribution to the releases of CO_2 emissions. (Carbon Capture & Storage Association, 2011) The process of CO_2 capturing consists of separation of CO_2 from other emissions that can also be divided into three steps.

Post Combustion Capture means the isolating process of Carbon Dioxide is done after the burning of fossil fuels. This technology suits for the existing and new power plants. The fuel is injected into the boiler and burned in there with air. This combustion generates the steam for the turbines, which provide energy, and flue gas (gas released into the atmosphere through pipes and flues) consisting of Carbon Dioxide, Nitrogen and water, usually in the form of gas. The next step is the cleaning of CO_2 from Nitrogen and water through special chemical wash. After dehydration and purification, CO_2 is captured and ready to be transported and stored. (ZEP-Zero Emissions Platform, 2011)

Pre-Combustion process includes the processes of removing and gasification, where any fuel is transformed into the composite of Carbon Dioxide and Hydrogen. The system of pre-combustion aims to increase the energy output to a maximum level. The unit of air separation generates pure Oxygen and Nitrogen. Oxygen goes to the gas generator and reacts with the fuel added. The combustion of Oxygen and fuel is called syngas – a composition of Hydrogen, Carbon Monoxide, Carbon Dioxide and water. The next step is converting Carbon Monoxide into CO_2 and Hydrogen by the shift reactor. After that Carbon Dioxide is ready to be captured, dehydrated and compressed. The energy is produced later from Hydrogen which is combusted and used to power turbines. The unnecessary heat produced can be recovered and used to power steam turbines in order to optimise energy output. The system of pre-combustion is already used in chemical plants and housing. (ZEP-Zero Emissions platform, 2011)

The oxy-fuel combustion implies the combustion of fuel not in the air, but in pure Oxygen. An air separation unit removes Nitrogen from the air to get almost pure Oxygen as a result. After, this fuel is injected into the Oxygen for the burning process which generates steam to produce the energy. The flue gas consisting of Carbon Dioxide and water vapour is recirculated for the control of boiler temperature and cooled after. The final step is to capture Carbon Dioxide, compress it and dehydrate. (ZEP - Zero Emissions Platform, 2011)

After the various possible processes of capturing $CO_{2,}$ it is transported to an area of storage. The main modes of transportation are pipelines or ships, so basically the same technologies which are used for transporting oil or natural gas as CO_2 is usually liquefied under the high pressure for the future storage. The best transportation method is chosen according to the destination, area and other factors. (Carbon Capture & Storage Association, 2011)

After the transportation of collected CO_2, it should be stored in geological formations, ocean or ground ecosystems, which are many kilometers down from the Earth’s surface. (Carbon Capture & Storage Association, 2011) There are several storage types for Carbon Dioxide preservation.

Storage of CO_2 in geological formations implies its injection into gas and oil reservoirs which are already used for commercial purposes and is known as Enhanced Oil Recovery technique (EOR). (Rackley, 2009) EOR is the method of increasing crude oil amount extracted from a field. Almost a half amount of oil is left after the primary oil recovery. Carbon Dioxide injections to the oil field help to get dispersed petroleum. An injected CO_2 creates favourable conditions for oil to expand and recover, for example by decreasing tension between crude oil and rock. (Tzimas, et al., 2005) CO_2 is usually located below 800 metres, where it achieves liquid condition. In these circumstances, a sealing rock which is covering CO_2 is highly important for keeping the gas under the ground for a long time.

One more possible way to store CO_2 is to inject it straight into the deepest part of ocean (deep is more than 1000 metres) where the greater amount of gas will be kept for more than 100 years. In this particular case, pipelines or tankers are modes used in CO_2 transportation to the bottom of the ocean through a venting process – the hole in the oceanic bottom that exudes hot water and minerals. Venting is implemented by fixed pipeline or a raiser trailed to the back of the ship. One more option to store CO_2 in the ocean is as a lake of supercritical fluid. (Rackley, 2009) Potential ways of CO_2 storage are shown in the Figure 2. The storage in the ocean is still a theory and has never been experimented. Oceans cover more than 70% of Earth's surface and have an ability to absorb Carbon Dioxide as a result of the natural exchange between CO_2 and water at the ocean surface. (Intergovernmental Panel on Climate Change, 2005)

Nowadays, the Carbon Capture and Storage System is one of the main possible solutions to reduce the significant releases of Carbon Dioxide into the atmosphere. This instrument is a good opportunity for industries associated with power, cement and steel production to continue to operate without any contribution to climate change.

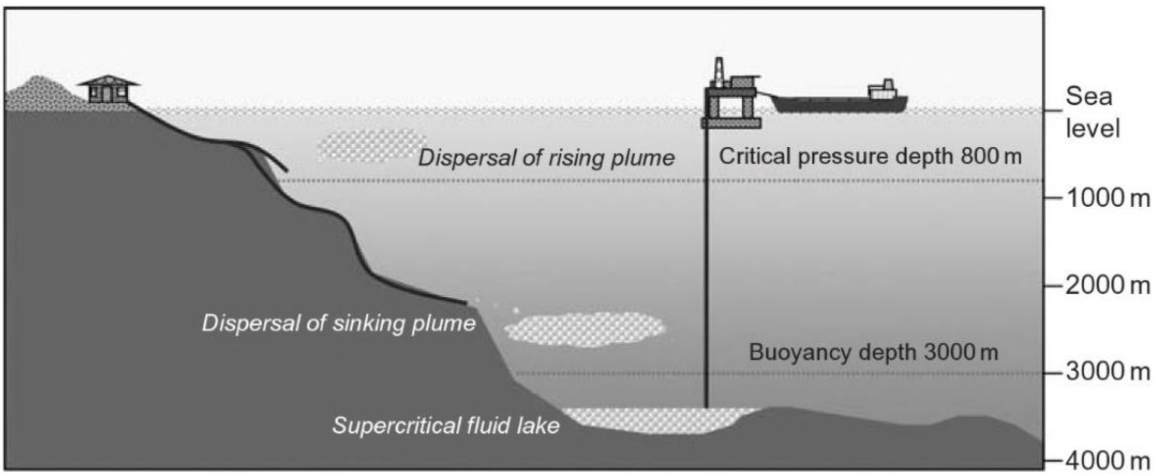

FIGURE 2. Options for CO_2 storage in the oceans (Rackley, 2009)

Mineral carbonation implies the formation of stable carbonates such as Magnesium Carbonate ($MgCO_3$) and Calcium Carbonate ($CaCO_3$ - limestone) as a result of reactions of CO_2 with Magnesium Oxide (MgO) and Calcium Oxide (CaO). Mineral carbonation generates silica and carbonates which are sustainable for a long time, so they can be eliminated to silicate mines or re-used in constructions. The natural process of mineral carbonation itself is slow enough, so it must be significantly accelerated to implement the storage process. (Intergovernmental Panel on Climate Change, 2005)

Also, Carbon Dioxide is widely used in industrial processes, for example in gardening, packaging of food, chemical and biological processes. The stock of carbonaceous industrial products has a possibility to contribute to preventing CO_2 release into the atmosphere. The implementation of the process and its influence on the Earth atmosphere is only possible if the amount and storage of Carbon Dioxide are significant. (Intergovernmental Panel on Climate Change, 2005)

4.2 Main concerns and risks

The assessment of potential environmental influence of the CCS technology usage is essential as the system is associated with the high level of risk. The main possible hazardous outcome of the CCS project is the leakage of CO_2. The expected behaviour of Carbon Dioxide must be analysed in the very beginning when the project is planned. The risks connected to CCS system should be considered on national and international level. The benefits of Carbon Capture and Storage must prevail the potential environmental risks.

The majority of concerns that arise from the development of Carbon Capture and Storage are based on the long term storage of the captured Carbon Dioxide. The possibility of the unexpected or gradual leakage of CO_2 distract the attention from benefits of this system. The consequences of possible CO_2 leakage can be catastrophic. (Anon., n.d.)

The sudden leakage of Carbon Capture during its storage is the greatest fear and can even lead to people’s deaths. This particular problem is possible in a case if the well seal will fail during the storage of CO_2. Moreover, some concerns are based on the analysis that prove the possibility of seismic events because of the pressure involved. Another point of view, CCS places can become the target for terrorist attacks due to the immediate terrible results after a sudden leakage. (Anon., n.d.) All the information discussed above shows the evidence of the importance of choosing a proper location site for Carbon Storage to minimize risks.

The gradual leakage of Carbon Capture stored makes the whole idea and the aim of the CCS system meaningless. The problem of incremental release of CO_2 can occur due to the poor analysis during the selection process location. Greenpeace (non-governmental environmental organisation) states that the process of storage location choosing must be implemented on case by case basis because of the complexity of geological formations. Unfortunately, nowadays there is no proof that the storage well and "the shelter" of Carbon Dioxide will remain the same for a long period of time. (Anon., n.d.)

Figure 3 shows the possible ways of CO_2 leakage to the atmosphere that will result as isolated, catastrophic events (earthquakes), chemical change in ground (drinking) water, displacement of fluids in the underground reservoirs (salty brine water can flow into the drinking water).

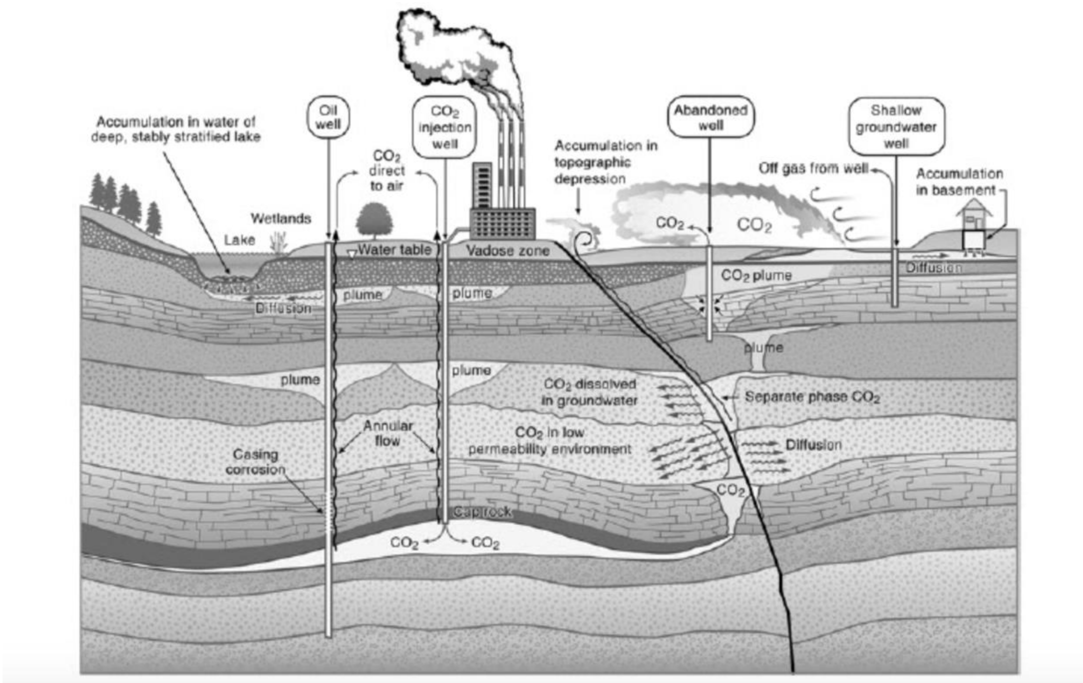

FIGURE 3. Possible ways of Carbon Dioxide leakage to the surface (Global CCS Institute, n.d.)

Unfortunately, nowadays there is no experience in the world associated with the leakage of Carbon Dioxide during the human-made storage as the CCS is still not developed. However, it is possible to draw the parallel with the existing examples of leakages of natural occurring CO_2 from the underground reservoirs. One of the greatest examples is the sudden release of Carbon Dioxide from Lake Nyos in Cameroon. During the long period of time, waters of the lake were saturated with Carbon Dioxide from the volcanic discharges. Suddenly, during one night the lake released a great amount of CO_2 and covered the suburbs that led to the death of 1700 people. Another example is related to the gradual and continuous release of naturally occurring Carbon Dioxide from the Mammoth Mountain in California. The CO_2 was released constantly for 15 years in small amounts killing all the nature around and altering the soil and water chemistry in this region. Existing examples of leakages were mainly because of the highly fractured volcanic zones where Carbon Dioxide was located. Thus, Lake Nyos and Mammoth Mountain examples prove the importance of detailed analysis of the storage location as it causes and influences not only the nature, but human lives. (Global CCS Institute, n.d.)

The possible influence scale of Carbon Dioxide leakage can be viewed from two different points – global and local risk aspects as shown in Figure 4. As stated above, the local risks mainly cause natural disasters, for example earthquakes, and the pollution of the groundwater. While the global risks are considered to be the overall natural disasters because of CO_2 releases straight to the atmosphere. The global influence of the leakage is mostly associated with the amount of CO_2 released and its speed.

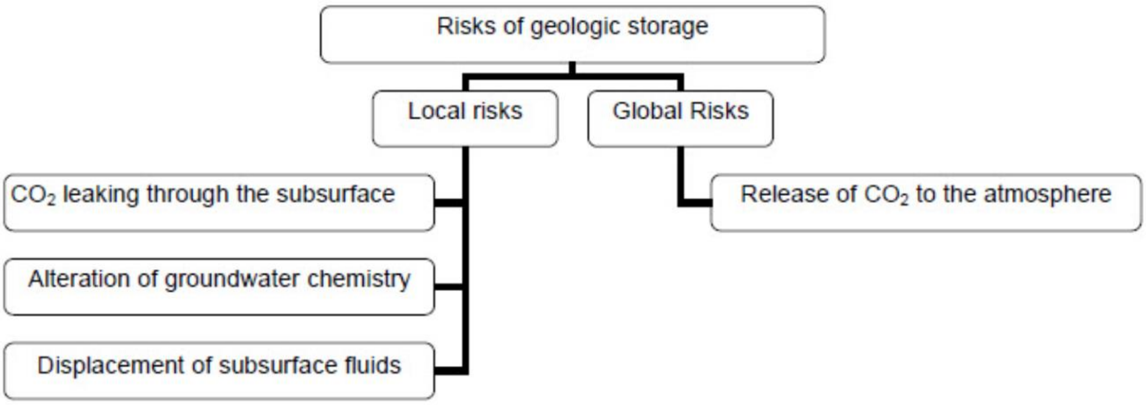

FIGURE 4. Level of risks associated with CO_2 storage (Global CCS Institute, n.d.)

The main concerns of CCS projects are also concentrated on other potential risks that should be known and considered while designing the system. First of all, the CO_2 storage can disturb the normal life of plants and animals below and above the ground. There are some specious of microbes or insects under the ground that are able to live only in special environmental conditions, so injected CO_2 will kill them. Moreover, the Carbon Dioxide storage can obstruct the respiration of roots by displacing the soil oxygen that is essential for plants to function normally. Secondly, another concern consists of the acidification of soil that will not only directly influence the wildlife but also can indirectly result as the increase of toxic metals. Finally, from the point of ocean storage of Carbon Dioxide, the possible impact in this area will affect the benthic zone – the environment at the lowest level of an ocean. All the plants and animals living in the benthic region can be injured because of the particular amounts of Carbon Dioxide.

The Carbon Capture and Storage risks directly affect lives of plants, animals and people. Sudden or gradual leakages lead to irreversible consequences and can eliminate all the benefits and the overall idea of Carbon Capture and Storage systems. Nevertheless, all the risks and details must be considered while designing the system and discussed as future problems can be prevented by deep and serious analysis. Moreover, establishing the CCS system in a particular site, all people living nearby must be warned about all possible risks and their opinions and concerns should be taken into consideration as well. Fortunately, with the development of monitoring and leakage recovery systems, planning, managing and evaluation of risks is easier to implement. (Global CCS Institute, n.d.)

4.3 Development and existing CCS systems

The Carbon Capture and Storage system is the hope for human-beings to prevent the climate change or at least decrease its pace. The development of CCS projects is quite slow due to the insufficient popularity of the system, lack of information and no financing from governments. However, nowadays already some small and large CCS projects exist, which help to prove the possibility of the development of this area in the future.

4.3.1 Boundary Dam Carbon Capture Project, Saskatchewan, Canada

The Boundary Dam Carbon Capture Project is the first and biggest commercial-based CCS system in the world. The project is integrated with the Boundary Dam Power Station (lignite and brown coal), and mainly aimed to decrease the emissions from power generation with the help of Carbon Capture and Storage system. The project was launched in 2008 with the support and financing from the Saskatchewan Government responsible for the capturing and Cenvous Energy that has built the pipeline for the Carbon Dioxide transportation to the well owned by the Power Station.

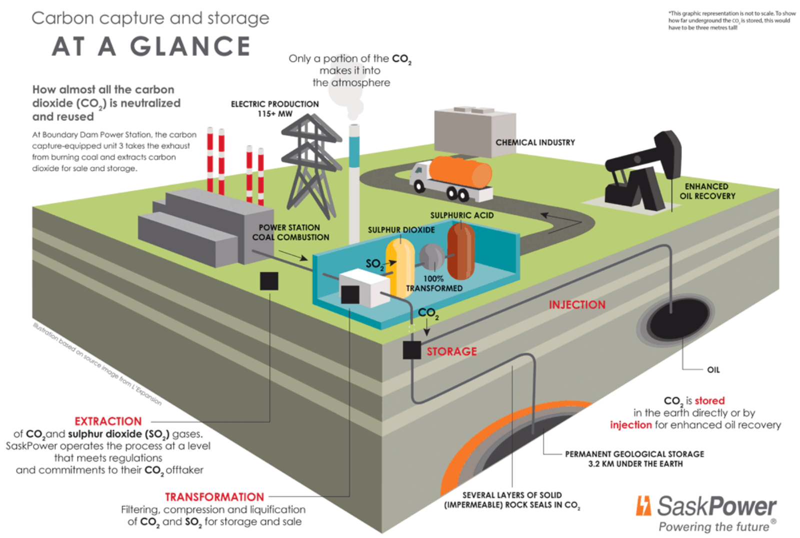

FIGURE 5. The process flow of CCS at the Boundry Dam Power Station (SaskPower, 2015)

Carbon Capture and Storage system installed at the Boundry Dam Power Station allows to reduce about 1 million tons of CO_2 per year which is comparable to removing up to 250000 cars from roads in Saskatchewan, Canada. (SaskPower, 2015) Figure 5 shows the overall process flow of the emissions utilization with the help of CCS at the Boundary Dam Power Station. During coal burning at the power station, the emissions are caught and sent to the extraction point where Carbon Dioxide and Sulphur Dioxide (SO_2) are educed. The plant is using the Post Combustion technology where the isolation of CO_2 is done after the burning of coal. During the transformation process CO_2 and SO_2 exhausts are separated and provided for future storage and sale. Sulphur Dioxide is transformed to Sulphur Acid (H_2SO_4 strong corrosive mineral acid with the great application in domestic acid drain cleaners) and sold to the chemical industry. Carbon Dioxide is sold further to Cenvous Energy for the injections for enhanced oil recovery or for the long-lasting storage in the solid rock seals 3,2 km below the surface of the Earth.

Nowadays countries all over the world determine the strict regulations on releasing CO_2 emissions into the atmosphere. The Boundry Dam project is the leader in the development of CCS system which helps the power plant to capture almost all CO_2 exhausts from coal burning. Started in 2008, the project is still successfully in run and is an example of a future solution for climate change.

4.3.2 Sleipner CO_2 Storage Project, Central North Sea, Norway

Sleipner CO_2 Storage Project is another offshore large-scale system located in Europe, Norway. The system was built in September 1996 and mainly consists of the capturing of CO_2 during the natural gas processing from the Sleipner West field and transportation directly to Utsira Formation in the Central North Sea. (Global CCS Institute, 2015)

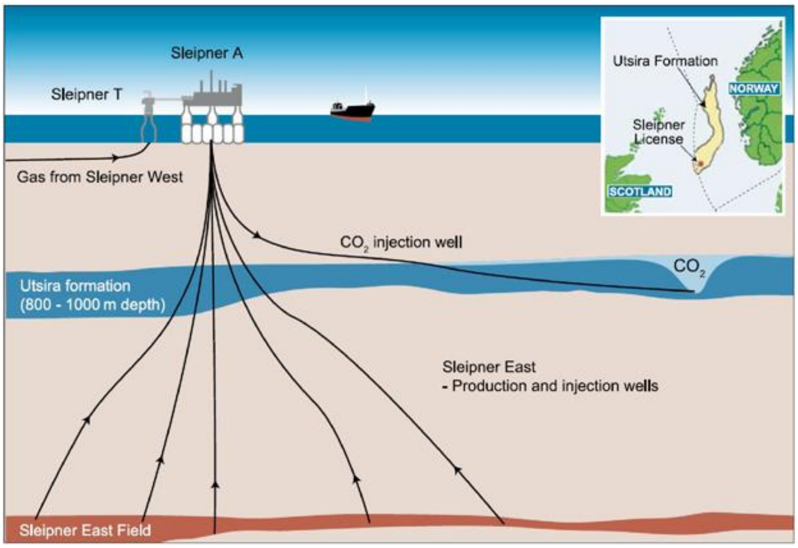

FIGURE 6. Sleipner CO_2 Storage Project Process Flow (Global CCS Institute, 2015)

According to the latest data, approximately 10 Mt of Carbon Dioxide was captured and stored for the operating period of Sleipner Project. Figure 6 shows the simplified capturing and storage flow of the system installed on an offshore platform in the North Sea. CO_2 emissions are isolated from the natural gas, compressed and transported through pipelines into the Sleipner A, where they are injected into the Utsira Sand Formation which is 1000 m below the Field. The method of the capturing is Pre-Combustion where the natural gas is transformed into the composite of Carbon Dioxide and Hydrogen. (Global CCS Institute, 2015)

The Sleipner CO_2 Storage Project is one of the first CCS systems where the usage of the deep saline reservoir is applied. The project installation was forced because of the increasing emissions taxes on CO_2 emissions per ton applied by the Norwegian Government in 1996. The project is financed by many organisations and the European Union and constantly monitored through up-to-date 3D and 4D survey programmes. The Carbon Dioxide, which is extracted from the natural gas, compressed and later injected, is almost pure, only 2% of all injections contain Methane (CH_4). (Global CCS Institute, 2015)

4.3.3 In Salah CO_2 Storage, Krechba, Algeria

The CCS project in the industry of natural gas processing is located in Algeria, North Africa. The onshore system was launched in 2004 by a joint venture of BP, Sonatrach and Statoil companies. In Salah there are seven gas fields in the southern Sahara Desert which have the production capacity of about nine billion cubic meters per year. (Global CCS Institute, 2015)

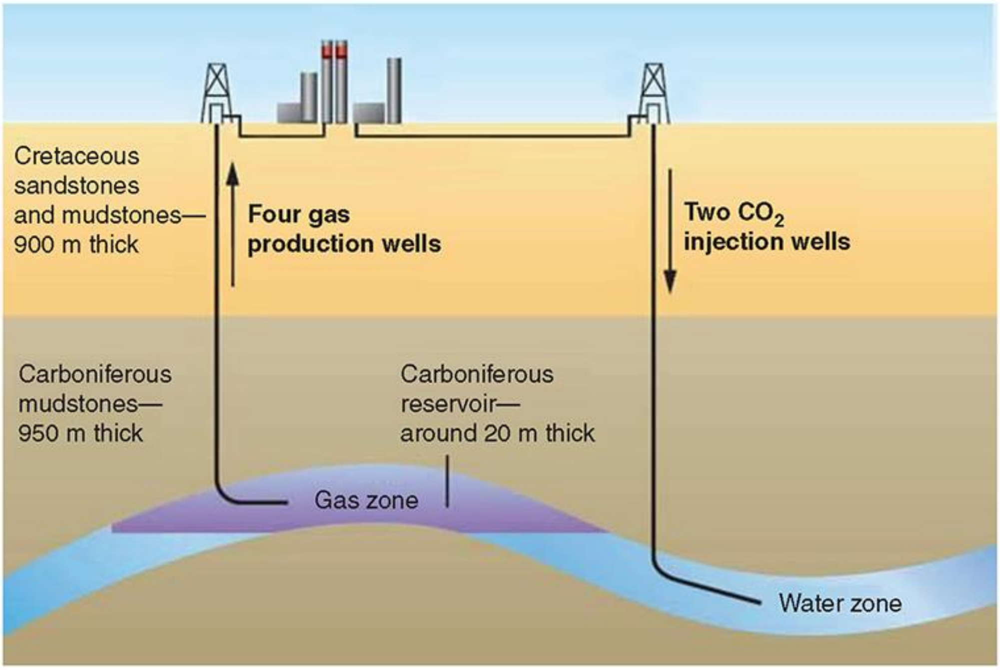

FIGURE 7. In Salah CO_2 Simplified Process Flow (Henni, 2016)

Figure 7 shows the simplified process flow of CCS in Krechba, Algeria. The method of capturing used is pre-combustion process same as in the Sleipner CO_2 project in Norway. Approximately 7% of Carbon Dioxide is contained in the natural gas in Salah. The main motive for this project establishment was the requirement of the government concerning emissions. Carbon Dioxide with the purity of 98% is captured and injected into a similar geological formation from where the natural gas is extracted. The injection well is located 1000 meters under the surface. The project is well monitored with the help of various systems such as geochemical and geophysical equipment. (Global CCS Institute, 2015) Moreover, according to the many articles, the project is sponsored by the Center for Energy and Sustainability that invested 25 million dollars into the development of Carbon Capture and Storage in the Middle East. (Henni, 2016)

4.3.4 Other examples and developing systems

Alongside the large existing CCS systems all over the world, there are the development of small and planned projects. Unfortunately, some of the projects have been closed due to the lack of funds or support from the government. One of the most popular examples is the tender project launched in 2007 and lately cancelled in 2011 by the United Kingdom. BP, EON UK Plc, Peel Power Limited and Scottish Power Generation Limited were among the candidates to win the tender process. However, in 2011 companies were not able to find the accord with the UK government on project costs and implementations. (Department for Business Innovation & Skills, 2007)

The largest existing and planned CCS projects are reflected in the Appendix 1 which provides the summary information of countries, years and the industry of operation from where Carbon Dioxide is captured.

The survey conducted by the Global CCS Institute states that the development of CCS projects is too slow for the significant climate change and always faces the problem of insufficient financing or too high costs. That is why plenty of projects were shut down. (Romm, 2013) The New York Times says: "…the technology for capturing carbon has not been proved to work on a commercial scale, either in the United States or abroad. The Energy Department canceled its main project demonstrating the technology in 2008". (The New York Times, 2013) Although, some of the projects are really successful and prove the possibility to store almost all the emissions from the production, the lack of the knowledge and high risks associated with leakages prevent the growth of this system to grow.

5 THE EFFECT OF CCS ON ENERGY PRODUCTION IN THE WORLD

5.1 Sustainability and the role of energy

The term sustainability means the ability of the environment to resist the harmful human activities. Sustainability for people implies the support of the standard of lives and health of every person. It involves ecological, economic and social development and stability of the whole world. (Thwink.org, 2014) Nowadays, the manufacturing actions and the development of transportation are the primary sources of pollution imposed by humans. Various chemical substances received from the production wastes directly influence the environment and the health of people, plants and animals. Many researches and surveys prove that the excessive use of natural resources by humans leads to unavoidable ecological and economic problems in the future. (What's YOUR Impact?, 2015)

To be sustainable is the ultimate goal for responsible businesses in today's world. Many companies state and explain their sustainability policy in annual reports. Modern production facilities or businesses aim to decrease the amount of emissions in order not to bring harm to the environment and to achieve the economic stability of the company and accordingly of the whole country as well.

The growth of energy is directly connected to the ecological and economic sustainability in countries. The growing demand for energy implies the development of manufacturing, transportation, economic changes and other factors. The effect of energy is ambivalent – it makes our life better and helps the economy to grow and indirectly influences harmfully the health of people, climate change and brings diversification to countries' growth levels. Despite the negative effects of energy on the environment, the energy consumption grows year by year and does not cause anxiety for the general public in the world. This issue is mainly resulted from the ignorance or unawareness of facts or predictions. Even knowledge of the problem does not suggest a possible solution avoiding global warming. The renewable energy (biomass, solar, hydropower, etc.) is still in the developing stage and cannot yet replace or decrease energy consumption. (Carnegie Mellon University , 2001)

Energy involves a combination of different sectors which supply the economy of the country with energy sources. Examples of these sectors are electric power and fuel industries including the investigation, reclamation, production and transportation of energy sources. With the help of today's world observation, it is possible to state that countries which possess the energy sources are "suppliers" and developing countries are mainly "consumers" of energy. The main source of energy is oil which has displaced other fuels, for example coal. (Carnegie Mellon University , 2001)

Energy production, processing and usage directly affect the sustainable development of humans. Carbon Capture and Storage system is one of the possible solutions in spite of high risks and costs. Although countries and the whole world are concerned about the current problem of fast climate change, the financing and the development of new systems such as renewable energy, CCS or Carbon Capture and Utilization is too slow to change the situation immediately, even in a decade. Unfortunately, the climate will not wait for ages.

5.2 The effect of CCS on energy and production

During the period when the energy sources and consumption such as oil or coal are essential for the ordinary life of every person, Carbon Capture and Storage system is a significant innovation and a solution. The main benefit or the idea of CCS is that this project allows to remain the production and power generation capacity with the lowest emissions possible. As stated earlier, the renewable energy sources which exist today cannot fully replace the energy produced. Moreover, CCS is aimed to reduce CO_2 emissions not only from power generation or gas industries but it is applicable to bioethanol and hydrogen production. Many industries are well suited for the introduction of CCS, especially where Carbon Dioxide is easily captured and isolated. As existing projects show, the CCS capturing process enables to store the 98% pure CO_2 with 2% of other inevitable impurities. (Center For Climate Change And Energy Solutions, 2012) Although, for electricity generation processes, the establishment of CCS system can cause problems as the whole system must be changed and renewed in order to capture and transport CO_2. Moreover, although people are concerned about the climate change, many researches show the stable future growth of the fossil fuels usage for the energy production. So, CCS is theoretically a great decision in order to decrease emissions by approximately 90%. (Center For Climate Change And Energy Solutions, 2012)

Besides, the European or other governmental policies on Carbon Dioxide emissions prove the attention to climate change problem. It means the possible future investments into fossil fuels the extraction and usage will be decreased and it will be mostly targeted at green or new energy technologies such as CCS.

Even if the development of CCS is too slow and mainly because of the lack of funds, more and more people get interested in this possibility and are ready to support it. Different CCS institutions already exist all other the world and follow the current situation of the development of future projects. Also, CCS projects and analyses were discussed and covered in various sources including The New York Times and The Economist. Unfortunately, the future of CCS is still undetermined as the system implies many limitations and high risks.

To cover all above, CCS has the right to exist and surely must be taken into account as a possible solution for climate change. Compared to renewable energy, CCS system allows to save production capacity and reduce about 90% of CO_2 emissions at the same time. Public opinion exceedingly differ as the system is a great solution but with a lot of hidden dangers. Nevertheless, it is possible for the system to develop if the existing and future projects all over the world will be successful and fruitful.

5.3 Possible future of CCS

International Green Agencies and CCS Institutions are planning the development and the implementation of future projects for few decades. Being associates, they set the goals and see the high growth of this system. The Figure 8 shows the goals by years set for the CCS development in the world.

The first goal must be implemented by the year 2020 and involves the 30 operating CCS projects all over the world in different industries – power generation, gas processing, refining and so on. The implementation of this goal means that the projects being executed and planned will be successful and the existing ones will not be shut down. Moreover, the aim includes the financial support from governments and other institutions, although almost all of the current systems are commercially funded.

By the year 2030, the CCS institutions aim to develop the current projects and create new ones in many industries such as cement or iron manufacture where the establishment of CCS involves funds and a complete change of the equipment.

The target for 2050 is to use CCS widely in all applicable industries without exception. The ultimate goal by that time is to reduce Carbon Dioxide by approximately 7000 Mt per year which is 1/6 of total CO_2 emissions in 2050. (International Energy Agency, 2013)

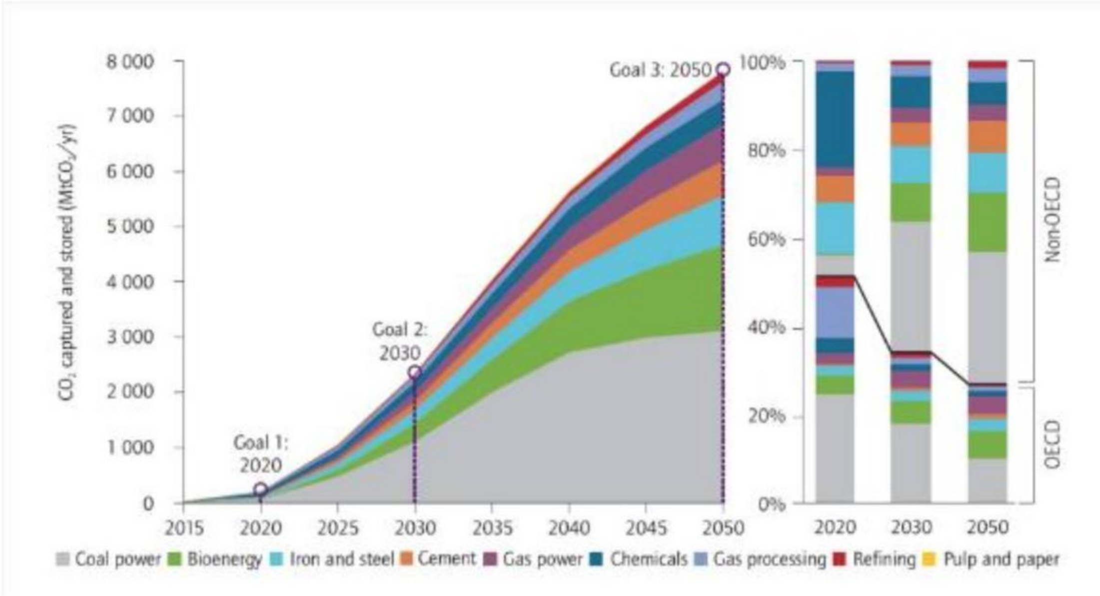

FIGURE 8. Future goals in the development of CCS (International Energy Agency, 2013)

The main actions that should be applied to implement all the three goals of CCS development till the year 2050 are:

- Financial support
- Governmental policies towards the development of this system
- National laws and regulations
- General public awareness and interest
- Costs reduction. (International Energy Agency, 2013)
-

All the stages above are the key elements for the successful future of Carbon Capture and Storage projects. Thus more practical knowledge and promoting it to the public and government will determine the successful development of the system everywhere. Unfortunately, nowadays goals seem to be unrealizable because of the various limitations and high costs.

5.3.1 Limitations

Unfortunately, the benefits of Carbon Capture and Storage create even more risks and limitations than opportunities. In order for the system to work the analysis should show the efficiency and the favor of this projects that has not been proved yet. As the system must be established from the beginning and it involves many steps from the transportation to monitoring and immediate action in case of leakages, it means even more energy consumption for the enterprise than usually.

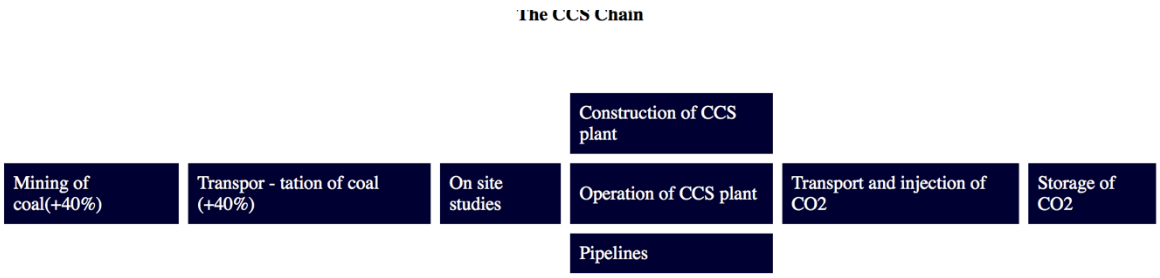

FIGURE 9. The simplified CCS supply chain (CCS Info, n.d.)

Figure 9 shows the integration of Carbon Capture and Storage into a coal power generation enterprise. It states that the CCS will involve additional energy consumption in mining and transportation process of approximately 40%. So huge rise in energy consumption will accordingly low the CCS efficiency from 85% to 70.5%. (NOAH Friends of the Earth Denmark, 2009)

Moreover, the development of the system is too slow to capture the "green" market. Unfortunately, governments do not create a favorable atmosphere for CCS establishment, so immediate action is needed. In this case, the favorable atmosphere implies rules and regulations allowing the existence of the system, lower costs and the promotion of the system to people for additional financing. Vaclav Smil, a Czech scientist stated at the energy conference that: "Sequestering a mere 1/10 of today's global CO_2 emissions would thus call for putting in place an industry that would have to force underground every year the volume of compressed gas larger than or (with higher compression) equal to the volume of crude oil extracted globally by petroleum industry whose infrastructures and capacities have been put in place over a century of development. Needless to say, such a technical feat could not be accomplished within a single generation". (Romm, 2013)

Public unawareness and concerns also play a crucial role in the life of CCS. As this system still is not completely studied and all predictions and benefits are mostly theoretical, the general public prefers not to take actions or finance the projects. So, the system cannot be fully analysed because of insufficient practices, high risks of leakage and bad influence of Carbon Dioxide storage on the surrounding environment, knowledge and funds. The Figure 10 shows the main technological and financial problem caused by human mistakes or sudden leakages.

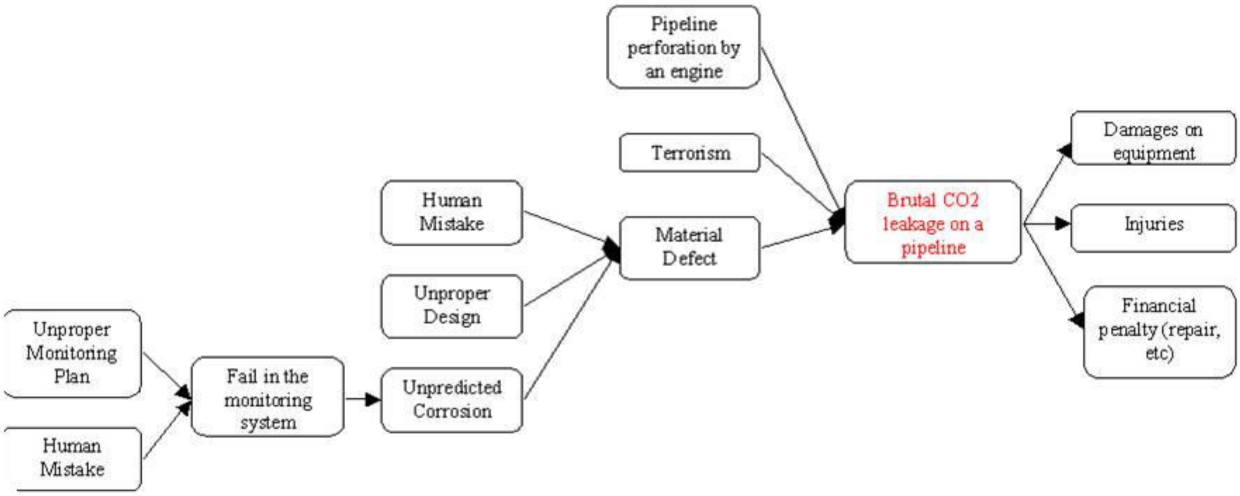

FIGURE 10. The main risks associated with CCS project (ISIGE, 2010)

5.3.2 Costs

The successful operation and the development of CCS in the industry requires increased investments in technologies. As stated in previous chapters, some of the industries can easily be transformed into CCS, and for others this process will demand to build new facilities. Main costs connected with the CCS system integration include:

- Capturing technologies,
- Desired amount of CO_2 captured,
- Type of the industry,
- Transportation distance to storage,
- Type of the storage location.

In a perfect CCS costs curve, the cost of first and new established projects will be higher than subsequent ones. The main possibility to lower the costs is to sell the captured Carbon Dioxide which will reduce risks of investing in the system. Moreover, enhanced oil recovery, which is mainly used nowadays, gives the opportunity to utilize captured CO_2. (Center For Climate And Energy Solutions, 2013)

Costs of CCS are considered to be the main barrier for the distribution of projects. The researches of existing projects show the inefficiency of commercial operation of CCS. (Romm, 2013) First of all, the CCS market is undeveloped due to the limited progress and the cancellation of many of planned projects. There are no national or international regulations and policies concerning the CCS implementation, as well as no government funding and support. Moreover, the lenders almost have no interest in the financial support to new unproved technologies and demonstrating the real efficiency and the success of CCS today is very difficult. The project also includes high risks and uncertainties which are impossible to assess while CCS is not widely practiced. Also, the cost structure itself is complicated to predict and mainly based on the industry. Operational and capital costs of the creation or integration CCS are still unknown, so nowadays many consumers of the system simply cannot afford it. (Global CCS Institute, 2011)

One of the main limitations to build a CCS system is costs and effects on energy price. The illiquid market, too high risk of leakage and new unproven technologies, lack of knowledge and the great diversification in opinions concerning CCS future – all prevent governments and investors to finance projects.

5.4 Political influence on CCS

In today's world the political influences in all areas of technological developments, Carbon Capture and Storage is not the exception. The political concern of the exceeded Carbon Dioxide emissions has had a positive effect on the development of CCS. The Kyoto Protocol based on the United Nation convention that regulates the amount of gases released and creates the future emissions policy, has been concluded because of the governmental concerns about the climate change. However, the CCS technology is considered to be a supplemental technology for CO_2 exhausts to the atmosphere, not a direct solution to the problem. (Stephens, 2006) That is why governmental support for the technology is not sufficient for its successful implementation and distribution.

Environmental innovations mainly depend on governmental support. The help from governments is directly connected to the location and the resources a country possesses. As a consequence, the governmental policies and financial supports varies globally. The United States is the leader in the governmental support of CCS technology. The goal of the country is not to reduce the growth of Carbon Dioxide emissions, but better support the development of new technologies. The European Union also helps the increase of CCS technology. In previous years, European governments have financed some CCS projects and especially R&D processes (Research & Development). (Stephens, 2006) Nevertheless, with the development of the renewable energy sources, CCS has moved aside from the point of governmental support and funds.

Another political aspect is the influence of current actions in the world to the economic stability of countries. It involves the great distrust among countries in many issues. For example, the suggestion of the Russian government to sequester the Carbon Dioxide emissions on its territory for money, cause dissenter opinions due to the high level of bribery and no political trust in this country. The main problem is that there is no certified monitoring system in the geological formations where CO_2 is stored, so the technology implies a lot of uncertainties and disbeliefs. (Romm, 2013)

5.5 Summary

Nowadays it is difficult to predict the future development of Carbon Capture and Storage. The system proposes undisputed benefits while the high risks and uncertainties frighten a lot of people from investing and voting for these projects. On the one hand, theoretical analysis and commercially-based existing projects show the capability of the system to reduce and store up to 90% of Carbon Dioxide which in the future will lead to an approximate capturing of 1/10 of total amount of CO_2 emitted into the atmosphere. On the other hand, governments and public do not show great interest in the system because of high risk of leakage or human mistakes that will bring even more costs and problems. Moreover, missing financing aid from lenders interfere new projects and so the development and growth of CCS.

6 AWARENESS AND PERCEPTIONS OF SAVONIA STUDENTS

One of the barriers for the development of CCS in the world is the public unawareness of climate change problems and possible solutions. Due to the slow development of CCS, this technology is almost unknown for the general public who is not deeply interested in technological systems that can help to reduce CO_2 emissions globally. In order to analyse the awareness and the perceptions of the general public, conducted a research in cooperation with the Savonia University of Applied Sciences. The aim of conducted research was to follow the process of familiarization of Savonia students with the CCS technology and to evaluate their personal opinions and perceptions as an example of public opinion.

During the course of Sustainability and Engineering held by Eric Buah, the lecturer and doctoral researcher, the students were familiarized with the world's solutions of Carbon Capture and Storage. The group of students consisted of participants from France, the Netherlands, Germany and Russia. The total number of students attending the course was 29, and all the students had a common program of study – Industrial Engineering and Management. A detailed table of all the participants in the research, where all students are grouped by the nationality, is provided in the Appendix 4. Figure 11 shows the proportion of all participants by gender.

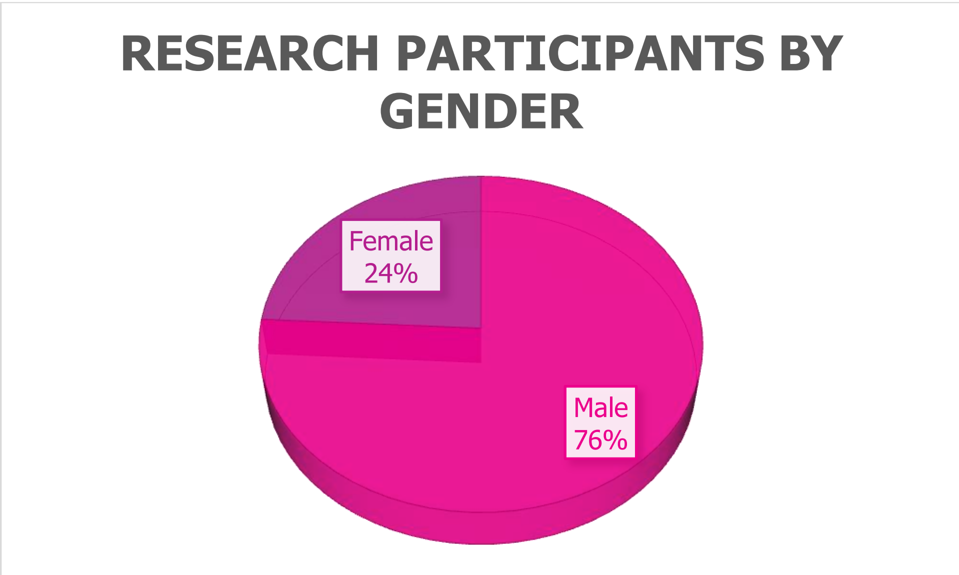

FIGURE 11. The relation of participants by gender

During the course the following issues were discussed:

- Fossil fuels,

- Renewable energy,
- How “black” energy may be “green”,
- Carbon emissions,
- Environmental changes caused by the emissions,
- Possible solutions (carbon capture and storage).

All the students had been studying studied at least for three years in the Engineering Department, so they already had the preliminary knowledge in Environmental technologies. However, in the beginning of the course most students either did not know anything about the CCS or had some overall information regarding the topic. The study process included lecturing and active open discussions (example is illustrated in Picture 1), which played a crucial role in understanding the issue. As soon as the topic was clear to all the participants of the course, it became possible to analyze the problem, define their personal attitudes to an environmental solution such as CCS, and evaluate its impact and possible consequences.

PICTURE 1. Open group discussion during the Sustainability and Engineering course

In the beginning of the research, the students were asked to find information about the CCS technology and comment on their first impressions and opinions concerning this innovation. The questions provided to the students were:

- Should fossil fuel-based energy be allowed to be part of the future world in addition to renewable energy, if the world can develop a new technology that can make burning fossil fuel cleaner and safe for the planet and people?
- What is your opinion about having carbon dioxide stored in your backyard? (Buah, 2015)

According to the answers of the preliminary student opinions, most of the students do not see the future of energy without the usage of both – fossil fuels and renewable energy sources. Moreover, the majority of the students is not against the storage of CO_2 in their backyard. Although some of the participants were concerned about the high risks and the possibility of leakages, so they have refused to accept CCS technology.

After the preliminary research of students' perception, additional information about CCS was taught by the lecturer – Eric Buah. Most of lessons were conducted in the way of discussions and tasks. The students identified several advantages and disadvantages of CCS. Due to the fact that the technology is relatively new, it requires high development expenses and at the moment is not very reliable. The method would raise the electricity costs at the range of 20-100%, and seemed dangerous to the students as far as the CCS technology is not appropriately tested yet. Moreover, some students suggested that CCS is not a solution itself, but just a method to delay of the problem which allows to win more time for finding a real solution research. Another group of the students considered CCS to be a reliable, effective and safe solution in a long term. According to the scientific researches in the field, the possibility of a disaster is 0,01%, which means that the technology is safe and it is just a matter of time to identify its reliability in practice. Moreover, Carbon Capture and Storage may have positive implementation in the Netherlands specifically. In the province of Groningen (the north part of the Netherlands) there is a huge area of natural gas which is currently being pumped out. As a result of this natural process, earthquakes take place in that part of the country. Some students considered that Carbon Capture and Storage might replace the gas in the ground and would prevent the ground from "collapsing" and prevent the earthquakes. This means that CCS may solve one of the major political problems in the country.

In the end of the course another part of the research was carried out. The opinion of students concerning CCS technology in the energy future was evaluated again after the additional knowledge received by reviewing the answers to the questions:

- Given the discussion we have had in the class concerning CCS, do you wish to change your overall reaction to carbon storage than what you first thought about the technology, which you told in the beginning of the course?
- According to the answer to the first question, would you still like to store the Carbon Dioxide in your backyard if it is the only perfect place?
- According to the questions above, will you support CCS in your country or not?
- As you learnt in class, to ensure that Carbon capture and storage project do not cause any big problems to human health and environment, it requires strong commitment. Who do you think should control and monitor the development of Carbon Storage? (Government/Energy industry/Local government/Environmental Organisa-

tion/Environment Agency/Citizens/the European Union/End Consumers) (Buah, 2015; Buah, 2015)

Despite the conflict between the advantages and disadvantages, defined by the students, 62% of the course participants supported CCS technology. Around one third of these 62% mentioned, that they would even agree to store the carbon "in their backyard". The other 28% of the students supposed that CCS is not safe and is too expensive to proceed on, and there should be other technologies to be developed instead. Other 10% of students could not define their exact opinion of the technology and its future. Figure 12 provides the final results in percentage. Nevertheless, the course participants showed clear understanding of the fact that continuous use of fossil fuels prevents the world from thinking of renewable energy, and that even though CCS is not the best solution (or not even a solution), the Carbon Capture and Storage is one of the few options how to prevent or delay the greenhouse effect and influence the environment in a positive way.

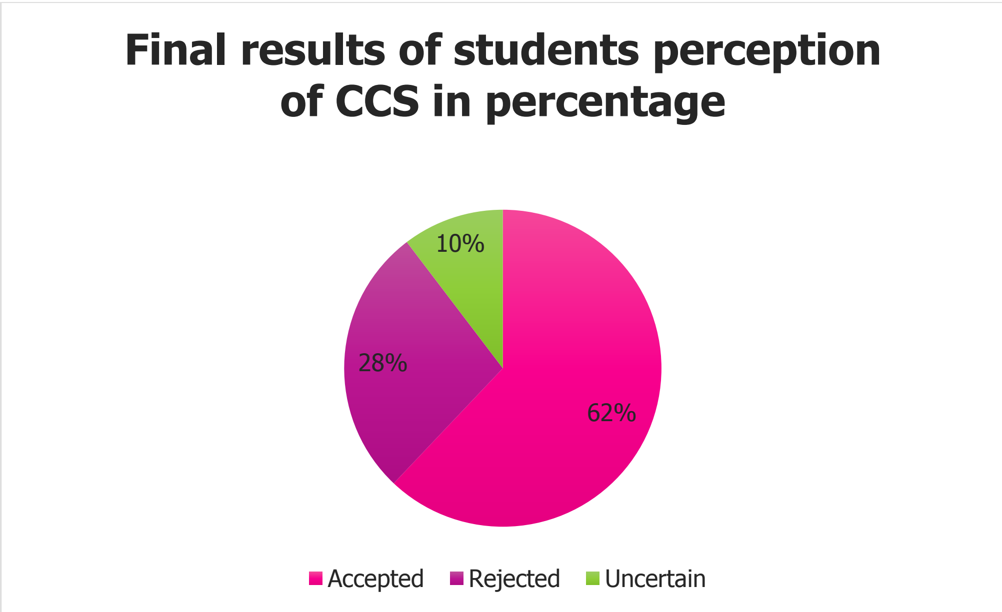

FIGURE 12. The final analysis of the students' opinions in percentage

From the point of view of the students, the country government, environment agencies, and oil and energy industries must control and monitor the development of Carbon Capture and Storage. In addition to these parties, the people should also take part in decision making and commitment. Every party takes its own role in the process, for example oil and gas companies perform the process themselves, government of a particular country takes care of the safety regulations which were made by an environment agency, etc. The figures 13 and 14 show the percentage relation of the institutions that might take care of the development of CCS systems.

The institution responsible for CCS	Votes	Percentage relation
Government	10	18%
Oil & energy industry	15	27%
Other industry	3	5%
Local government	5	9%
Environmental Organisation e.g. Greenpeace	12	22%
A new Government Agency	2	4%
Citizens	1	2%
EU	5	9%
End consumers	2	4%
Total number of votes:	55	100%

FIGURE 13. The institutions responsible for CCS establishment and development according to students

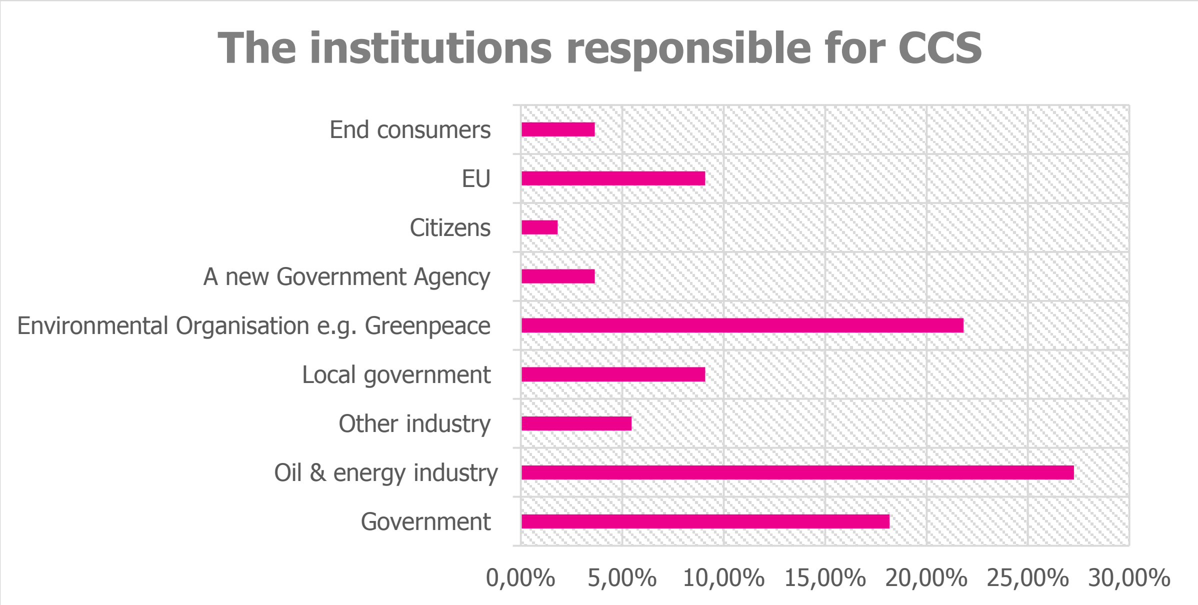

FIGURE 14. The institutions responsible for CCS according to the opinions of research participants

The results of the research, which was conducted under the supervision of the lecturer – Eric Buah, can be used to draw the parallel with the general public's opinion. The analysis is based on the discussions and the answers to question during the Sustainability and Engineering course. The 62% out of 29 students have accepted the CCS system and consider it to be a great and innovative solution for the reduction of CO_2 emissions in the nearest future. Only 28% of all students decided that the technology is too risky and has no future development. Moreover, these participants would never accept the establishment of Carbon Dioxide storage nearby because of the possible leakages and unknown consequences. Some students do not have a particular opinion concerning CCS and its future. Also, based on the research, participants suppose that oil & energy industry, environmental organisations and governments must handle the CCS implementation, risks and costs. Awareness research of the Savonia students showed the great diversifications in the opinions concerning the necessity and the capability of CCS which reflects the current situation and opinions of general public globally.

7 CONCLUSION

7.1 Current situation

In today's world approximately 80% of energy is generated from fossil fuels. According to the latest data, the fossil fuels will still be the leaders in power generation till the year 2040. The developed countries have enough resources to create and work on the alternative energy sources, while the developing countries will still demand for higher fossil fuels amount. (Global CCS Institute, 2015)

Around 25% of total Carbon Dioxide emissions are generated in the industrial sector. The largest power generation industry and the biggest source of emissions is coal burning. Moreover, industries like gas processing, steel, cement and chemicals manufacturing also contribute to overall industrial CO_2 emissions. Unfortunately, renewable energy is not so developed and cannot replace totally the fossil fuels and provide the same output to people in the near future. (Global CCS Institute, 2015)

Carbon Capture and Storage system allows to catch CO_2 during or after industrial processing, transport it and inject it to geological formation or the deepest part of ocean for years. Theoretically, the technology can capture up to 90% of Carbon Dioxide emitted from industrial processes. Many researches and institutions consider CCS to be the only technology which can replace the burning and the use of fossil fuels. (Global CCS Institute, 2015)

Nonetheless, the development of the system is too slow to capture the green market due to the high risk of leakages and human mistakes, lack of the governmental supply and policies and financing. Lenders and investors have serious doubts concerning the new unproved technology. An international argreement, binding to all nations, at least the important polluters, is needed in order to solve the problem of rising energy price. Unfortunately, there are countries in which short sighted internal policy and politicians hinder the implementation of the treaty worldwide. (Ministry of the Environment, 2013)

In 2015, 15 large-scale CCS projects operated in the world and the capacity of capturing CO_2 was approximately 28 million tonnes. Many of planned projects were canceled by governments or because of the impossibility to bear all the costs. (Global CCS Institute, 2015)

7.2 Future

The CCS institutions propose a three-step plan for the system development. According to plans, the CCS aims to reduce up to 6,000 million tonnes of Carbon Dioxide emissions in 2050 in case the system will be successfully adapted.

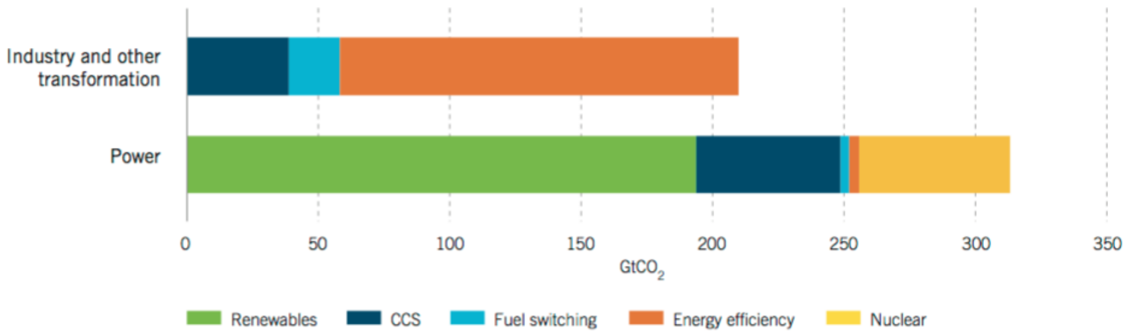

FIGURE 11. Cumulative CO_2 emissions in industries from 2012 to 2015 (Global CCS Institute, 2015)

Moreover, the future goals include the distribution of CCS projects all over the world and accordingly the reduction of costs on the system interaction into the plant. Figure 11 reflects the cumulative Carbon Dioxide emissions by industries from the year 2012 to 2050. (Global CCS Institute, 2015)

The Savonia student awareness research showed great diversification in the opinions concerning the necessity and the capability of CCS. The perceptions of scientists and researchers conflict nevertheless less and less. Unfortunately, it is difficult to predict the future but nowadays the successful implementation of CCS institutions plans seems to be impossible due to lack of support of planned projects and high risks.

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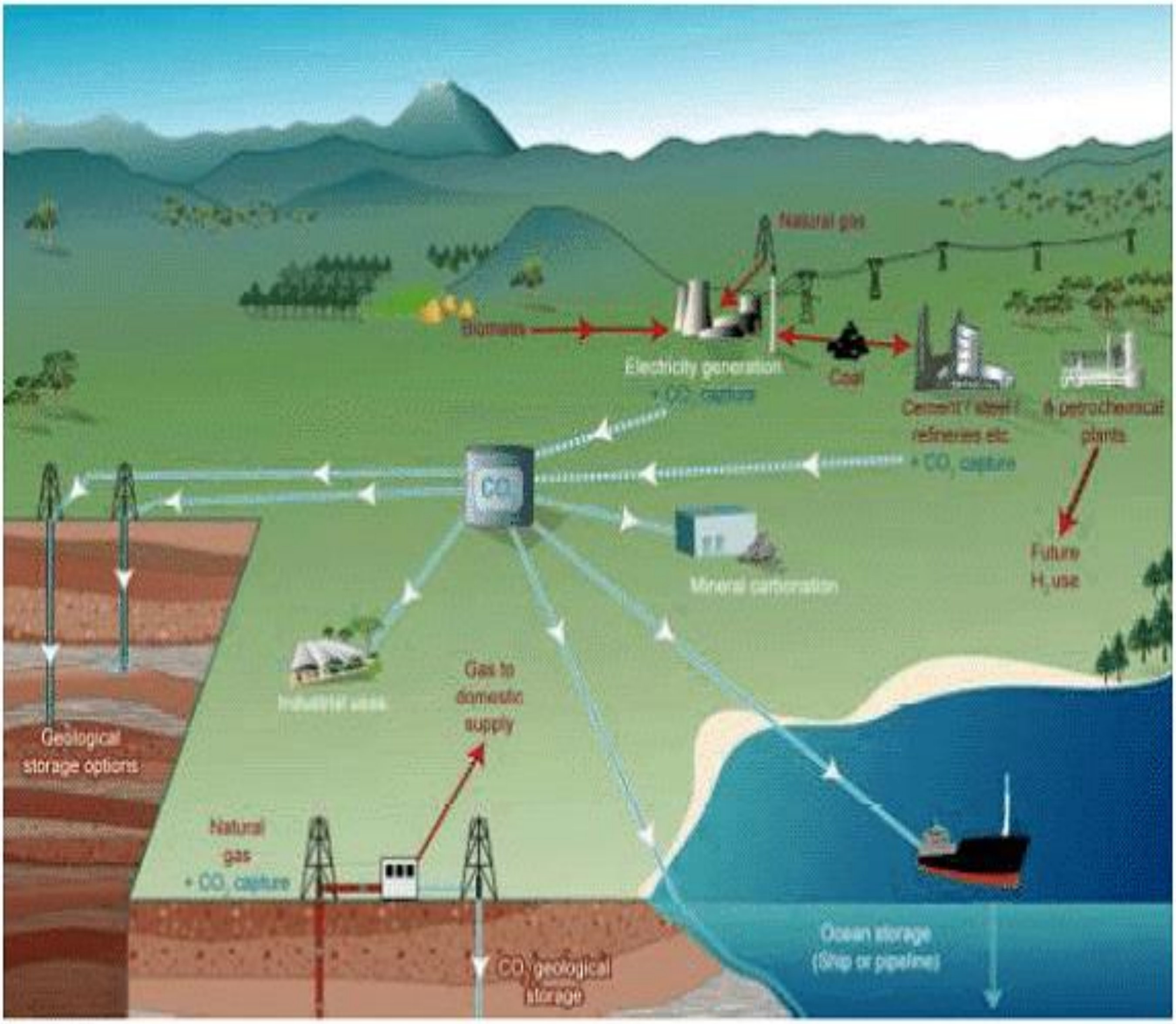
APPENDIX 1: CARBON CAPTURE AND STORAGE SYSTEM



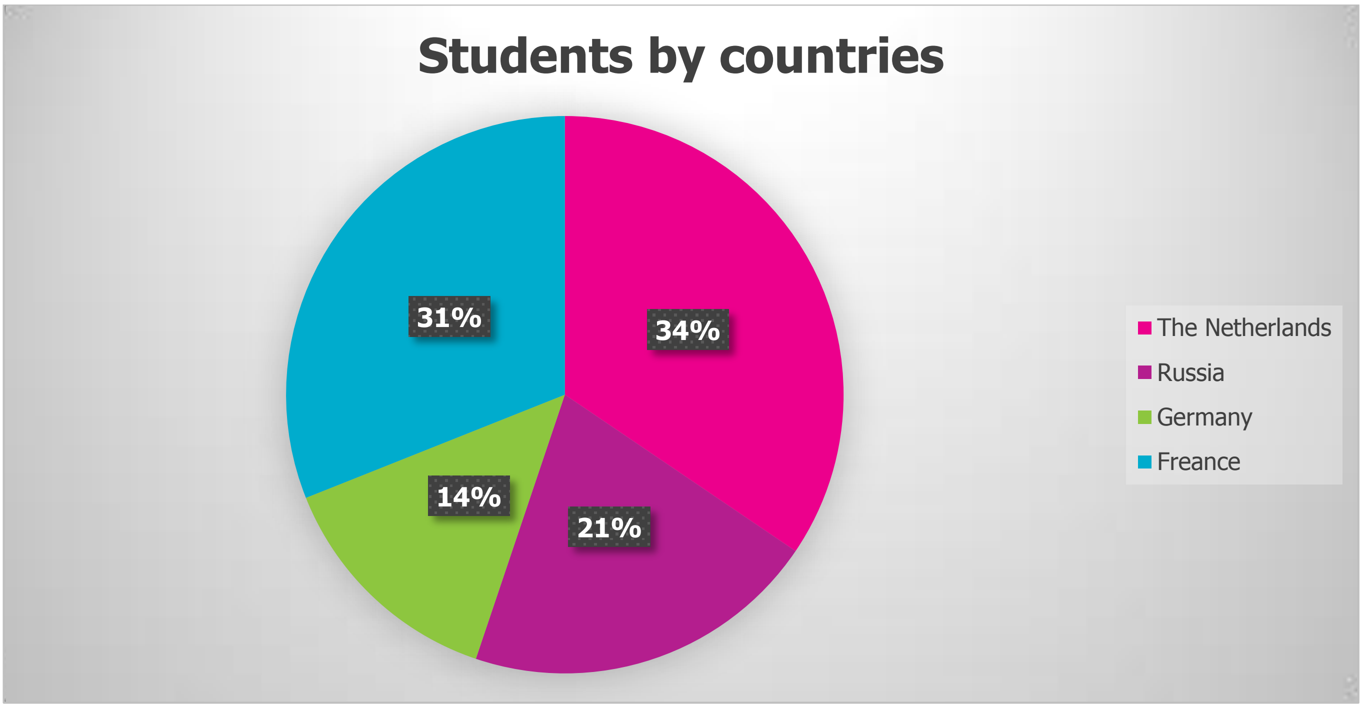
(Ramgen, 2008)

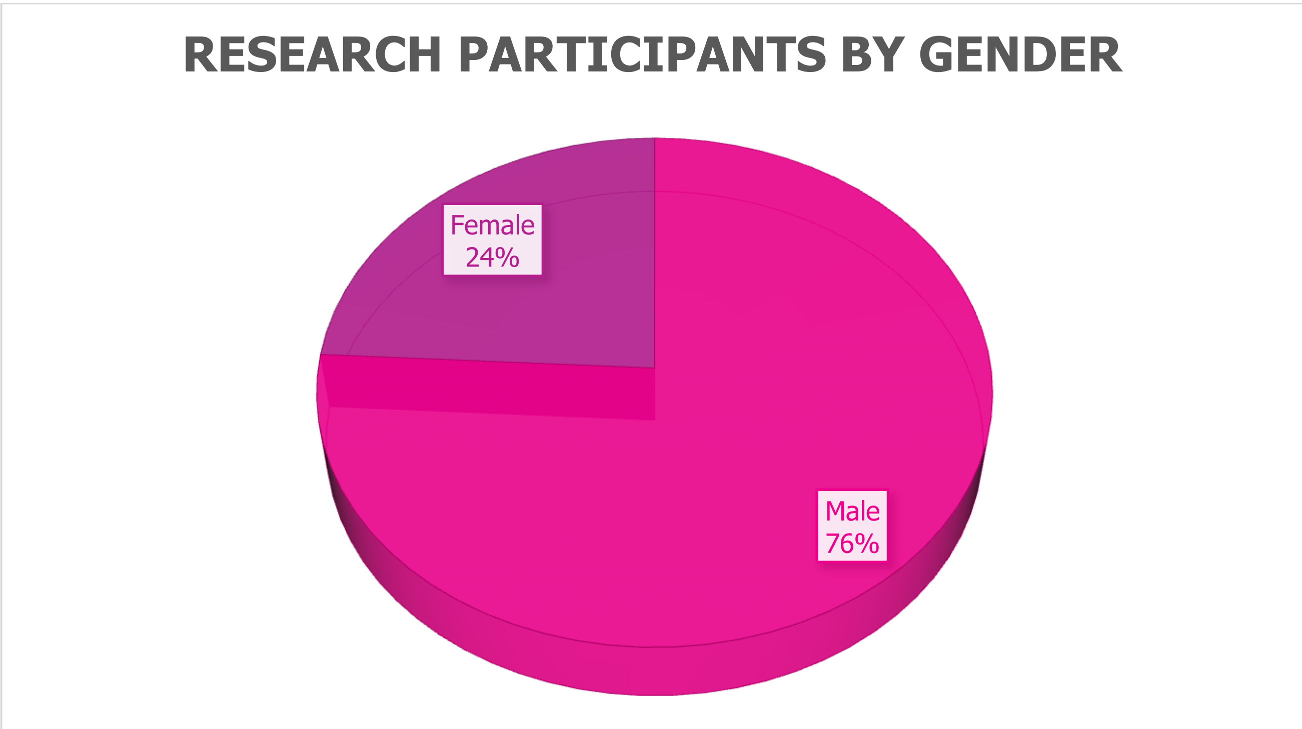
APPENDIX 2: THE LARGEST OPERATING AND PLANNED CCS SYSTEMS IN THE WORLD

Project	**Country**	**Year**	**Status**	**Industry**	**Capturing**	**Transportation**	**Storage**
Century Plant	United States	2010	In action	Natural Gas	Pre-combustion	Pipeline	Enhanced Oil Recovery
In Salah CO_2 Storage	Algeria	2004	In action	Natural Gas	Pre-combustion	Pipeline	Geological Formations
Petrobras Lula Oil Field	Brazil	2013	In action	Natural Gas	Pre-combustion	No	Enhanced Oil Recovery
Sleipner CO_2 Storage	Norway	1996	In action	Natural Gas	Pre-combustion	No	Geological Formations
Boundary Dam Project	Canada	2008	In action	Power Generation	Post-combustion	Pipeline	Enhanced oil recovery and geological formations
Abu Dhabi CCS Project	United Arab Emirates	2016	Execution	Iron and Steel Production	Separation	Pipeline	Enhanced Oil Recovery
Gorgon Carbon Dioxide Injection	Australia	2017	Execution	Natural Gas	Pre-combustion	Pipeline	Geological Formations
Kemper Country energy Facility	United States	2016	Execution	Power Generation	Pre-combustion	Pipeline	Enhanced Oil Recovery
Alberta Carbon Trunk Line	Canada	2017	Execution	Oil Refining	Separation	Pipeline	Enhanced Oil Recovery

(Global CCS Institute, 2014)

APPENDIX 3: ANALYSIS OF SAVONIA STUDENT AWARENESS

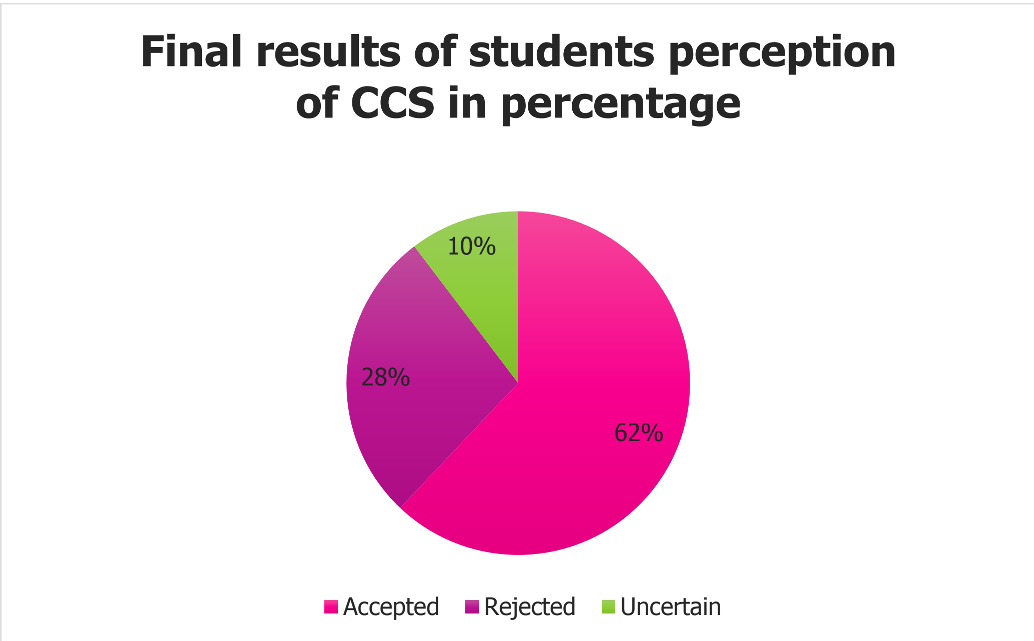




APPENDIX 4: ANALYSIS OF SAVONIA STUDENT AWARENESS

The simplified results of the research

Nationality	Age	Gender	Study Programme	Attitude to the system
French Participants				
FP1	23	Male	Engineering in Safety, Environment and Risk Prevention	Uncertain
FP2	20	Male		Accepted
FP3	21	Male		Rejected
FP4	21	Male		Accepted
FP5	20	Male		Rejected
FP6	21	Male		Accepted
FP7	20	Male		Accepted
FP8	20	Female		Accepted
FP9	23	Female		Rejected
FP10	23	Male		Accepted
Russian Participants				
RP 1	21	Female	Industrial Engineering and Management	Accepted
RP2	22	Male		Uncertain
RP 3	20	Female		Rejected
RP 4	21	Female		Accepted
RP 5	21	Male		Accepted
RP 6	21	Female		Rejected
German Participants				
GP1	20	Male	Engineering and Management	Accepted
GP2	22	Female		Accepted
GP3	24	Male		Accepted
GP4	20	Male		Accepted
Dutch Participants				
DP1	27	Male	Technical Corporate Management	Accepted
DP2	24	Male		Accepted
DP3	18	Male		Rejected
DP4	19	Male		Accepted
DP5	19	Male		Rejected
DP6	19	Male		Uncertain
DP7	19	Male		Rejected
DP8	19	Male		Accepted
DP9	19	Male		Accepted
Total:29				



APPENDIX 5: ANALYSIS OF SAVONIA STUDENT AWARENESS

The institutions responsible for CCS establishment and development according to students' views

The institution responsible for CCS	Votes	Percentage relation
Government	10	18%
Oil & energy industry	15	27%
Other industry	3	5%
Local government	5	9%
Environmental Organisation e.g. Greenpeace	12	22%
A new Government Agency	2	4%
Citizens	1	2%
EU	5	9%
End consumers	2	4%
Total number of votes:	55	100%