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Abstract

This study aims to map what misconceptions students in lower secondary and upper secondary school possess concerning the carbon cycle. Data was gathered quantitatively using an anonymous survey. Over 200 students from two lower secondary schools and one upper secondary school in the Stavanger region (Norway) completed the survey. Results from the survey show that students have misconceptions concerning the dissolution of carbon dioxide, carbon capture in the natural carbon cycle and differentiation of the carbon cycle from other environmental issues.

Contents

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This endeavour would not have been possible without the help and support of friends and family. The journey has been long and hard. Thus, I am forever grateful to Henriette for her support, guidance and patience.

This master thesis marks not only the end of five years of studying to become a teacher but also the end of ten years of being a student. However, the journey does not end here. When one chapter ends, another begins.

Stavanger, June 2022
Eirik Midbøe Lunde

1 Introduction

Climate change is really one of the most pressing issues for modern society. However, do students today understand climate issues in line with current scientific theories? Or do students possess their own understanding of climate processes such as the *carbon cycle*? Incorrect scientific understanding, not in line with current scientific concepts, is referred to as a *misconception*. These misconceptions can hinder learning. Thus teachers must be aware of what misconceptions students may possess in order to mitigate such misconceptions.

One significant concept in chemistry is the carbon cycle, which describes the continuous travel of carbon atoms between the atmosphere and the earth. The carbon cycle can be divided into the slow and the fast carbon cycle, and each cycle consists of several processes. Due to this complexity, many students may have misconceptions about the topic, such as the greenhouse effect, solubility of carbon dioxide (CO_2) and natural carbon capture.

This study aims to map which misconceptions students in lower secondary schools and upper secondary schools in Norway have concerning the carbon cycle using a quantitative student survey. The survey questions consisted of topics with abstract concepts regarding the carbon cycle and common misconceptions among students found in previous studies. In total, over 200 students participated from lower secondary school and upper secondary school.

2 Theory

This section will cover the scientific processes which make up the carbon cycle and give insight into current research on how changes may affect the cycle. Furthermore, this section will present what misconceptions are, how they originate, and common misconceptions concerning the carbon cycle found among students in schools.

2.1 The carbon cycle

Carbon is the element which all life on earth is based on. Carbon chemistry is so vast and complex that an entire branch of chemistry, called *organic chemistry*, revolves around carbon. Organic chemistry explains simple compounds like methane (CH_4), ethanol (C_2H_5OH) and acetic acid (CH_3COOH) as well as complex molecules ranging from sugars, fats, and proteins to deoxyribonucleic acid (DNA), cells and all living creatures on earth (UCMP, 2018a). Another part of chemistry, namely *inorganic chemistry* incorporates elemental gases, metals and salts. However, some carbon-based molecules are also regarded as inorganic carbon. Such compounds include carbon dioxide (CO_2), and different compounds containing carbonate such as carbonic acid (H_2CO_3), bicarbonate (HCO_3^-) and calcium carbonate ($CaCO_3$). Carbon can form inorganic and organic compounds in the earth, ocean and atmosphere. The cycling of different compound that make up carbon is referred to as the *carbon cycle*. The way carbon changes form can be divided into slow and fast carbon cycles. The carbon cycles have kept the earth at a relatively stable temperature (with some fluctuation) over thousands of years. Over millions of years, the earth's temperature has changed according to the concentration in CO_2 in the atmosphere (Riebeek, 2011).

2.1.1 The slow carbon cycle

The slow carbon cycle starts with rain. CO_2 in the atmosphere dissolves into rainwater, making rain slightly acidic with carbonic acid ($CO_2 + H_2O \rightleftharpoons H_2CO_3$). When the rainwater starts to fall and hits the ground, the carbonic acid reacts with rocks on the ground in a *chemical weathering*. Chemical weathering occurs when acidic rainwater dissolves ions like calcium, magnesium, sodium and potassium from rocks. Rainwater carries these dissolved ions to the ocean along rivers and groundwater. When calcium ions reach the ocean, it reacts with carbonate ions dissolved in the ocean to form calcium carbonate ($Ca^{2+} + {CO_3}^{2-} \longrightarrow CaCO_3$). Calcium carbonate precipitates and sinks to the ocean floor together with shells and dead organisms. This precipitate will be covered in more detail in section 2.1.3. Calcium carbonate, shells and dead organisms settle as sediment along the ocean floor. Over time, these sediments form calcium carbonate-based rocks such as *limestone* (Riebeek, 2011).

Approximately 80% of carbon-based rocks are formed in this manner, and the remaining 20% are formed from organic matter trapped in mud which, under high pressure and temperature over

millions of years, form a type of rock called *shale*. In some cases, the organic matter builds up faster than it can break down. In these cases, the high pressure and temperature will transform the organic material into coal, oil and natural gas instead of shale (Riebeek, 2011).

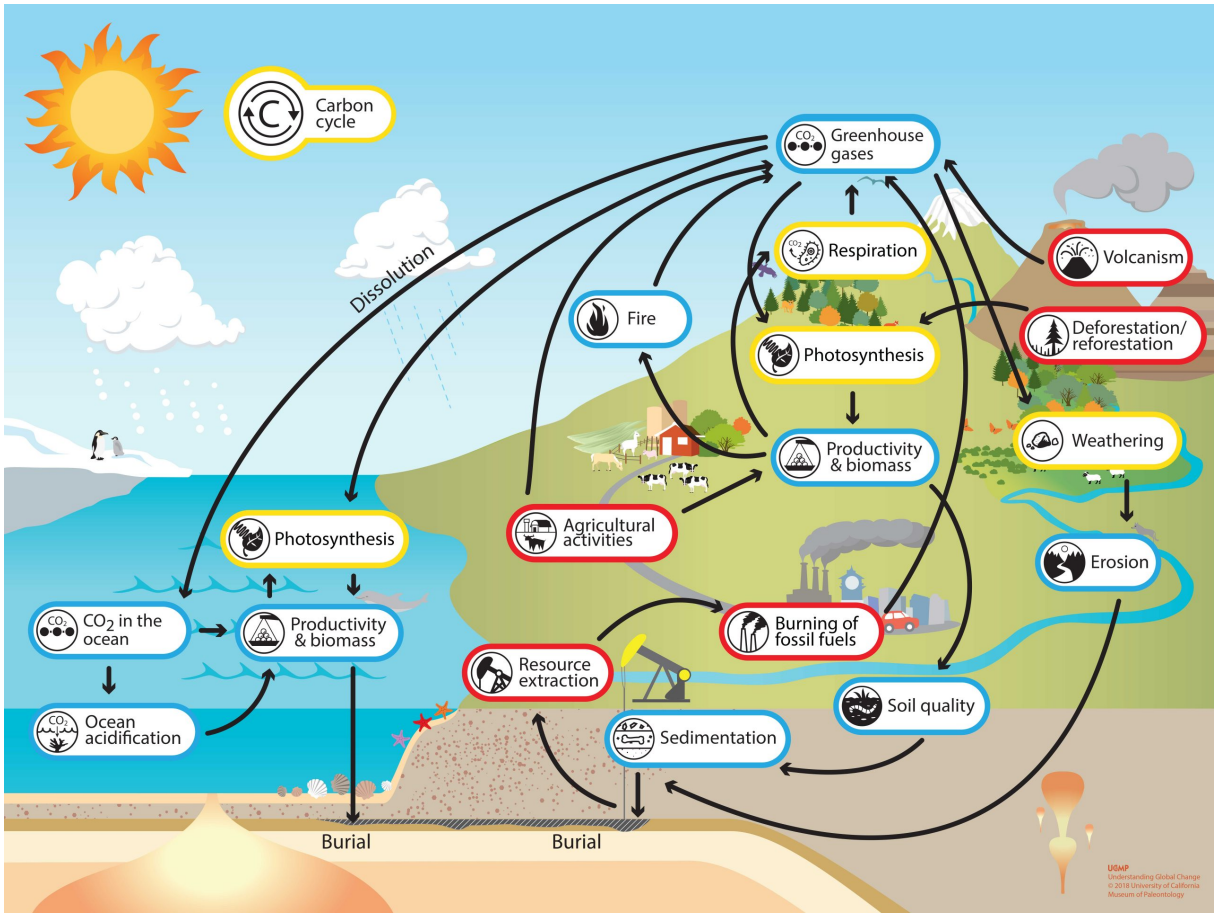


Figure 2.1: An infographic showing some of the different processes which make up the carbon cycle (UCMP, 2018a). The colours of the process show the causality of the process. Yellow processes represent the earth system, including the atmosphere, hydrosphere, biosphere and geosphere. Red processes represent the causes of global change. Blue processes represent measurable changes to the earth system (UCMP, 2018c).

The carbon-based sedimentary rocks then move along with the tectonic plates due to continental drift for millions of years. Rocks are then exposed to volcanic activity at the plate boundaries. In the volcanoes, the rock melts, forming silicate and releasing carbon as CO_2. Large quantities of CO_2 are released from the earth's crust into the atmosphere through volcanic eruptions and volcanic activity. The slow carbon cycle then starts all over again.

The slow carbon cycle is self-regulating over a few hundred thousand years as CO_2 from volcanic eruptions cause the temperature to increase, which induces more rainwater to form. More rainwater leads to more chemical weathering, which carries more ions into the ocean, forming more sedimentary rocks. In summary, the slow carbon cycle is a process of inorganic chemical reactions which cycles carbon between CO_2 in the atmosphere and carbon as rocks, coal, oil or natural gas. This process takes 100 to 200 million years. Without human interference, carbon in

coal, oil and natural gas would be slowly released into the atmosphere in the slow carbon cycle. However, the release of carbon stored by the slow cycle has been accelerated due to humans burning fossil fuels. As a result, carbon which took millions of years to store, is released into the atmosphere at an alarming rate (Riebeek, 2011).

2.1.2 The fast carbon cycle

Contrary to the long carbon cycle, which takes hundreds of millions of years, the fast carbon cycle occurs in a single lifetime. The fast carbon cycle mainly revolves around organic chemistry with living organisms. Carbon can form four covalent bonds with other elements. This property of carbon is why carbon can bond with other atoms to form simple and complex molecules. Such covalent carbon bonds can store energy released in chemical reactions. Life on earth is dependent on these reactions as a source of energy. This exchange of energy is the basis of *photosynthesis*.

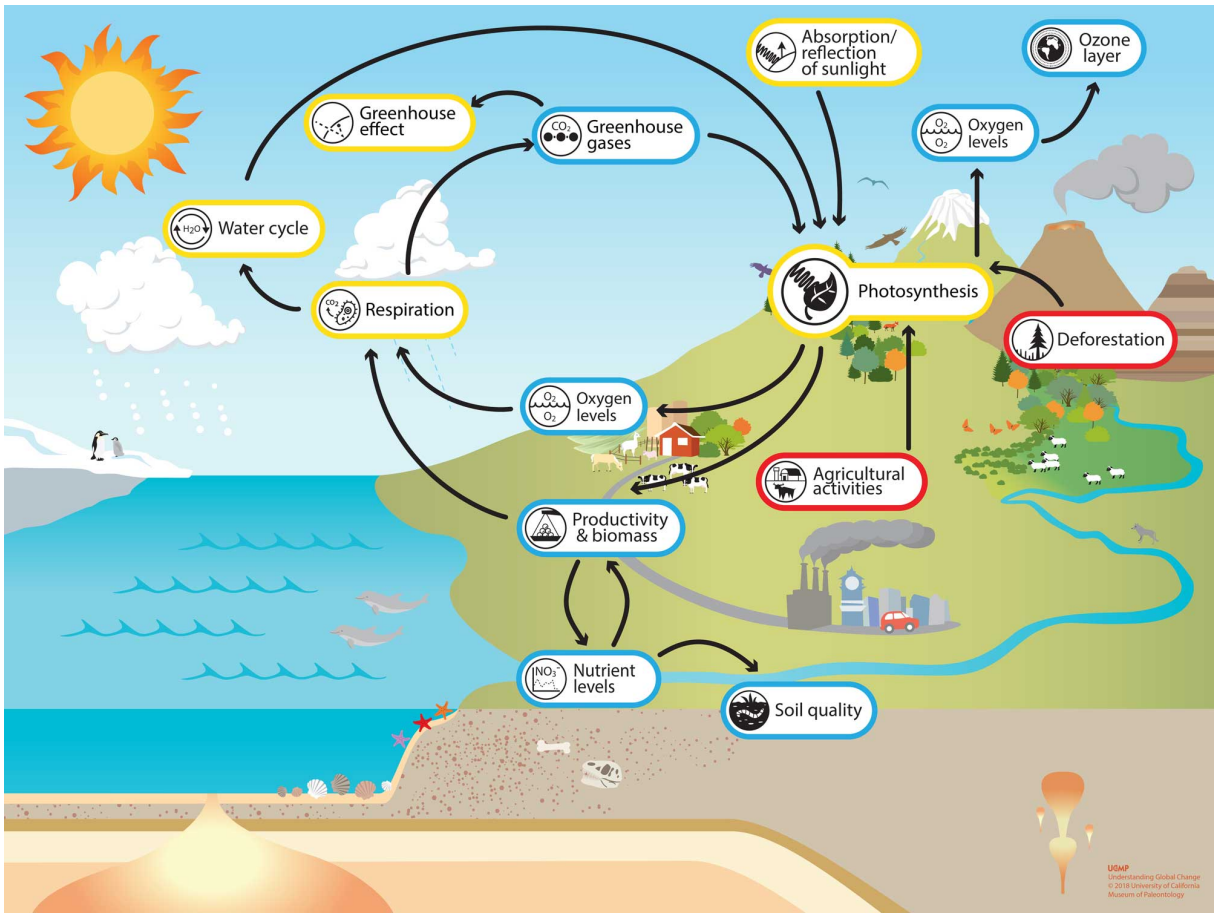


Figure 2.2: The process of photosynthesis where carbon circulates through living organisms to convert CO_2 to glucose and back again to CO_2 (UCMP, 2018b).

The cycle begins with living organisms like plants, trees and phytoplankton, which can absorb energy from the sun through light. These organisms use this energy to convert CO_2 in the atmosphere with water to create glucose and oxygen (energy + CO_2 + H_2O $\longrightarrow$ $C_6H_{12}O_6$ +

O_2). Glucose is a molecule which contains much energy. This energy can be released in a few different ways. However, all the chemical processes for releasing the energy is the same. Plants can use this energy to grow or consume glucose as energy when there is little to no sunlight available at night or during the winter months. Next, plants can be eaten by herbivorous organisms which can digest plant cells. Carnivorous animals can then eat the herbivorous and utilise them as energy. After a plant dies, it will rot and decay. This process releases the energy stored in the plant. The last option for releasing the energy stored in plants is burning. Forest fires burn down trees and plants. These processes are based on the same oxidation where glucose and oxygen are reacted to produce CO_2, water and energy ($C_6H_{12}O_6 + O_2 \longrightarrow CO_2 + H_2O +$ energy). This energy is released as heat. Thus plants absorb CO_2 in order to grow and live, and CO_2 is released when plants die, decay, and burn or is eaten by animals (Riebeek, 2011).

2.1.3 The effects CO_2 has on the ocean

CO_2 is a gas which can dissolve into water. The solubility of gases is quantifiable by *Henry's law* which states that the solubility of gas is proportional to the partial pressure above the solvent (Zumdahl and DeCoste, 2012). The dissolution of CO_2 is usually an equilibrium reaction which means that CO_2 constantly dissolves and releases depending on external factors. With the increase in CO_2 in the atmosphere, the ocean dissolves more CO_2 than it can release. The solubility rate is determined by temperature, pH, waves and oceanic currents. The solubility of CO_2 is inverse proportional to temperature. In other words, when the temperature increases, the solubility decreases. The same is true about the reverse. When the temperature decreases, the solubility of CO_2 increases (Weiss, 1974). Currently, the ocean has the potential to capture 85% of the added CO_2 in the atmosphere (Riebeek, 2011). However, to become a long-term carbon storage, the CO_2 needs to be stored in the ocean depths and not in the shallow surface water where CO_2 is released back into the atmosphere. The process of long-term CO_2 capture is slow as it depends on the ocean currents and sinking of dissolved CO_2. In the long-term, the ocean has the potential of capturing and storing a third of the total human-made CO_2 emissions (Sabine et al., 2004).

When CO_2 dissolves into the ocean, it reacts with water to create carbonic acid, which lowers the pH resulting in the ocean becoming more acidic. The term for this process is referred to as *acidification* of the ocean. Carbonic acid reacts with dissolved carbonate ions forming bicarbonate. With the reduction of available carbonate ions, the rate of formation of calcium carbonate decreases, resulting in less calcium carbonate perspiration in the slow carbon cycle. The decrease in carbonate ions also affects marine life like corals, shellfish and plankton as they create their shell and protective structure out of calcium carbonate. By reducing the concentration of carbonate ions, marine organisms need to use additional energy to make shells, resulting in thinner and more fragile shells. For example, current models of how the pH will change in future decades show that the shells of live pteropods start to dissolve if the pH continues to decrease (Orr et al., 2005). In addition, an increase in CO_2 concentration in the ocean has been shown to affect the auditory response of juvenile clownfish (Simpson et al., 2011).

The changing CO_2 levels also affect phytoplankton. Phytoplankton is tiny marine organisms that use photosynthesis to absorb CO_2 and produce energy. The increase in gaseous CO_2 results in increased energy production by phytoplankton since there is more CO_2 available for phytoplankton to grow and thrive. However, phytoplankton thrives in cold water. With the increase of CO_2 in the atmosphere, the temperature in both the ocean and atmosphere increases (EPA, 2021). This worsens the conditions for the phytoplanktons, and reduse their ability to absorb CO_2 is reduced (Behrenfeld et al., 2006). The ocean is made up of many complex chemical and biological processes, which makes it hard to predict how climate change will affect the ocean.

2.1.4 The effects CO_2 has on the atmosphere

There are multiple gases in the atmosphere which can absorb heat. Some examples include water vapour, CO_2, and halocarbons. These gases absorb electromagnetic energy at different wavelengths. The short wavelength energy from the sun is transparent to these gases, which lets the energy through to hit the earth's surface. The earth absorbs some of the energy, and the rest is reflected in a longer wavelength in the form of infra-red heat radiation. Water vapour, CO_2, methane and halocarbons can absorb and then re-emit the longer wavelengths back to earth. This process is referred to as the *greenhouse effect*. The gases that can absorb and re-emit heat are called *greenhouse gases*. The greenhouse effect has been a naturally occurring process for billions of years and is an important part of the earth's temperature regulation system. Without the greenhouse gases, the earth would have been a frozen planet at -18 °C and life on earth as we know it would be hard to imagine (Riebeek, 2011).

Approximately 20% of earth's greenhouse effect is caused by CO_2, 50% is caused by water vapour, 25% from clouds and the remaining 5% from aerosols and the other greenhouse gases like methane and halocarbons (Schmidt et al., 2010). Thus, water vapour is the most significant contributor to the greenhouse effect among greenhouse gases. However, the amount of water vapour in the atmosphere is dependent on the earth's temperature. When the temperature rises, more water vapour evaporates from the ocean, which raises the temperature further in a positive feedback loop. If the temperature in the atmosphere decreases, water vapour will condense into water droplets, resulting in rain or snow. Rain and snow decrease the amount of water vapour in the atmosphere, which reduces the greenhouse effect resulting in a negative feedback loop. An increase in snow and ice also increases the *albedo* of the earth's surface. Albedo is the ratio between absorbed and reflected radiation. Thus, a higher albedo means more of the sun's radiation is reflected towards space, and less radiation is absorbed by the earth, decreasing the earth's temperature (Taylor, 2005).

CO_2 stays in the gas phase over a wider range of temperatures than water vapour. Thus, the amount of CO_2 in the atmosphere is not as dependent on the temperature as water vapour. However, when CO_2 increases in the atmosphere, the temperature also increase. An increase in temperature causes more water to evaporate, which causes the temperature to increase further.

Thus, the greenhouse effect is closely related to the amount of CO_2 in the atmosphere (Lacis et al., 2010).

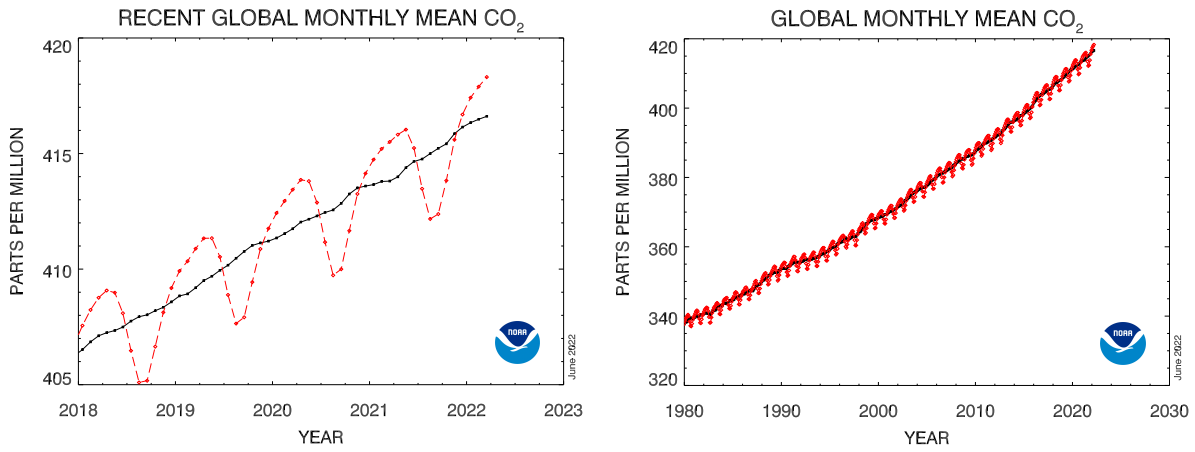
According to thermodynamics, ideal gases distribute evenly inside a container. However, atmospheric gases distribute differently throughout the atmosphere. A well-known example of this property of atmospheric gases is ozone (O_3), which increases with altitude with peak concentration at 25 km, then the concentration of ozone declines with altitude (Taylor, 2005). This layer of high ozone concentration is referred to as the *ozone layer*. Though ozone concentrations are higher in the stratosphere, ozone can also be found on ground level. Ground level ozone is also referred to as tropospheric ozone. Ozone is considered a greenhouse gas, however it is only tropospheric ozone which is considered harmful, as stratospheric ozone is beneficial for UV protection (EIA, 2021). The concentration of water vapour in contrast decreases with altitude until 15 km, where the concentration stays the same. Thus, the concentration of both ozone and water vapour changes with altitude. However, the concentration of CO_2 does not. Therefore, CO_2 concentration is the same and evenly distributed throughout the atmosphere (Van Wijngaarden and Happer, 2020).

2.1.5 The effects CO_2 has on plant growth

The fast carbon cycle is closely related to the growth and decay of plants throughout the seasons. When plants sprout during spring, they need more CO_2 to grow. During the autumn and winter, when light from the sun is reduced, plants need to use glucose to produce energy which releases CO_2 in the process. Plants and trees which die and rot also release CO_2 as they decay. Thus, the CO_2 concentration in the atmosphere changes throughout the seasons as if the earth is breathing CO_2 (Riebeek, 2011), as shown in Figure 2.3

Plants are dependent on multiple factors to grow. During photosynthesis, sunlight, CO_2 and water are needed to produce glucose. However, plants also depend on nutrients such as nitrogen, phosphates and potassium. With an increase in atmospheric CO_2, plants have more CO_2 available to absorb during photosynthesis. Thus, increased atmospheric CO_2 could result in increased plant growth. Rising temperatures, more sunlight, and increased humidity could also increase plant growth. However, with a higher growth rate comes a higher need for water. What is the limiting factor prohibiting plant growth? Higher temperatures also result in more water evaporation, reducing plants' access to liquid water in the soil. A study conducted by Angert et al. (2005) has shown that during drier summer months, there has been no increase in CO_2 capture from photosynthetic activity, indicating that warmer and drier climates do not lead to an increase in CO_2 absorption. The limiting factor depends on the region, even though a decrease in water would harm all earth's forests, including tropical areas. If water is a limiting factor, less water will result in tropical forests reaching a limit of how much CO_2 it can capture through plant growth. Drier soil will give better conditions for forest wildfires which burn down trees and release CO_2 into the atmosphere. The prevention of wildfires is vital to limiting CO_2 emissions of organic carbon, which have been captured and stored by trees and

plants over decades. Forest fires have started to occur more frequently (Sullivan et al., 2022). Approximately 25% of human CO_2 emissions are absorbed by plants and trees (Riebeek, 2011).



(a) (b)

Figure 2.3: Data from the Global Monitoring Laboratory (GLM), which is part of the National Oceanic & Atmospheric Administration (NOAA). Figure 2.3a shows data from the last four years up to the current month. While Figure 2.3b show data reaching back to 1980. The red data points show the monthly concentration of CO_2 given in part per million (ppm). The periodical changes in the red data are caused by seasonal changes in the capture and release of CO_2 by trees and plants. The black data point is an average over the last seven seasonal cycles (NOAA, 2022). The variations in CO_2 levels show how plants and trees breathe CO_2 in and out throughout the seasons.

2.2 What is a misconception?

Students continuously create an idea of how the world work. However, this image is not always in line with scientific theories. Norwegian chemistry didactics separates this concept into two different terms. The first is called *hverdagsforestillinger* and can be translated into everyday conceptions, which cover conceptions students make by themselves before they are taught a subject. The second term is referred to as misconceptions. In Norwegian chemistry didactics, misconceptions consist of conceptions during class or concepts incorrectly taught by the teacher. In English, both terms are referred to as misconceptions and do not differentiate the origins of the misconception. The term misconceptions in this study refer to false constructs and cognitive networks students make regardless of the origin. Teachers need to be aware of students' misconceptions as they give an insight into their cognitive structure and existing knowledge on a topic. In addition, teachers can use diagnostic tools to mitigate misconceptions further and help the students build new knowledge (Ringnes and Hannisdal, 2014).

2.2.1 Constructivism

Learning does not occur in a vacuum. Ideas and concepts are not created out of thin air. From the moment a child is born, it begins experiencing the world around them. Children experience

the world through their senses and social interactions with other people. The way children create this construct of the world is called *constructivism*. All concepts students construct in advance of education are regarded as personal knowledge. Such preexisting knowledge is individual and can be different from student to student. Personal knowledge is constructed in a network called the *cognitive structure*. Constructivism in education means that all students have existing knowledge, which an educator must consider when building new knowledge or expanding and restructuring the students' cognitive structure (Ringnes and Hannisdal, 2014). Constructivism is used in psychology and pedagogy and is often credited to researchers like Jean Piaget, Lev Vygotsky and John Dewey. However, there is no single unified theory of constructivism (Woolfolk, 2014).

2.2.2 Misconceptions regarding the carbon cycle and pollution

Over the past decades, researchers have made a great effort to map common misconceptions and their origins. Different studies across multiple countries and education levels have found similarities in how students perceive environmental challenges. One such similarity comes from all pollutants contributing to CO_2 emissions and causing climate change (Rajeev Gowda et al., 1997). A study conducted in the UK shows that students divide environmental actions into two actions. These actions are friendly and unfriendly. The environmental-friendly actions will help mitigate all environmental issues such as climate change. In contrast, unfriendly action will contribute to an increase in CO_2 levels and climate change. Unfortunately, students do not grasp the cause and effect of environmental issues (Boyes and Stanisstreet, 1993). Students believe all types of pollutants contribute to CO_2 emissions and, in turn, climate change. Some of these pollutants includes littering and nuclear waste (Boyes et al., 1993). Most students agree that reducing the pollution from driving cars would reduce CO_2 emissions (Pruneau et al., 2001). However, there are some misconceptions regarding energy production, as less than half of a group of students regarded nuclear power plants as beneficial to reducing climate change. This contradicts the fact that nuclear power is considered the energy source which produces the least CO_2 per gigawatt of energy (Ritchie, 2020). A recent article presents statistics where young boys are more optimistic about nuclear power compared to girls (Kumano-Ensby and Larsen, 2022). A study conducted over a larger timespan shows that misconceptions regarding littering and CO_2 emissions tend to decrease as the level of education increases (Boyes and Stanisstreet, 2001). Boyes and Stanisstreet (2001) argue that misconceptions concerning concrete pollutants become less abstract with higher levels of education. However, misconceptions regarding gaseous pollutants remain, as they are still too abstract to comprehend.

2.2.3 Misconceptions of the greenhouse effect

Climate change resulting from the greenhouse effect is perhaps our planet's most pressing issue. Thus mapping misconceptions regarding the greenhouse effects is vital to make educated choices to mitigate the issue. In a study from Greece where students were asked to explain

how the greenhouse effect occurs, researchers found clear misconceptions concerning the greenhouse effect. As this study aimed to map the cognitive structure and the student's reasoning of their model, a qualitative method was regarded as the best method. The study conducted by Koulaidis and Christidou (1999) created five different models of the greenhouse effect based on the interviews with students. The result showed that students had trouble understanding how atmospheric gases distribute. Most students were categorised as understanding the greenhouse effects in a manner where CO_2 rises into the atmosphere where it covers the earth in a layer. This CO_2 layer traps heat from dissipating into space. One of the participants explains:

> Carbon dioxide rises in the atmosphere and makes a layer that is a disaster for the earth, because the sun's rays can come in from this layer but then they can't go out into space... (Koulaidis and Christidou, 1999)

This misconception occurs across multiple studies, as Andersson and Wallin (2000) also show results of students not understanding the distribution of different atmospheric gases. This conception causes some differentiation issues between the greenhouse effects and the ozone layer. This issue with differentiation between the greenhouse effects and the ozone layer affects both processes. Since students believe this process is the same, ozone is also believed to influence the regulation of the earth's temperature (Khalid, 2001). Misconceptions regarding CO_2 distribution and differentiation between CO_2 and ozone has been shown across age groups with children (Koulaidis and Christidou, 1999), high school students (Rajeev Gowda et al., 1997; Boyes et al., 1993), students in the teacher training program (Khalid, 2001) as well as adults (Pruneau et al., 2001). This misconception occurs regardless of age and education level is supported in a study by Gautier et al. (2006), where the participant showed no signs of changing their conceptual knowledge on the topic over time. As many of these studies are between 20 to 30 years old, the survey conducted in this study sets out to explore if students today possess similar misconceptions.

Another incorrect model presented by Koulaidis and Christidou (1999) shows that students think the greenhouse effect is caused by dust and particles suspended in the atmosphere. These dust particles absorb the heat and cause an increase in temperature. With the misconception of dust causing the greenhouse effect, students also think that the greenhouse effect decrease the air quality (Koulaidis and Christidou, 1999). Indoor air quality is shown to cause physiological problems like headaches and reduced work capacity at 1000 ppm (FHI, 2015). The concentration of CO_2 is currently at 420,2 ppm and rising (NRK, 2022).

2.2.4 Origins of misconceptions

The origins of misconceptions can be plenty, as they are often based on the individual's own experiences. Misconceptions across different age groups can occur. Boyes et al. (1993) suggest that a common understanding can occur in individuals who are part of the same culture. This shared understanding can be based on logic. However, when the logic it is based on is incorrect

misconceptions occur (Ausubel et al., 1968). There is also the issue of students (and the general public) not being confronted with their misconceptions. When students are not aware they suffer from misconceptions, then they cannot change their cognitive structure, and thus the misconceptions are unchanged (Gautier et al., 2006).

When students were asked where their knowledge of environmental processes came from, studies have shown students often get their environmental concepts from televised media and news (Rajeev Gowda et al., 1997; Boyes and Stanisstreet, 2001). Blaming television for the origins of misconceptions is an easy scapegoat. As Rajeev Gowda et al. (1997) discuss how it is hard to completely cover environmental topics in the science classroom, as understanding the concept often requires interdisciplinary topics. In order to grasp the complexity of environmental sciences, students need to be familiar with physics, chemistry, biology, and geology, as well as the historical development of humanity and the politics of how we try to fix environmental challenges. Students report that they find chemistry hard since chemistry is often regarded as too academic and not relatable for the students in their everyday life (Treagust et al., 2000). Little do these students know that this climate change they keep hearing about revolves around chemical principles.

Some misconceptions can be traced to have originated from the curriculum itself. Choi et al. (2010) looked at common misconceptions regarding the greenhouse effect and compared them to illustrations, models and explanations in multiple science textbooks. Their study concluded that science textbooks could be responsible for causing misconceptions. One example is how textbooks represent heat from the earth like an arrow bouncing in the atmosphere as it is stuck between the surface and a layer in the atmosphere. This model supports the misconception that CO_2 traps heat in a distinct layer in the atmosphere. One way to mitigate misconceptions originating from inaccurate representations of models would be to show multiple different views, models and interpretations of the concept (Choi et al., 2010). More variation in teaching methods gives students different experiences and enhances their cognitive structure.

3 Method

This section of the study covers the research design of the survey. More specifically, this section explains how the research method was chosen and who the participating students are. Purposeful questions are crucial for both a qualitative and a quantitative research method; this section covers the set of questions used in the survey and the misconceptions each question aims to map. In addition, this section covers both the data collection process and data analysis.

3.1 Choice of method

The aim of the study was to map misconceptions concerning the carbon cycle in lower secondary and upper secondary schools in Norway. There are two possible approaches to use for investigating this. One approach is to conduct qualitative interviews with students, where their responses map their understanding. A qualitative method is excellent for investigating students' reasoning and reflections. However, the interview sessions can be different for each participant. The data analysis for an interview is time-consuming as the data has to be recorded and transcribed. The analysis suffers from a subjective interpretation of what the participants is communicating. As this methods suffer from time restraints, the sample size tends to be small. Thus a qualitative method is a deep analysis of a small group of participants.

The second approach is a quantitative survey. A survey consists of a standard set of questions to which the participants respond individually. The questions can have correct and incorrect answers, or a set of statements to which the participants must agree or disagree to varying degree. The data is quantifiable as the number of responses to each option given in the survey. A survey requires planning as each question must have a reason behind it. However, a survey is quick to conduct. Thus, a survey is suitable for evaluating a large group of participants. Furthermore, the results from a survey are suitable for seeing trends in options and understanding a population. Therefore, this study's choice of method is a quantitative survey.

3.2 Participant selection

The target demographic of interest in this study is young adults between the ages of 15 and 16. However, to map all misconceptions among young adults across Norway, every 15 and 16-year-old would have to participate in the survey. Such an approach was not feasible to complete. Thus a representation of the population is needed. A representation of participants should contain random selection from the target demographic. When the representation is random, then one can assume results are representable of the entire population (Gleiss and Sæther, 2021). For this study, a random selection was not used, thus the results can not be concluded to be representative of the entire demographic.

For lower secondary school students, two schools were contacted and asked if they were interested in letting their students participate in the survey. Both schools accepted the request. The lower

secondary schools will be referred to as *school A* and *school B*. School A was chosen based on acquaintances with teachers at the school. There are above 500 students who attend school A, and the location is close to the city centre. Two teachers agreed to participate. Each teacher was responsible for two classes each, resulting in four classes from school A participating in the survey. School B was contacted based on a recommendation from a friend who worked there. School B is located in a suburban area approximately 10 km from the city centre and has approximately 230 students. The teacher who was contacted was able to gather three classes of students who were given the opportunity to participate in the survey. Seven 10^{th} grade classes from schools A and B participated in the survey.

For upper secondary school students, one upper secondary school was contacted and asked if they were interested in participating in the survey. The upper secondary school is located approximately 3 km from the city centre, and about 900 students attend the school. The upper secondary school will hence be referred to as *school C*. The school in question was contacted based on acquaintances from teaching practice training at that particular school. Three teachers responded positively to letting their students participate in the survey. Two teachers were responsible for one class each, while the third teacher was responsible for two classes. It resulted in four 1^{st} grade upper secondary classes participating.

3.3 Creating questions for the survey

The study aimed to map what misconceptions students in the lower secondary and upper secondary school have concerning the carbon cycle. As the method of investigation is a survey, the questions need to be predetermined. Some questions address misconception which were already known to be common among children and students as presented in sections 2.2.2 and 2.2.3. In addition to known misconceptions, other difficult concepts were thought of and discussed during supervising conversations and included in the survey to investigate how students perceive these difficult concepts. The following eight parts represent areas of possible misconceptions among students: "the solubility of CO_2 in water", "natural carbon capture", "sources of CO_2 emissions", "CO_2 from biofuel", "CO_2 in the atmosphere", "CO_2 and its effects on plant growth", "the greenhouse effect" and "humans changing the climate, and willingness to stop the change". The questions were worded so to be understandable for the participants reading level. An overview of all questions in both Norwegian and English are presented in appendix A.1 and A.2 respectively. And if they accepted to participate in the survey, they could not skip any questions or the website would prompt an error message. Thus all participating students had to respond to all given questions.

3.3.1 Participants demographic

In order to categorize the students, some background information was asked for. The first page displayed question 1: "do you want to participate in the survey?". The option given was "yes" and "no". In order to proceed with the survey, the participants were forced to answer the

first question. If the participants chose the option "no", the survey would end and no further questions were given. On the other hand, if the participant chose the option "yes", the survey would continue to the next page of questions.

The second page displayed questions 2 and 3. Question 2 asked: "Gender?" to which the participants had four options. The options given were: "boy", "girl", "other", and "does not want to answer". The option "other" was included for students who, for some reason, did not fit into the first two options. The option "does not wish to answer" was included as a gender anonymous option for participants concerned for their privacy.

Question 3 was "Which school do you go to?". The options to question 3 were the names of the different schools that participated in the survey, thus "school A", "school B", and "school C". For participants who selected schools A or B, the survey would continue to the next set of questions. Finally, participants who chose school C were given question 4: "which lower secondary school did you attend?" This question was aimed to map if there were any differences in responses based on which lower secondary school participants at school C had attended previously.

3.3.2 The solubility of CO_2 in water

The first part of the survey is related to possible misconceptions concerning the solubility of CO_2 in water. These questions relate to the concept of using the ocean as a means of carbon capture and how the dissolution of CO_2 affects the oceanic ecosystem.

Question 5 was: "does CO_2 dissolve better in cold or hot water?". The participants were given five options to choose from in their responses. Options were "(a) hot water", "(b) cold water", "(c) temperature does not affect solubility", "(d) CO_2 does not dissolve in water" and "(e) do not know". The options "hot water" and "cold water" were given in the title of the question. In contrast, the options (c) and (d) were included as options if the participants did not think hot or cold water was correct. The question aimed to see how students think the dissolution of CO_2 is affected by temperature. Options (a), (c) and (d) are possible misconceptions students could possess. Another possibility was that participants did not know the answer. That is why option (e) was included.

Question 6 continued with the theme of dissolving CO_2 in water. The question was: "If CO_2 dissolve in water, does it affect the pH of the water?". The participants were given four options: "(a) lower pH (more acidic)", "(b) higher pH (more alkaline)", "(c) no change in pH" and "(d) do not know". The aim of question 6 was to investigate if students grasp the concept of dissolved CO_2 affect pH. The four options were designed as the only possible changes in pH as they can either decrease, increase or stay the same. Once again, an option was included for students who did not know the answer. Options (b) and (c) are the misconceptions to this question.

The last question in this part will look at how the dissolution of CO_2 affects ocean life. Question 7 was: "Can an increase in CO_2 concentration in the ocean be beneficial to ocean life?" The

four options given was "(a) true", "(b) false", "(c) both" and "(d) do not know". Options (a) and (b) were chosen for students who believe dissolution of CO_2 is either good or bad for marine life. Option (c), however, was included as an option for participants who believe that some processes in the ocean could react differently as some marine life could benefit from an increase in CO_2 while others would not. Option (d) was an option for participants who did not know the answer or did now understand the question. The question is not simple, as the ocean ecosystem is complex. The question is worded if CO_2 concentration could benefit ocean life. It depends on the life form. Some ocean life could be sensitive to changes in temperature, while others could be sensitive to changes in pH.

3.3.3 Natural carbon capture

The second part of the survey was natural carbon capture. This part was included to see what processes students regard as carbon capture in the natural carbon cycle. The part about natural carbon capture consisted of only one question, which was question 8: "which of these options can be denoted as natural carbon capture?". Question 8 consisted of five options where the participants could select multiple options. The option available to choose from were: "(a) solubility in water", "(b) photosynthesis (plant growth)", "(c) oil", "(d) natural gas" and "(e) do not know". Options (a) and (b) are part of the fast carbon cycle, and options (c) and (d) are part of the slow carbon cycle. Thus all options can be denoted as carbon capture except for option (e).

3.3.4 Sources of CO_2 emissions

The third part of the survey investigated what the participants consider as sources of CO_2 emissions. This part consisted of two questions: questions 9 and 10. Question 9 asked: "which of these options are sources of human CO_2 emissions?". As there are many sources of CO_2, question 9 had 18 options. Participants could choose multiple options. The options to choose from in question 9 were:

"(a) Gas for plants", which was included as plants produce CO_2 gas during periods with little to no light. Options (b) and (c) were "Transportation (cars, boats and planes)" and "Industry", which perhaps are the most well-known sources of CO_2 emissions. The option "(d) acidic rain" was included as an option based on students' misconceptions. Similarly, option "(e) ocean plastics" was included based on the misconception that littering causes the greenhouse effect. Finally, option "(f) gases from animals" was based on animals producing CO_2 in order to produce energy.

The topic of the following options was energy production. First, option "(g) nuclear power plants" was included to investigate if participants have misconceptions concerning CO_2 production from nuclear power plants. The next option related to energy production was an option "(h) hydro power plants", which also is a greener alternative to fossil fuels and produces low about of

CO_2 emissions. Possible uncertainties to options (g) and (h) as the participants not clarifying if their choice includes the constructing or just the emissions from energy production at the power plants. The third option related to energy production was an option "(i) oil production", which is considered to be a significant source of CO_2 emissions (Ritchie, 2020).

The following three options all address the emissions from organic matter. The options were: "(j) burning of wood", "(k) biofuels", and "(l) forest fires", which is based on the same process as an option (j) "burning of wood". However, forest fires can occur naturally or be man-made. As wildfires are becoming more frequent in some regions of the world, it is interesting to see what students think about forest fires affecting CO_2 emissions.

Option "(m) death of species" was inspired by the decomposition of dead animals as more species are at risk of becoming endangered. The endangerment of species can be considered an environmental-unfriendly action. Thus could such an action mistakenly cause CO_2 emissions.

Options "(n) farming" and "(o) waste/trash" were inspired by a list of sources of CO_2 emissions (Gaardsted, 2021). There was no specific misconceptions about what this option was aimed at. These options were included just as sources of CO_2 emissions.

The last three options were not examples of sources of CO_2 emissions or based on any misconceptions. Option "(p) none" was included as an option for participants who did not believe any of the examples were sources of CO_2 emissions. Option "(q) do now know" was an option for students who did not know if any of the given options were examples of CO_2 emissions. This option also served the purpose of giving an option to participants who did not care to respond truthfully.

The last option to question 9 was an option "(r) other". The design of option (r) was to give the participant other examples of CO_2 emissions which were not included in the survey. Participants who selected option (r) were given question 10: "do you have another example of a human-made CO_2 emissions?". In order to respond to question 10, participants were required to submit a written short answer of an example of a source of CO_2 emission. This question also served a second purpose. Surveys are excellent at mapping misconceptions based on existing options. By having the participants give a written answer, they can share their conceptual understanding.

3.3.5 CO_2 from biofuel

The option for biofuels in question 9 needs further investigation. Thus question 11 was created. Question 11 gives the statement: "biofuels result in an increase of CO_2 in the natural CO_2 cycle" to which the participants could choose one of the options "(a) yes", "(b) no", and "(c) do not know". The idea behind this question was to see what the participants know about biofuel as a part of the natural carbon cycle. Biofuels are made from organic matter, which captures CO_2 when grown and releases CO_2 when burned. Thus, the growth of organic material and burning of the fuel does not introduce any additional CO_2 to the carbon cycle. However, when including the production of biofuels, the net CO_2 emissions are positive since it takes energy to produce

biofuels. If the energy source in based on fossil fuels, it will increasing CO_2 in the natural carbon cycle. That is why it is interesting to evaluate students understanding of biofuels concerning CO_2 emissions.

3.3.6 CO_2 in the atmosphere

The next part of the survey covers the topic of how CO_2 distributes in the atmosphere, the correlations between CO_2 levels and air quality as well as the abundance of CO_2 in the atmosphere. The following three questions were displayed on-screen at the same time. Question 12 asked: "how does CO_2 distribute in the atmosphere?". Participants were given five options. The options were: "(a) In the top layer of the atmosphere", "(b) in a layer in the middle of the atmosphere", "(c) in the lowest layer in the atmosphere", "(d) evenly distributed in the whole atmosphere" and "(e) do not know". Question 12 was designed to investigate the misconception of how CO_2 distribute in the atmosphere. The reasoning behind the options is such that participants who choose options (a) and (b) show signs of misconceptions concerning the distribution of CO_2. Option (c) is a logical response, as CO_2 are a heavier gas than oxygen and nitrogen. However, the option is incorrect. Option (d) was the correct response as CO_2 concentration does not change with altitude. Finally, option (e) is an option for participants who do not know the answer.

Question 13 asked the statement: "an increase of CO_2 results in worse air quality outdoors?". The option available to the participants were: "(a) true", "(b) false" and "(c) do not know". The inspiration for question 13 comes from the misconception that the greenhouse effect is caused by dust, particles and other air pollutants, which lowers the air quality. Option (a) support these misconceptions, while options (b) and (c) do not. Do students think that the increase in CO_2 concentrations outside will result in worse air quality in the same way as indoors?

The last question in the part of CO_2 in the atmosphere was question 14: "CO_2 is the most abundant greenhouse gas in the atmosphere?" The options given to question 14 were "(a) True", "(b) false" and "(c) do now know". The question aimed to see if there were any misconceptions about which gases students think are greenhouse gases and how much of these gases is present compared to CO_2. If the students respond with option (a) "yes", they might show misconceptions that since CO_2 is the most well-known greenhouse gas, it must be the most abundant greenhouse gas.

3.3.7 CO_2 and its effects on plant growth

So far, the survey has covered part regarding the ocean and the atmosphere. The next part covers CO_2 and its effects on plant growth. This part consists of two questions, the first being a question in the form of a statement. Question 15 asked: "An increase in CO_2 in the atmosphere results in increased plant growth?". The options participants could choose from were "(a) true", "(b) false", and "(c) do not know". This question was asked to get an insight into how

the students think plant growth is affected by an increase in CO_2 available in the atmosphere. If the participants choose option (a), they think that CO_2 is the limiting factor in plant growth. Otherwise, if option (b) is chosen, the student thinks that plant growth is limited by other factors such as access to water, nutrients or sunlight. Participants who respond with option (c) do not know which processes are limiting plant growth.

The second question concerning CO_2 and its effects on plant growth was question 16: The greenhouse effects will be reduced by planting more trees?". This question was also a true or false statement. Thus, the options to choose from was "(a) true", "(b) false" or "(c) do not know". This question aims to investigate if the participants think planting more trees is a feasible form of carbon capture to reduce the greenhouse effect.

3.3.8 The greenhouse effect

The second to last part of the survey was aimed toward the greenhouse effect, specifically what causes the greenhouse effects. Questions 17 and 18 asked similar questions, however, with different angles; question 17: "is the greenhouse effect natural?" and question 18: "is the greenhouse effect man-made?". The choices of options were the same for both questions. The options were "(a) yes", "(b) no" and "(c) do not know". For both questions, option (a) is correct. The greenhouse effect is both natural and man-made as humans enhance the effects with CO_2 emissions.

Question 19 asked, "what causes the greenhouse effect?". To this question, the participants were asked to choose which of the options available were causing the greenhouse effects. Participants could choose as many options as they liked. The options participants could choose from were "(a) methane", "(b) dust and particles", "(c) CO_2", "(d) water vapour", "(d) ozone", "(f) oxygen", "(g) solar rays", "(h) other" and "(i) do not know". Options (a), (c) and (d) are common greenhouse gases and is considered correct answers. Option (g) is also correct as solar rays are essential to the greenhouse effect. Option (d) stems from the misconception that dust and particles from pollution cover the earth and traps heat. Option (f) is not considered a greenhouse gas and is thus incorrect. Option (d) "ozone" was included to see if any participants had trouble differentiating between the greenhouse effect and the ozone layer. Option (i) was given as an option to participants who do not know if any of these examples are causes of the greenhouse effect.

The option (h) "other" was an option for participants who had additional examples of greenhouse effect causes. Participants who selected these options were given question 20: "can you write what you think causes the greenhouse effect?". A written short answer is a possible way for students to show what they believe causes the greenhouse effect.

3.3.9 Humans changing the climate, and their willingness to stop the change

The last part; "humans changing the climate" was included to evaluate to what degree the participants are willing to change their lives to stop climate change. Question 21 asked: "are humans capable of changing the climate?". The participants could choose from a range of agreements starting with options (a) "disagree", (b) "agree a little", (c) "somewhat agree", to (d)" agree". The lower grade of the agreement shows signs of the misconception that humans are not causing climate change.

The final question of the survey investigates if the students are willing to change their way of life to stop climate change. The question given to the participants was question 22: "are you willing to change your way of life to stop climate change?" The participants could choose from option (a) "no", (b) "to a small degree", (c) "to somewhat degree" and (d) "to a large degree". Both questions consisted of an even number of options. Giving an even number of options was to force the participants to lean toward agreeing or disagreeing. If there were an odd number of options, the participants could have settled for a neutral answer in the middle.

3.4 Data collection

The survey was conducted digitally using the survey creator *nettskjema.no*, which was developed as an anonymous survey tool by the University of Oslo (Nettskjema, 2022). The University of Stavanger's privacy department recommended nettskjema as the best survey tool for an anonymous survey. A single survey was created, and then a link was shared with the teachers in each class to publish on their educational platform. The students accessed the survey on their personal computers or digital learning device. Nettskjema allows the survey to be opened an closed by the creator. The survey was opened before entering each class and then closed to prevent students from submitting results after the class.

The date of the survey was scheduled with each teacher. Before the survey was conducted, students were informed orally about the survey, steps taken to maintain their privacy, their rights not to participate, and data deletion if they were to change their minds about participating. Participants were also given written information of the details about the survey as well as contacts information in case they had any questions. The information was given by researcher to ensure that the students understood that the survey was voluntary and not a part of the curriculum. The written information given to the participants is presented in appendix A.3. As all participants were 15 years of age or older and the survey was anonymous, and no personal or sensitive information about the students was collected. The students could consent to participate without parental consent (NSD, 2022).

3.5 Data analysis

After the survey was conducted, the dataset from nettskjema was downloaded as a file containing the results. The results were then imported into Microsoft Excel for data analysis. Using

logic commands in excel, the number of responses to each question was counted. Certain conditions were programmed into the logic, so to count responses from different genders and schools separately. Finally, relative percentages were calculated from each school and the total across all the participating schools. The gender percentage was calculated relative to the number of responses to each option. All percentages are rounded to the closed whole number, thus the uncertainty of the percentage is $\pm 1\%$.

4 Results and discussion

4.1 Participants demographic

Table 4.1: Participants demographic sorted by school and gender.

School	Boys	Girls	Other	Total participants	Did not participate
A	34	44	4	82	6
B	14	21	2	37	4
C	47	52	0	99	0
Total	95	117	6	218	10

In total, 218 participants across all three schools participated in the survey. A total of 10 students did not want to participate in the survey. This was done by either responding "no" to participate in the survey or by not opening the survey link provided by their teacher. School C had the most participants, with a total of 99 participants. School A had the second most, with 82 participants. School B had the fewest number of participants among all three schools, with 37 participants. On average, the participants used between four to six minutes to answer the survey.

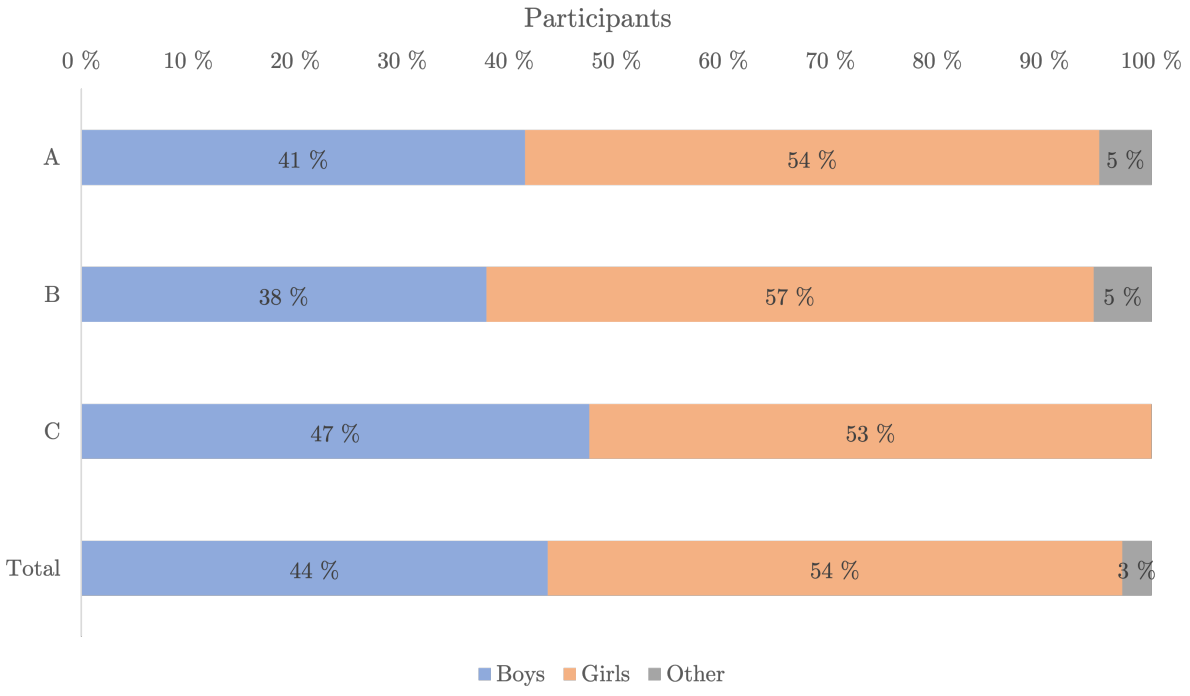


Figure 4.1: The distribution of participants in the survey was distributed according to school and gender.

The gender distribution across all three schools is presented in Table 4.1 and illustrated in Figure 4.1. These results show that girls are more represented at all participating schools. In total, girls represent 54% of the responses to the survey, while boys represent 44% of the responses. This

distribution has been considered when analysing differences in misconceptions between genders. In the survey, participants had the option to answer "other" or "Does not want to answer" to the question about gender. When analysing the results, these two options have been combined into the category "other". The gender category "other" consisted of less than 3% of the participants. Thus, no conclusions has been drawn concerning participants with "other" genders since the sample size was too small to be significant.

Information about question 4: "Which lower secondary school did you go to?" was not used in the data analysis. The variety of former lower secondary schools was wide, and the sample size from each school was small. Thus, information about which lower secondary school participants from school C attended was not taken into account when analysing data.

4.2 The solubility of CO_2 in water

4.2.1 Q5: Does CO_2 dissolve better in cold or hot water?

Results

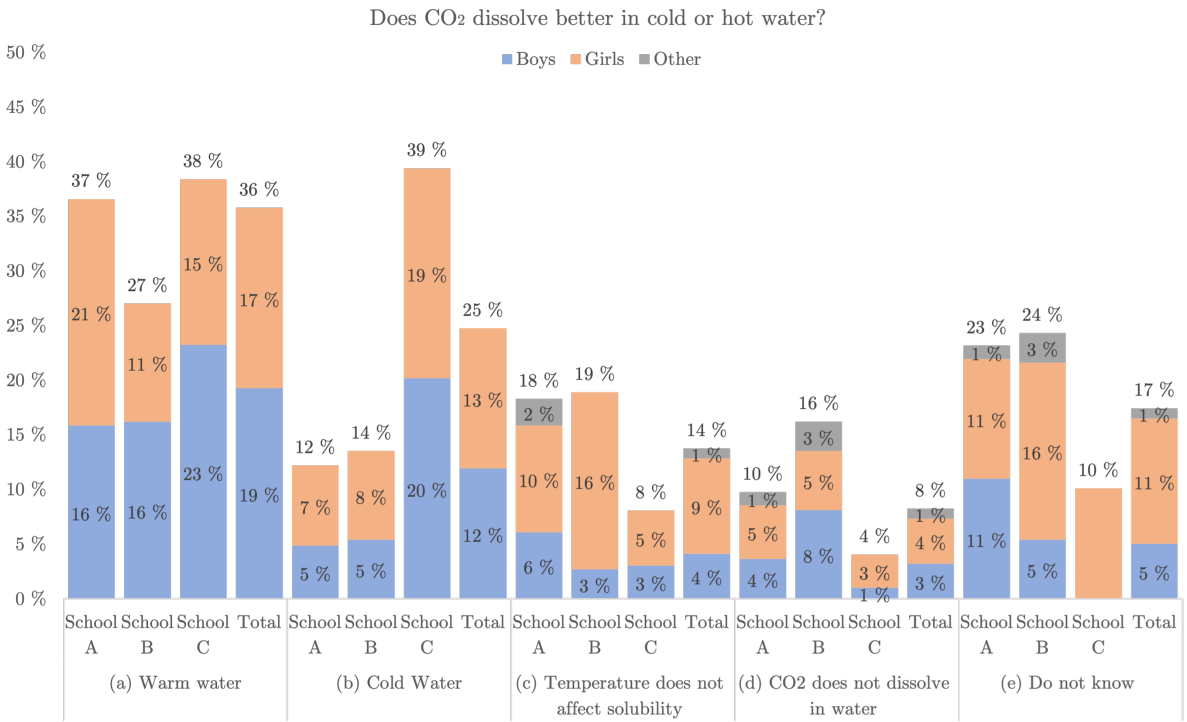


Figure 4.2: Results to questions 5 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.1 and A.2 in the appendix.

The response alternative with the highest number of responses was the option (a) "hot water", getting 36% of all responses. Responses from schools A and C were similar to the average response rate. School B had a 9% lower number of responses compared to the average. The

distribution among genders shows a lower number of girl choosing this option at schools B and C, but this option was more represented by girls at school A.

Response option (b) "cold water" got the second most responses with 25%. School A and B responded similarly, with respectively 12% and 14%. School C's responses were measurably higher at 39%. No particular differences in gender distribution compared to the participant demographic.

Option (c) "temperature does not affect solubility" have some responses, mostly at school A with 18% and school B with 19%. School C had a low response at 8%. Girls have responded with option (c) six times more than boys at school B. However, the sample size in total is seven, thus the sample size is small.

Option (d) "CO_2 does not dissolve in water" had 4% response rate at school C. School B had the most responses to this option with 16%, and school A at 10%. Overall, option (d) had the fewest responses to this question.

Option (e) "do not know" received 23% and 24% of responses from school A and B, as well as 10% from school C. Overall from girls chose option (e) compared to boys, except for school A, were the distribution between genders was even.

Discussion

Overall, the results to question 5 show that several of the participants possess misconceptions concerning how temperature affects CO_2 solubility in water. The misconception that CO_2 dissolves better in hot water is present across all schools participating in the survey. However, the students at school C show a better understanding of the fact that CO_2 can dissolve in water and that the dissolving rate is dependant on temperature, though they are split between cold and hot water.

The responses at school A and B are more og less similar to each other. A small number of the participants from schools A and B chose the correct option. Thus students at schools A and B possess the misconceptions that either CO_2 dissolves better in hot water, solubility is not dependet on temperature or CO_2 does not dissolve in water at all.

The percentages of participants who chose option (e) "do not know" show that many student at school A and B does not know the answer. There are several reasons why students could have chosen option (e). Either they have never been taught the solubility of CO_2 or have forgotten. Another possibility is that they did not understand the question. Finally, this option could have been chosen by participants who did not care to go through the survey correctly.

These results indicate that students use existing knowledge that hot solvents dissolve better than cold ones.The higher response rate at school C indicates some higher education level which mitigates the misconception that CO_2 is able to dissolve in water. However, the misconception that CO_2 dissolves better in hot water persists at higher levels of education.

4.2.2 Q6: If CO_2 dissolves in water, does it affect the pH of the water?

Results

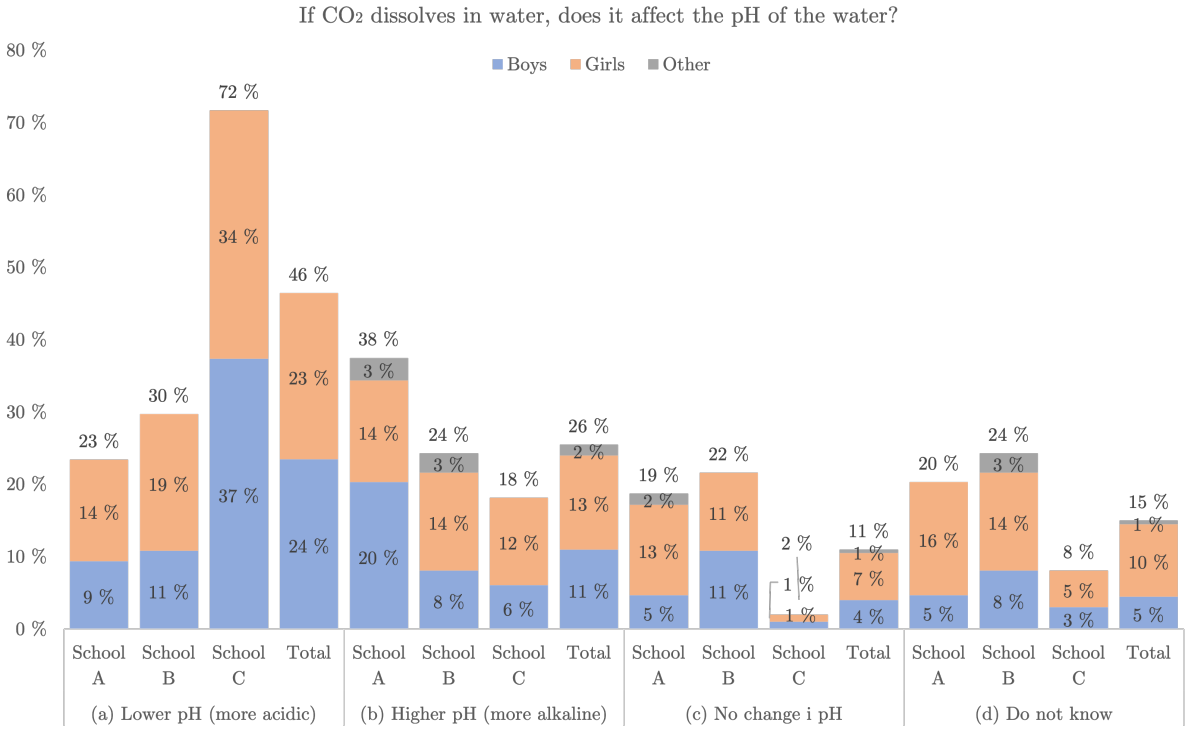


Figure 4.3: Results to questions 6 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.3 and A.4 in the appendix.

School C has clear spike at option (a), with 72% of the participants choosing this option. Continuing with school C, 18% of participants answered option (b), while only 2% chose option (c) and 8% option (d). The overall gender distribution at school C shows that 79% of boys chose option (a), while 64% of girls chose the same option. Girls have a slightly higher response rate to the other options compared to the boys.

School B has a more even distribution across all options, ranging between 20% and 30%. With this distribution, only 30% of participants answered correctly, which results in 70% of participants at school B responding incorrect. No distinct difference between genders at school B was found, as all answers have similar gender distribution to the total gender distribution.

The response distribution of school A is similar to school B, as the responses were distributed across all options. However, the number of responses shifted more towards option (b). At school A, 23% of students answered correctly, resulting in 77% incorrect answers. Analysing the gender distribution at school A, option (b) have more responses from boys, while option (c) and (d) were more common response for girls.

Discussion

The results to question 6 show that most of the school C students have a clear understanding that CO_2 dissolved in water lowers the pH of water and makes the water more acidic. Thus, students at school C show few signs of misconceptions regarding CO_2 and pH. However, in lower secondary school (school A and B), the students are more unsure as the distribution of response are spread out across all options. Therefore, many students at school A and B show presence of misconceptions regarding how CO_2 affects pH levels.

During a conversation with one of the teacher at school C, the teacher said that their class had just finished a topic in the curriculum concerning ocean acidification. This is a possible explanation why the results show a much better understanding between CO_2 and pH among the students at school C. Thus higher levels of education might help to mitigate the misconceptions found in lower secondary school.

One thing to note, is that school A had 18 fewer responses to question 6. The reason for this is because after the first class had completed the survey, a spelling error was discovered. Option (b) was written as "higher pH (more acidic)", which could be misleading to the participants. Thus the responses from that class were excluded from the results. The error was fixed before the rest of the participants responded.

4.2.3 Q7: Can an increase in CO_2 concentration in the ocean be beneficial to ocean life?

Results

Figure 4.4 shows that most participants chose option (b). In total, 71% of participants think an increase in CO_2 concentration is not beneficial to marine life. At school C, 83%, chose option (b), while a few chose options (a), (c) and (d). The students at school A mostly agree with option (b), getting 68% of the responses. Options (a), (b) and (c) got slightly higher number of responses with 6%, 18% and 7%, respectively. School B had the lowest percentage of option (b) responses with 46%. Thus, school B had a wider distribution of responses across all options. Options (a) and (c) have slightly more responses. However, school B has a larger portion of the participants choosing the option "(d) do not know".

Discussion

In the end, most participants agreed that an increase in CO_2 concentration in the ocean is not beneficial to marine life. Which is true for organisms that depend of calcium carbonate and some types of fish. Thus, students in lower secondary and upper secondary school poses little misconceptions with regard to the acidification of the ocean.

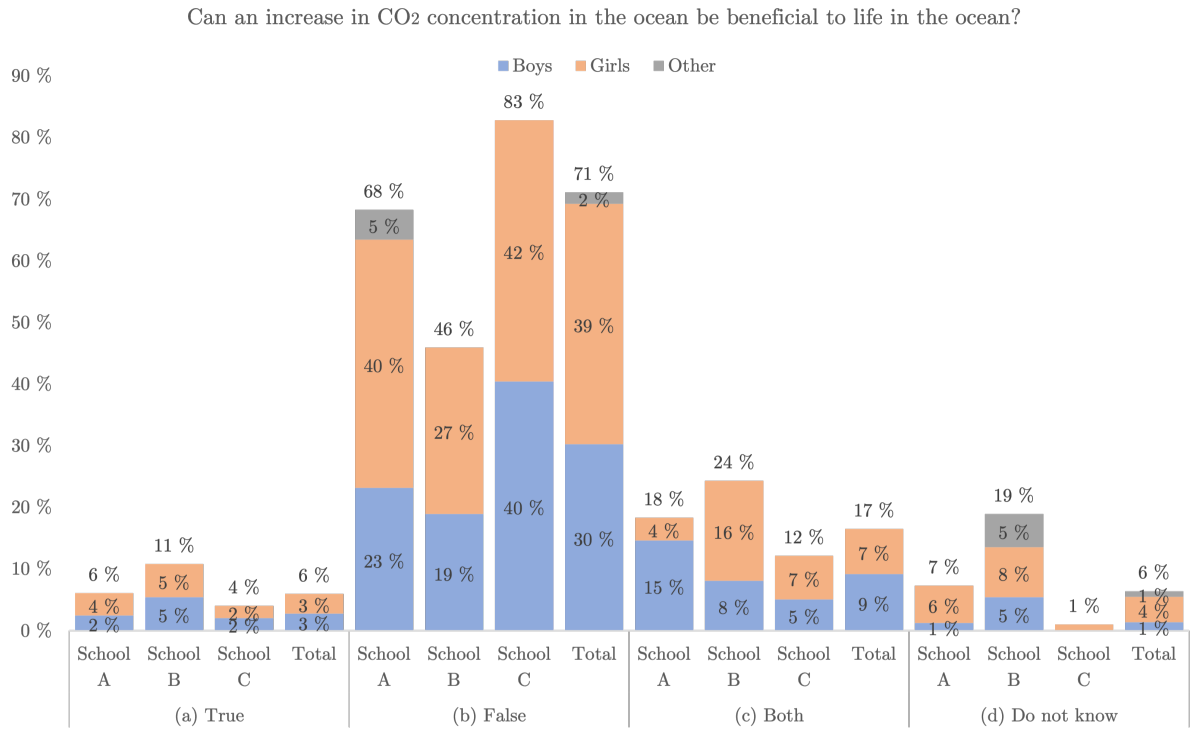


Figure 4.4: Results to questions 7 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.5 and A.6 in the appendix.

4.3 Natural carbon capture

4.3.1 Q8: Which of these options can be denoted as natural carbon capture?

Results

Figure 4.5 shows that some options have more responses than others even though all options are correct. The option with the highest number of responses was option (b) "photosynthesis (plant growth)", with a total of 70% of participants choosing this option. The response rates varied between 67% and 73%, thus their response rates were similar between schools. There was no apparent differentiation between genders either.

In total, 18% of participants chose option (a). There were some differences between schools as school A responded with 10%, school B with 27% and school C with 22%. Mainly boys chose this option at school A and C, while school B had a more representative gender distribution to their own demographic.

Option (c) "oil" got 28% of responses, with a somewhat even distribution between the schools (23% at school A, 27% at school B and 31% at school C). No apparent gender difference was observed at either of the schools.

Option (d) "natural gas" got 31% of responses, with uneven distribution across schools. School A had the lowest number of responses at 21%, while school B had the highest response rate at

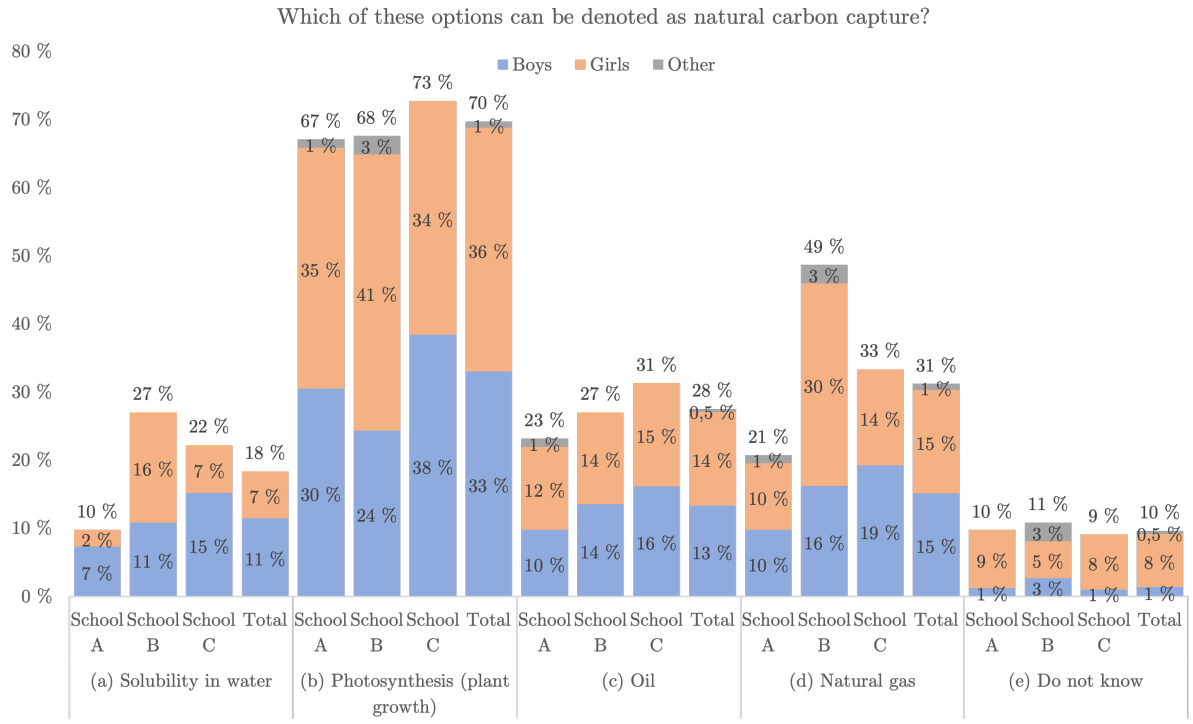


Figure 4.5: Results to questions 8 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.7 and A.8 in the appendix.

49%. School C had 33% of participants choosing option (d). There is a slight gender difference in school B and C, as more girls at school B and more boys at school C chose this option.

Figure 4.5 shos that 10% of participants do not know which option could be denoted as natural carbon capture. Most of these participants were girls across all schools.

Discussion

The results to question 8 indicate that some students have misconceptions about natural carbon capture. In general, students in both lower secondary and upper secondary school mistakenly did not regard CO_2 dissolving in water, oil and natural gas as being part of the carbon capture process in the natural cycle. Since primary school, the students have been taught photosynthesis and are thus familiar with the process. However, dissolving CO_2, oil and natural gas were not established concepts concerning carbon capture. One possibility could be that these concepts are too abstract or take too long time so students struggle to comprehend the natural carbon capture process. Another possibility could be a misconception that the concept of carbon capture is only regarded as industrial process and man-made.

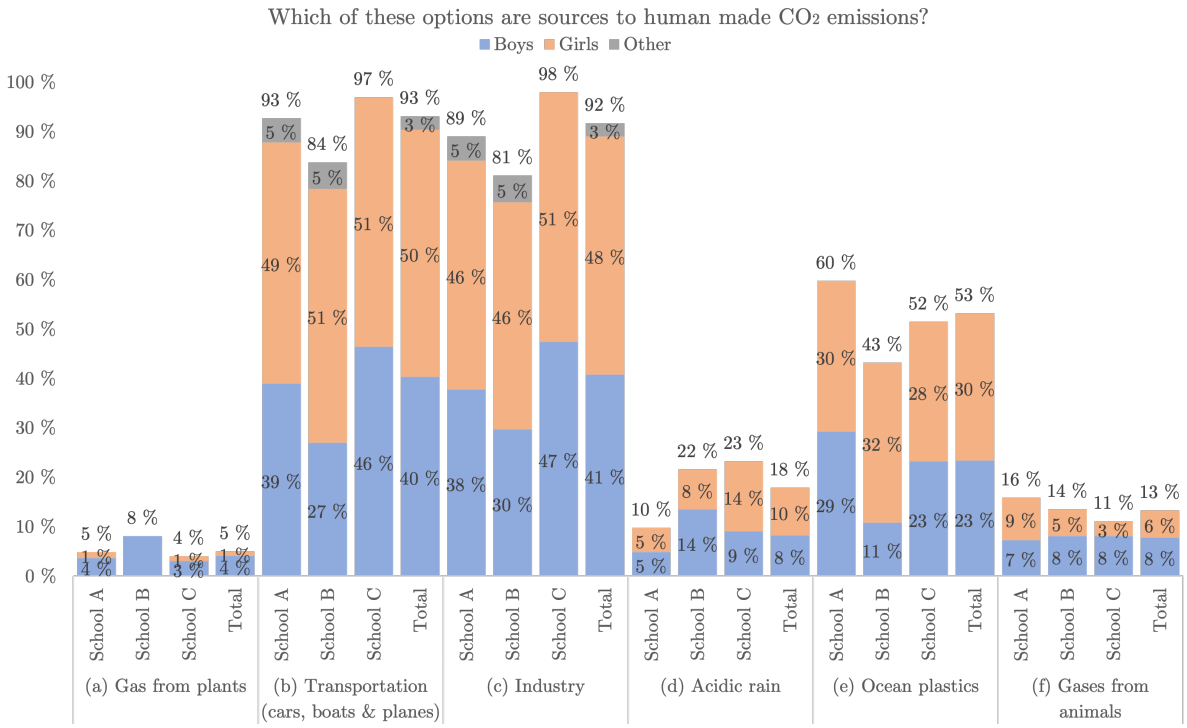
As the participants could choose multiple options, the individuals who responded with option (e) were further investigated to see if this option was the only option they selected. Across all schools, except for one individual, this is true. In other words, all except one chose option (e) as the only option to this question. One possible reason could be that the participants did not

know the answer. Another possibility could be that the participants did not understand the question.

4.4 Sources of CO_2 emissions

4.4.1 Q9: Which of these options are sources of human made CO_2 emissions?

Results

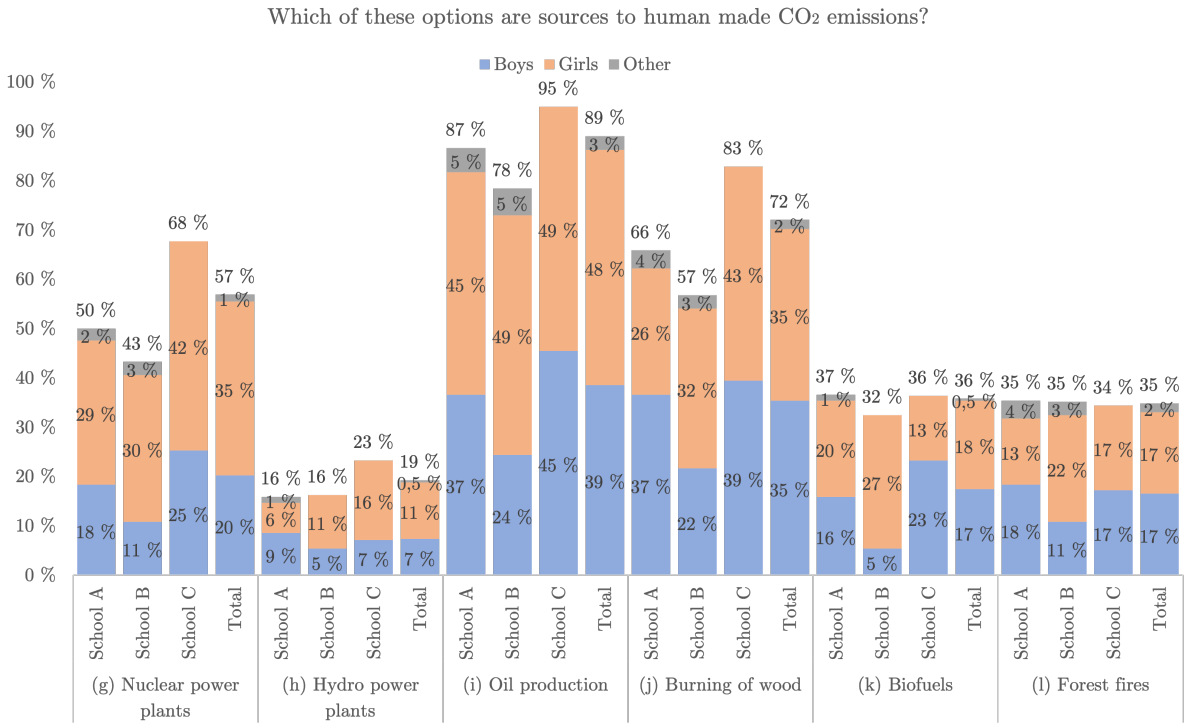


(a) The response of options (a) to (f) to questions 9.

Figure 4.6: The results to question 9 shown as percentages relative to the number of responses at that school. Each option shows the percentage at each school and the gender distribution at each multiple-choice option. The result of the questions is presented in Table A.9 as the number of responses and as percentages in Table A.10.

This questions consist of 18 options where participants selected sources of man made CO_2 emissions. Since this question had many options, the results list span multiple pages. The plotted results are split into multiple sub-figures 4.6a, 4.6b and 4.6c.

Options (b) "transport (cars, boats and planes)", (c) "industry", and (i) "oil productions" were the options with the most responses. In total approximately 90% of participants chose these options. In school C, over 90% responded on all these options, and in school A responded between 87% and 93%. School B had the lowest percentage of responses, between 78% and 84%. No perceivable gender differences was observed in these responses.



(b) The response of options (g) to (l) to questions 9.

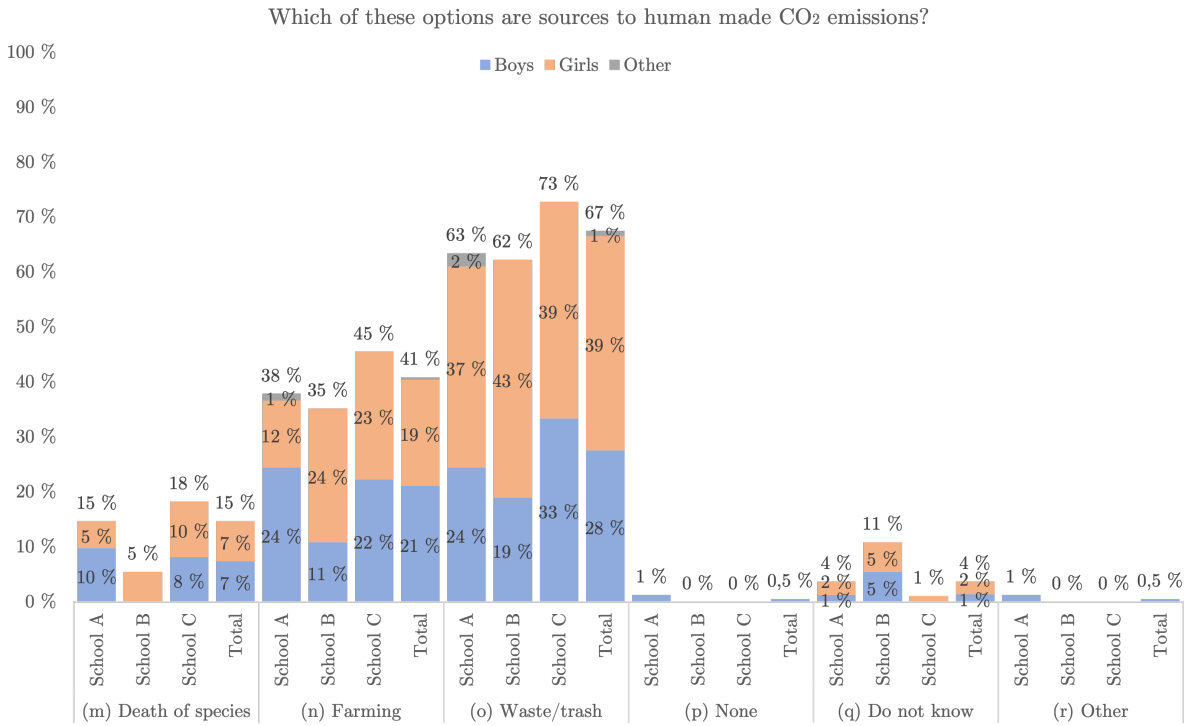
Options (a) "gas from plants", (d) "acidic rain", (f) "gases from animals", (h) "hydro power plants", (m) "death of species", (p) "none", (q) "do not know" and (r) "other" all had few to none responses. Options (d), (h) and (m) had some responses.

Option (e) "ocean plastics" resulted in 53% of the total responses. School A responded with 60%, school B with 43%, and school C responded 52%. The option (g) "nuclear power plants" result was 57%. School A and B responded slightly lower at 50% and 43%, respectively, while school C had more responses at 68%. At school B, show option (g) was chosen more among girls than boys. Option (o) "waste/trash" received a response rate between 63% (at school A) and 73% (at school C), with no apparent shift in the gender distribution.

72% of participants chose option (j) "burning of wood" as a source of human made CO_2. However, only 35% of participants chose option (l) forest fires. Option (k) "biofuels" received in total 36% with an even distribution across all schools. The gender distribution varied across schools. At school B, mostly girls chose option (k), while at school C mostly boys chose this option. 41% of the participants chose option (n) "farming" to be a source of human made CO_2 emissions. In total 67% of participants selected option (n) as a source of human made CO_2 emissions.

Discussion

The vast majority of the students correctly recognized transportation, industry and oil production as examples of man-made CO_2 emissions. These results are similar to finding by Pruneau et al. (2001) where students responded that reducing the pollution from driving cars will reduce



(c) The response of options (m) to (r) to questions 9.

CO_2 emissions. Thus, few students possess misconceptions regarding transportation, industry and oil productions with regard to CO_2 emissions.

However, results from question 9 do show misconceptions with regard to other sources of CO_2 emission. One of these misconceptions is that approximately half of all the students think that ocean plastics contribute to CO_2 emission. This includes both girls and boys. Ocean plastics is not good for marine life both large and small. However, it does not emit CO_2 into the atmosphere. Littering and ocean plastic is categorized by as being environmentally-unfriendly. Thus student create the misconception that since ocean plastics are bad for environment, it must contribute to CO_2 emissions and the greenhouse effect. Similar results have been found by both Rajeev Gowda et al. (1997) and Boyes and Stanisstreet (1993), where students regard littering and general pollution as a cause to the greenhouse effect. This is also supported by the high response rate to option (o) across all schools. However, this results begs the question if students chose option (o) because of waste disposal facilities burning waste or because they think the wast will end up in nature as pollution.

Another misconception found in these results is that about half of the students regard nuclear power plants as a source of CO_2 emissions. Such a result was also found by Boyes et al. (1993), were 58% of students in 9th and 10th grade agreed or slightly agreed to the greenhouse effect being made worse by nuclear waste. When looking at the gender distribution, option (g) was chosen more often by girls then boys. In total 45% of boys and 64% of girls chose this option. Thus supporting the claims made by Kumano-Ensby and Larsen (2022) that girls are more sceptical to nuclear power then boys.

The students appear to have some misconceptions concerning how burning of organic material contribute to CO_2 emissions.The high response rate to option (j) compared to the low response rate to option (j) appear contradictory as the source of CO_2 has the same origin. One possible reasoning could be that burning wood is a man made action, while forest fires occur naturally, hence it is not a man made CO_2 emission. The same applies to option (k) biofuels, as biofuels are made from plants. However, students maybe including the production of biofuels which could lead to net increase in CO_2 emission.

4.4.2 Q10: Do you have another example of human made CO_2 emissions?

Results and discussion

One participant chose option (r) in questions 9, thus only one participant was given question 10. The participant gave the written answer: "coal power plant" as a source of CO_2 emissions. The student is correct in recognizing coal power plants as a source of man-made CO_2, however this result can not be used to map any misconceptions in the target demographic. Thus, no conclusion can be draw from this.

4.5 CO_2 from biofuel

4.5.1 Q11: Biofuels result in an increase of CO_2 in the natural CO_2 cycle?

Results

The distribution of responses to this questions is spread out relatively evenly, although slightly leaning toward option (a). Option (a) was the response with the highest percentage, at 41%, options (b) and (c) both got 29% of the responses. This distribution across schools was relatively even, with schools A and C responding with 30% and school B responding with 24%. Schools A and C show no deviance in gender distribution. However, more girls at school B favour option (a), while boys at school B favour option (b).

Even though option (c) received the same total percentage of responses as option (b), the distribution across schools was different. School A had 18% of participants respond with option (c), while school B responded with 32% and school C with 37%. No apparent gender differences was observed at either school.

Discussion

These results show uncertainty on how biofuels contribute with CO_2 to the natural CO_2 cycle among lower secondary and upper secondary school students as a total of 41% of participants answered incorrectly, and 29% did not know the answer. These results indicate that many students either having misconceptions or a knowledge gap concerning CO_2 emissions from biofuel.

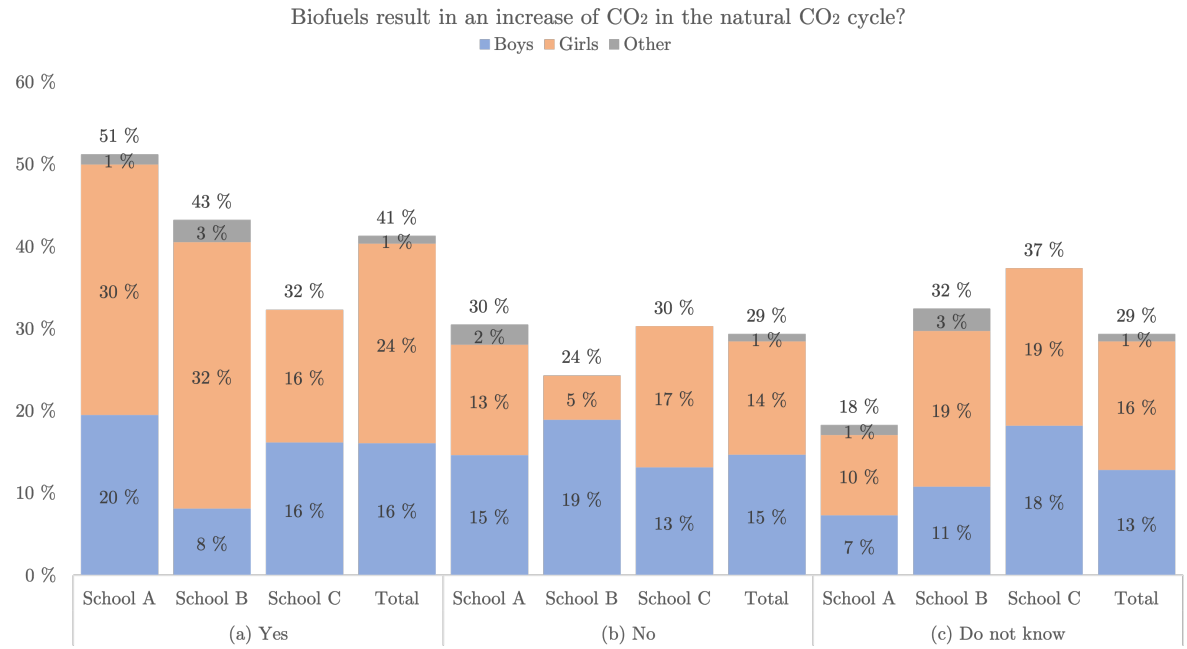


Figure 4.7: Results to questions 11 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.11 and A.12 in the appendix.

One possible factor is that the students included the production of the biofuel into the CO_2 footprint.There is also the possibility the students did not understand the question. Thus, a more precise question could help clarify the results to find out if the students possess misconceptions concerning biofuels.

4.6 CO_2 in the atmosphere

4.6.1 Q12: How does CO_2 distribute in the atmosphere?

Results

Figure 4.8 show option (a) receiving 31% of the total responses. School B and C had slightly lower respond rates at 24% and 27%. School A had more responses (39%). School A and C show no deviation in the gender distribution. However, more girls responded with option (a) than boys at school B.

Option (b) was the option with the lowest percentage of responses at 9%. School A responded the lowest with 7%, school B the highest with 11% and school C with 9%. The gender distribution was approximately equal across all schools.

Option (c) received the second highest response rate at 21%. School A and C responded similarly to the total at 23% and 20%. School B had a measurably higher percentage of response at 38%.

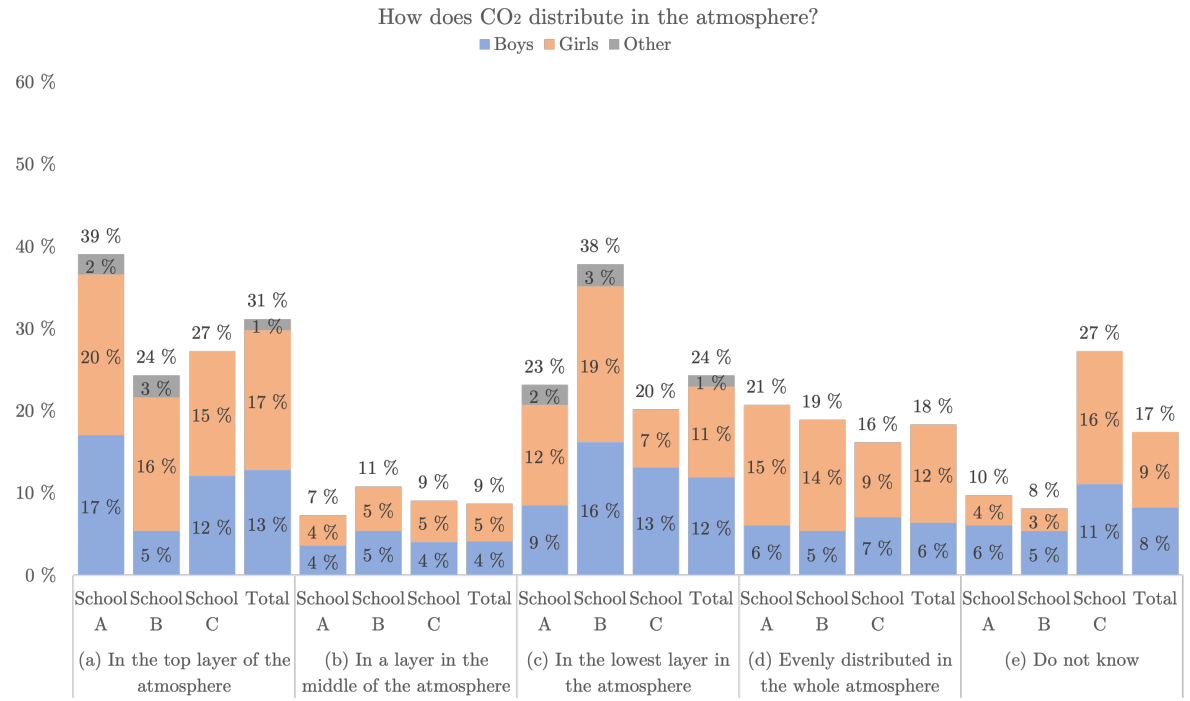


Figure 4.8: Results to questions 12 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.13 and A.14 in the appendix.

Overall the gender distribution was representative of the survey demographic except for school C, where boys were responsible for more than half of the responses.

The distribution to option (d) was more evenly distributed across all schools. In total, 18% of participants responded with option (d). School A responded with 21%, school B 19% and school C 16%. In general, this option was more favoured among girls than boys. The case was most apparent at schools A and B.

Option "(e) do not know" received a responses rate of 17%. School C had the highest percentage of responses with 27%. The responses from schools A and B were lower at 10% and 8%. In total, the gender distribution was evenly distributed. However, boys were more likely to choose option (e) at school A and B.

Discussion

The results to question 12 show that the 31% of students who chose option (a) poses the misconception that CO_2 form a layer in the top of the atmosphere which traps heat. Even though this is incorrect, it does not mean these student have difficulties differentiating the greenhouse effect and the ozone layer, as the question does not relate to the ozone layer. However, the similarity of their conceptual understanding gives an indication that the students who chose option (a) could be mixing the concepts.

Students who chose option (c) could perhaps be explained by the understanding that CO_2 is a heavier gas than oxygen and nitrogen, thus being distributed in the lower parts of the atmosphere. The participants who chose option (d) could have a conceptual understanding of gas distribution, that it disperses everywhere. Another interesting result to this question was the high amount of participants at school C who do not know how CO_2 distributed in the atmosphere.

4.6.2 Q13: An increase of CO_2 results in worse air quality outdoors?

Results

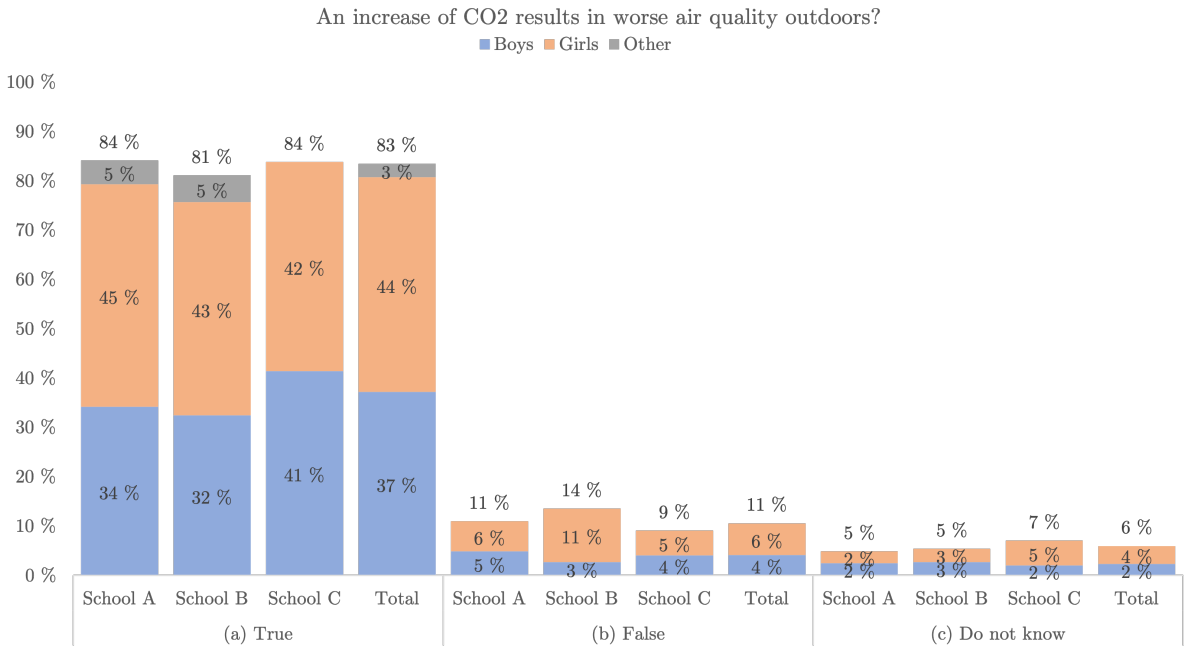


Figure 4.9: Results to questions 13 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.15 and A.16 in the appendix.

The results to question 13 shown in Figure 4.9 show almost a unanimous agreement across all schools that an increase in CO_2 will result in worse air quality outdoors. In total, 83% of the participants responded option (a), while only 11% chose option (b) and 6% chose option (c). There was no difference across schools and no apparent divinations from the norm in the gender distribution. One exception could be the participants at school B who chose option (b), where the gender distribution favours girls. However, the sample size was too small to draw any conclusions.

Discussion

These results show that most student think that an increase in CO_2 outside will result in worse air quality. No differentiation between schools and genders were found. Thus, the misconception that CO_2 worsen the air quality outside is not dependent on gender or education level. However,these result come with a degree of uncertainty as this question does dot take into account the students reasoning for thinking CO_2 will worsen the air quality outside. Thus, it is unknown if the students take air pollution, dust, particles or combustion exhaust into consideration when answering the question.

4.6.3 Q14: CO_2 is the most abundant greenhouse gas in the atmosphere?

Results

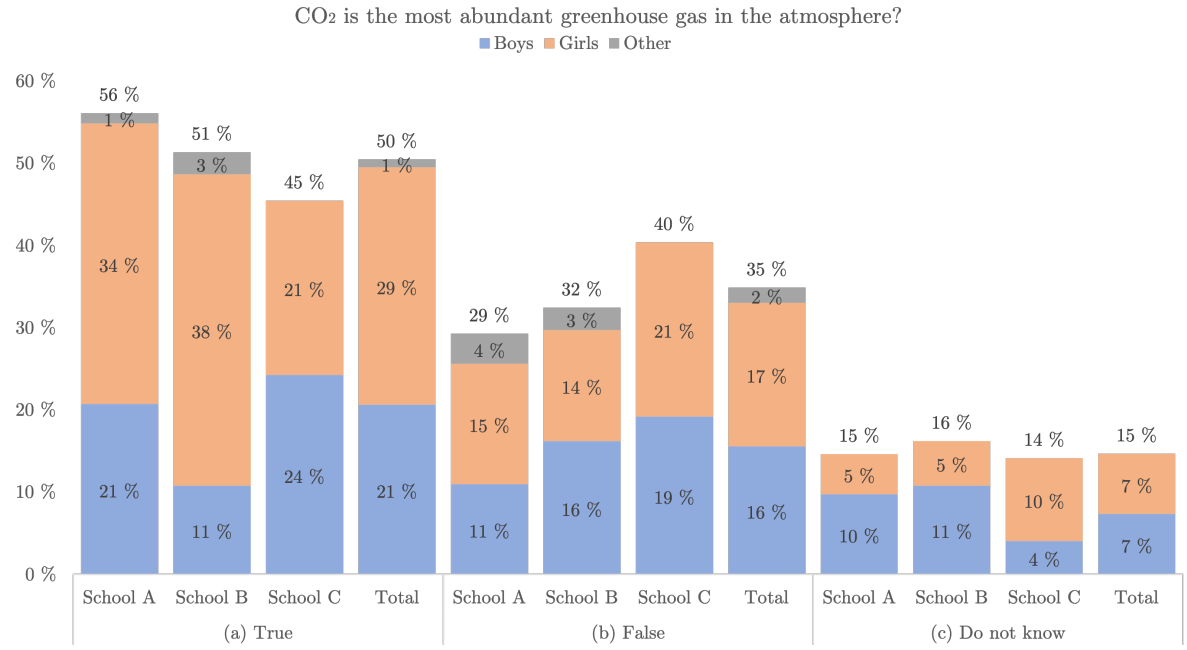


Figure 4.10: Results to questions 14 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.17 and A.18 in the appendix.

Results from Figure 4.10 show a decline in the response rate from option (a) to option (c), where option (a) has the most responses at a total of 50%. All schools' response percentages were between 56% and 45%, where school A responded with 56%, school B 51% and school C 45%. Option (b) received 35%, with school A responding with 29%, school B 32% and school C 40%. Option (c) had the fewest responses with a total of 15% and an even distribution between 14% and 16%.

The gender distribution for option (a) shows that girls at school A and B favoured option (a). However, at school C the opposite is true, that boys chose option (a) more often than girls. At school B this results in an increase in responses from boys to option (b) and (c). School A and B however, do no have measurable deviance in gender distribution to option (b). Option (c) received a slightly higher response rate from boys at school A and at school C girls chose option (c) more often.

Discussion

The misconception this question investigates is if CO_2 is the most abundant greenhouse gas in the atmosphere. Which it is not. The most abundant greenhouse gas is water vapour, and these results show that 50% of the participants have this misconception. In addition, 15% of participants do not know the answer to the question.Though the student could mix the concept of abundance and dependence. Even though CO_2 is not the most abundant greenhouse gas, it is the greenhouse gas which temperature of the earth depend on the most.

4.7 CO_2 and its effects on plant growth

4.7.1 Q15: An increase in CO_2 in the atmosphere results in increased plant growth?

Results

Results show that 66% of participants chose option (b) "false". The distribution to option (b) across all schools was consistent with the total percentage of responses. School A responded with 62%, school B 68%, and 69% of participants at school C chose option (b). In total, the gender distribution was slightly more shifted toward girls. Looking at the individual school, girls at school A and B chose option (b) more often than boys. At school C, however, the distribution was more evenly distributed.

Option (a) received 19% of the responses, with a somewhat even distribution. School A responded with 24%, school B with 22% and school C with 14% of participants. Option (a) was more prevalent among boys than girls. Option (c) received 15% with school A responding with 13%, school B 11% and school C 17%. At school A and B, the gender distribution was even, while more girls chose option (c) slightly more at school C.

Discussion

These results show that most participants believe that an increase in CO_2 will not increase plant growth even though plants depend on the CO_2 to live. Thus students do not think that CO_2 is the limiting factor for plant growth and that other factors such as nutrients, water, or light could be limiting factors.

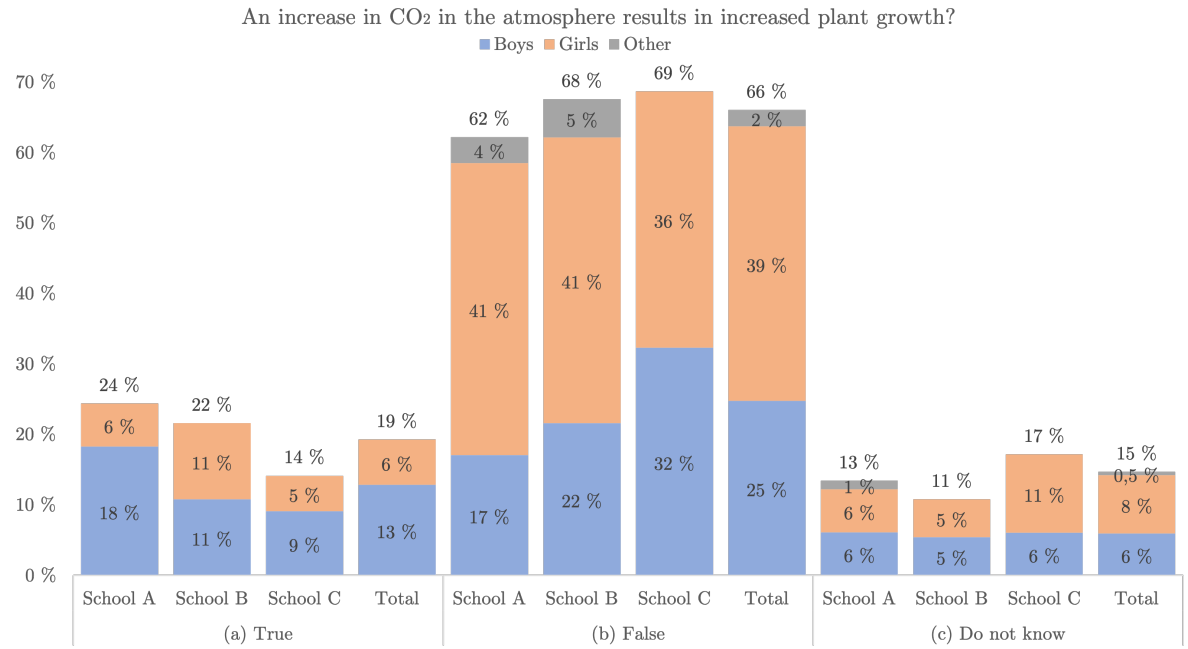


Figure 4.11: Results to questions 15 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.19 and A.20 in the appendix.

One possible misconception could be students thinking of CO_2 as emission from human activity. Hence CO_2 is unnatural and therefore not beneficial to plant growth. However, this misconception is not likely since 70% of the students correctly recognised plant growth as natural carbon capture.

4.7.2 Q16: The greenhouse effect will be reduced by planting more trees?

Results

The results presented in Figure 4.12 show that most participants believe that the greenhouse effect will be reduced by planting more trees, as shown by option (a) receiving 59% of the responses. School A and C results were similar to the total, where school A responded with 63% and school C with 61%.

Option (b) received 29% of the responses, with school A and C having 28% of participants choosing option (b). However, at School B, 35% of participants chose option (b). Option (b) was chosen slightly more often among girls than boys. Option (c) "do not know" received 12% of responses, whereas school A and B responded similarly to the total with 9% and 11%, respectively. Lastly, school B responded with 22% to option (c). The gender distribution to option (c) was a little mixed across schools, where boys at school A chose option (c) more often

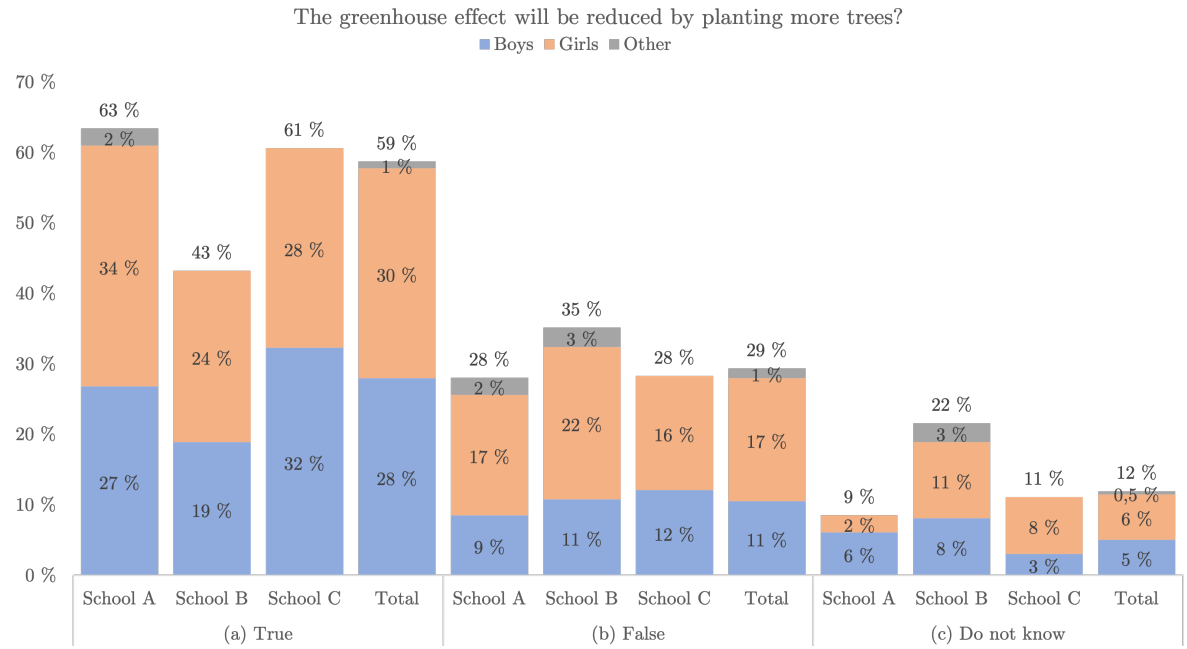


Figure 4.12: Results to questions 16 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.21 and A.22 in the appendix.

than girls, and the opposite was the case at school B and C. On average, the difference was negligible.

Discussion

Looking at the result for question 16, school A and C responded similarly to each other. More than half of the students believed planting more trees would reduce the greenhouse effect, and a third believed it would not. School B had fewer students responding with option (a) and more responses to options (b) and (c), indicating a more larger degree of uncertainty among students at school B on the effects planting trees have on the greenhouse effects. It is unclear why more than 40% of students do not believe or do not know if planting more trees will reduce the greenhouse effect. Perhaps they consider the CO_2 absorbing properties of algae to have a more significant effect than trees, or they are unfamiliar with the process of photosynthesis.

When comparing the results of question 15 and 16, the results appear contradictory as most students think that the higher levels of CO_2 in the atmosphere does not effect plant growth. However, with planting of more trees, the capture of CO_2 will increase. One explanation could be that students think that trees are currently absorbing as much as they can, thus more trees would contribute to the effort of carbon capture. However, more trees would also require other resources like nutrients and water, which according to question 15, is already the limiting factor

of plant growth.

4.8 The greenhouse effect

4.8.1 Q17 and Q18: Are the greenhouse effects natural or man-made?

Results

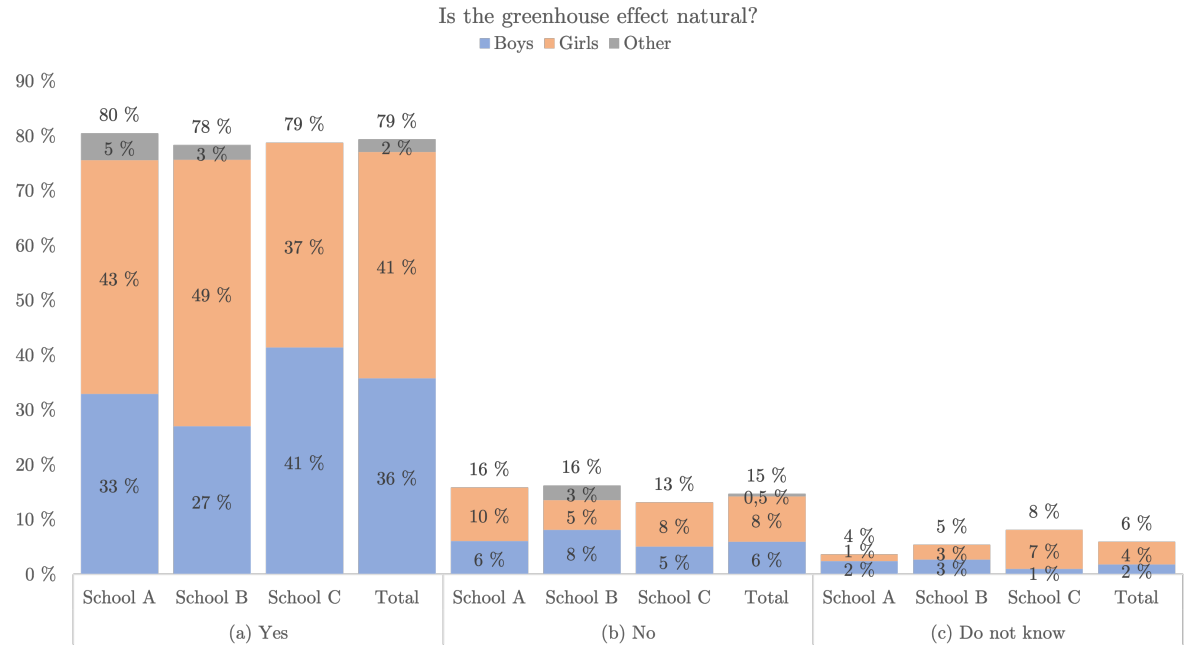


Figure 4.13: Results to questions 17 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.23 and A.24 in the appendix.

The results presented in Figure 4.13 show a clear agreement across all schools and genders that the greenhouse effects is a natural process. 79% of the participants responded with option (a) "Yes". Responses across schools were evenly distributed, with school A responding with 80%, school B with 78% and school C 79%. Option (b) received 15% of responses. This distribution was also very even, with each school responding between 16% and 13%. Lastly, a small group of participants chose option (c) "do not know" with a total of 6%.

The results of question 18 show similar results to question 17, though there are some differences. 69% of participants chose option (b) "yes". The distribution across schools was even similar to option (a) in question 17, the percentage was lower at 69% in total, and school A had 67%, school B 73% and school C 69% of participants responded with option (b).

Looking at option (c) "do not know", the response rate was approximately the same as question 17. Thus no conclusions could be drawn from those results. Option (a) received a total of 23%

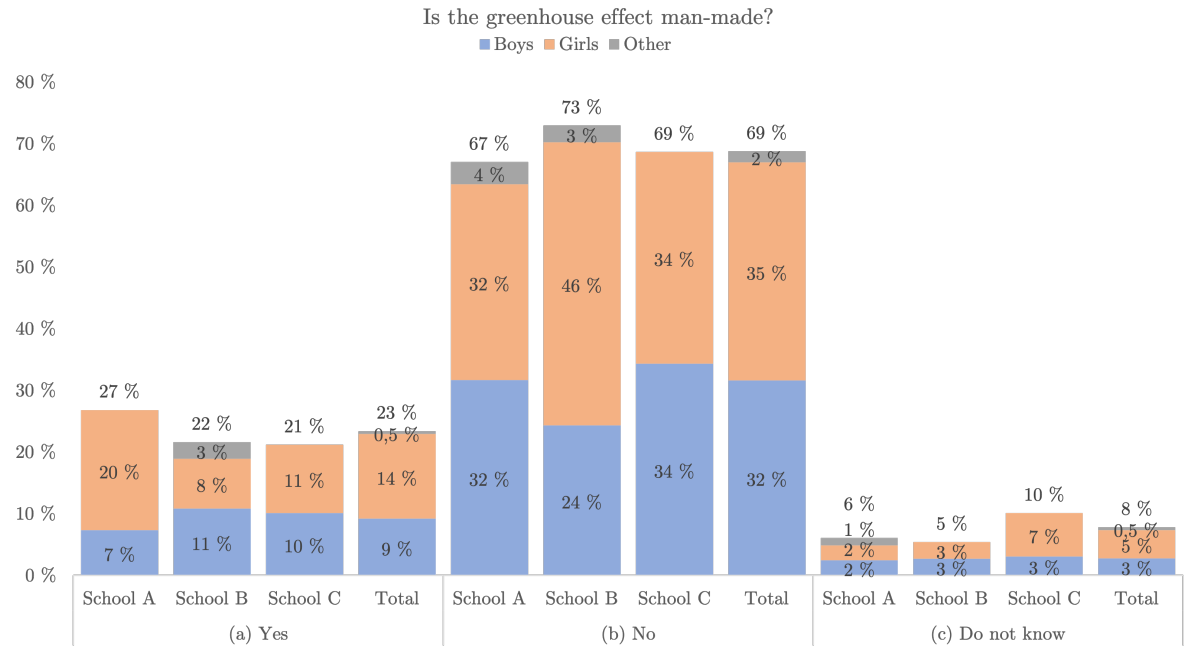


Figure 4.14: Results to questions 18 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.25 and A.26 in the appendix.

with similar responses at schools B and C. School A, however, had a slightly higher response rate at 27%. Gender distribution mainly was even except for school A, where girls had a higher response rate to option (a).

Discussion

Question 17 shows that most students grasp the concept of the greenhouse effect being a natural process. However, the 15% of students who responded with option (b) show posses the misconceptions that the greenhouse effect is only man-made. However, the question is perhaps not that easy as humans also contribute to the greenhouse effect, which is the next topic of discussion.

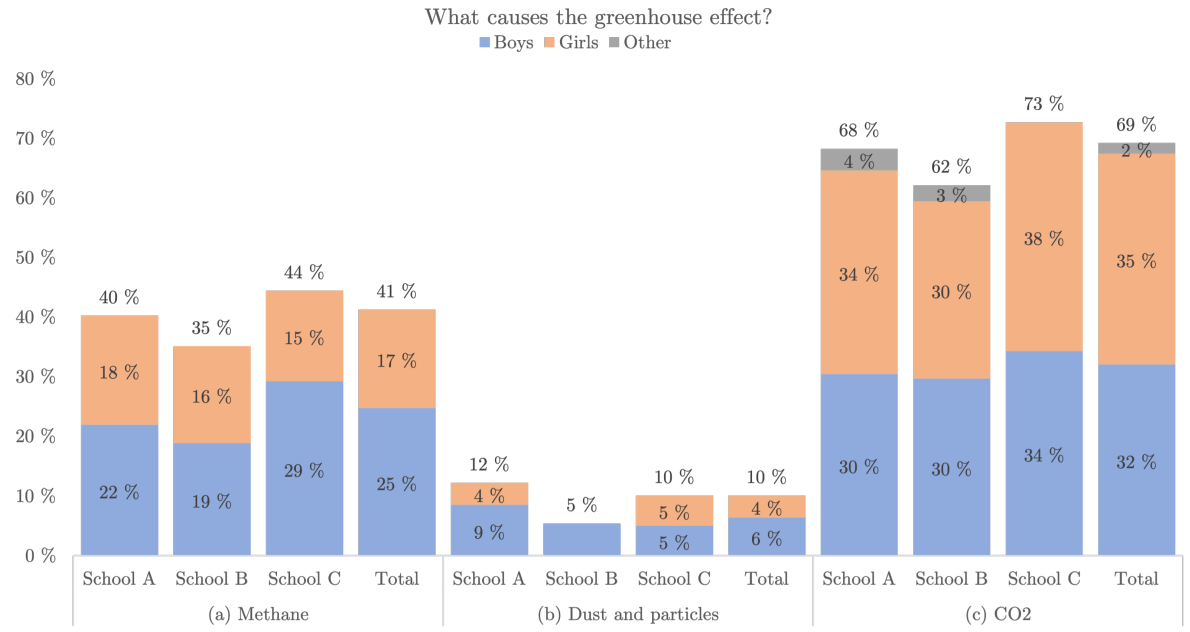
Comparing questions 17 and 18, most students responded that the greenhouse effect is natural and not man made. If the participants responded to option (a) "yes" to question 17, then it is likely the same student responded with option (b) "no" to question 18. However, option (a) increases by 10% and option (b) decrease by 10% when comparing question 18 and 17. Thus, 10% of students responded that the greenhouse effect is both natural and man made. Which results in 90% of students not thinking the greenhouse effect is both natural and man-made.

Questions 17 and 18 were shown to the participants simultaneously, which could have influenced them to choose that the greenhouse effect was not made if they had already chosen naturally. Thus, the response to question 17 influences the response to question 18. Another uncertainty

to the results is that the options given is very distinctive where the student had to response yes, no or do now know. However, in reality the question of natural compared to man-made is more granular, as both is true. Thus, students might have issues with choosing one or the other, when then in fact know it is natural with human contributions.

4.8.2 Q19: What causes the greenhouse effects?

Results

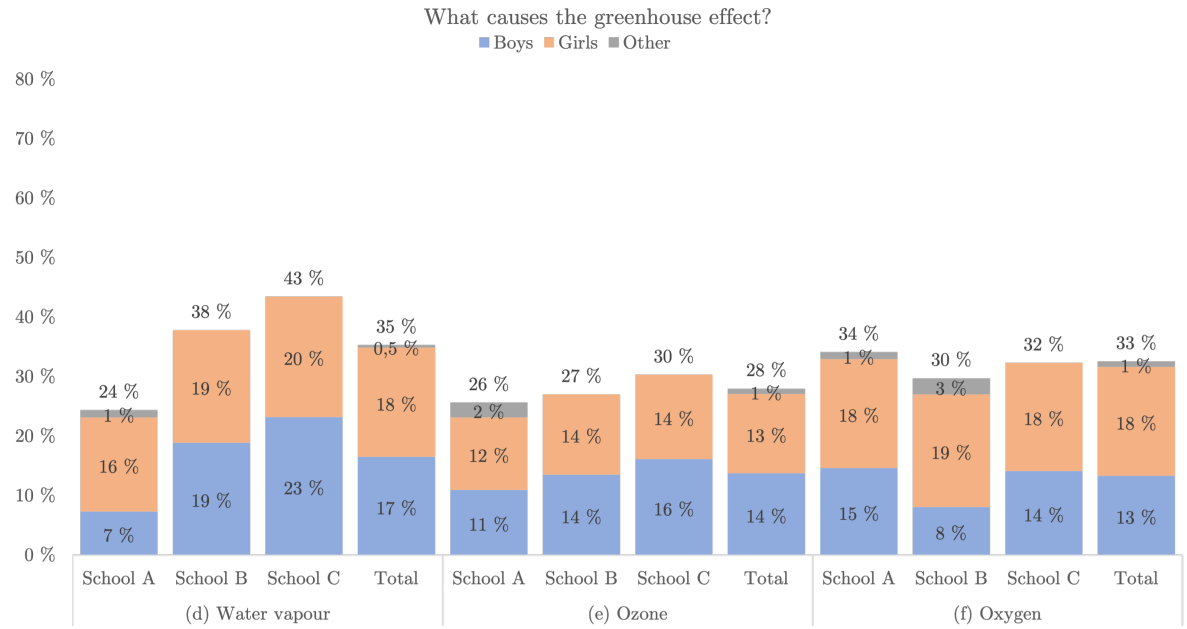


(a) The responses in percentages of options (a), (b) and (c) to question 19.

Figure 4.15: Results to questions 19 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.27 and A.28. As question 19 consisted of nine options to choose from, the results have been split into three Figures: 4.15a, 4.15b and 4.15c

Option (a) "methane" was chosen by 41% of participants. Some slight variations were observed across schools. At school A, 40% of students chose methane as a cause of the greenhouse effect. Slightly less at school B, where 35% of students chose methane, and at school C 44% of students selected methane as a cause of the greenhouse effects. In general, this option was chosen more often among boys than girls, as boys stood for 25% of the response while girls stood for 17%. The same trend can be seen across all schools.

Option (b) "dust and particles" received fewer responses as 10% of participants chose option (b). With school A having 12%, school B 5% and school C having 10% of participants choosing option (b) as a cause to the greenhouse effects. The gender distribution was even at school C, mostly boys at school A and only boys at school B.



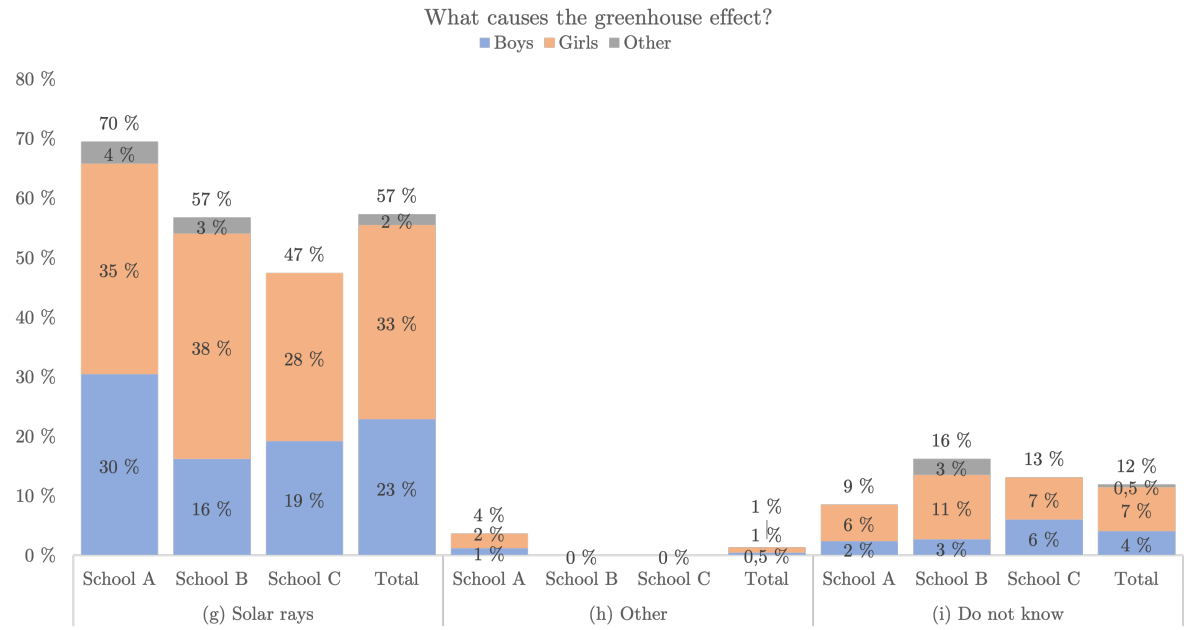
(b) The responses in percentages of options (d), (e) and (f) to question 19.

The next option was option (c) "CO_2" which, in total, 69% of participants chose as a cause of the greenhouse effect. There was some variation across schools. At school A, 68% of participants responded that CO_2 is a cause of the greenhouse effects. At school B, 62% of participants chose option (c), while 73% of participants at school C chose option (c). The gender distribution does not deviate from the participants' demographic. Thus, these results are representative of both girls and boys.

In total, 35% of participants selected option (d) "water vapour" as a cause of the greenhouse effects. The individual schools responded differently to this option. School A had the lowest percentage of responses at 24%. School B increased to 38%, then at school C, 43% of participants answered that water vapour causes the greenhouse effect. Most girls chose option (d) at school A, whereas the gender distribution at schools B and C were approximately equal percentage of girls to boys. Thus, an increase in boys responding was observed relative to the participant demographic at schools B and C.

Option (e) "ozone" received a total response rate of 28%, with all schools distributing close to the total. At school A, 26% of the participants chose option (e), at school B 27%, and in school C 30% of participants chose option (c) "ozone" as a cause of the greenhouse effect. The gender distribution was mostly even across genders. However, boys chose option (c) slightly more often than girls at school C.

In total, 33% of participants selected option (f) "oxygen" as a causes of the greenhouse effect. This result is consistent across all schools as the response rate at school A were 34%, school B 30%, and school C 32%. The distribution of genders shows that more girls chose option (f) over



(c) The responses in percentages of options (g), (h) and (i) to question 19.

boys across all schools. However, the results show only slight differences.

Figure 4.15c shows that in total, 57% of participants chose option (g) "solar rays" as a cause of the greenhouse effect. The school distribution show differences across schools. School A had the highest response rate at 70%, school B at 57% and school C the lowest at 47%. At school A, the gender distribution was similar to the gender distribution of participants at school A.

The last option to question 19 was an option (i) "do not know", which received in total 12% of responses. The response rate was lowest at school A with 9%, highest at school B at 16%, and school C had a response rate at 13%. Both girls and boys chose this option. However, girls were accountable for most of the responses at school A and B. At school A, the response rate between girls and boys was similar.

Discussion

From these results there are some interesting findings. Firstly, lets discuss the correct answers, which were options (a), (c), (d) and (g). Option (c) "CO_2" is the most recognized and well-known greenhouse gas. The whole theme of the survey have been linked to CO_2. Still, only 69% of the student selected this option, thus 31% of students did not choose CO_2 as an option for what causes the greenhouse effect. This misconception is not gender specific as an equal percentage of girls and boys did not regard CO_2 as a cause to the greenhouse effect. One portion of these participants could fall into the category of not taking the survey seriously and responding "do not know" to all questions to finish as fast as possible. However, these participants do not sum to 31%, thus a misconception or misunderstanding of the question is present.

The same goes of option (g) "solar rays", which as a necessity for the greenhouse effect. Which is why it is surprising that in total only a little more then half of the students consider solar rays as causing the greenhouse effect. These results indicate a misconception that solar rays are not part of what causes the greenhouse effects. The misconception concerning solar rays appear to be more prevalent in upper secondary school than lower secondary school. One possible reason could be students forgetting solar rays as part of the greenhouse effect. They mostly associate the greenhouse effects with greenhouse gases and forget that solar rays need to be present for the effects to occur.

The result that 35% of the students selected water vapour as a cause of the greenhouse effect show that most student do not know that water vapour is a greenhouse gas. There were noticeable differences between schools in this question as school A had a lower response rate than school B and C. This could give an indication of regional differences between schools and that higher levels of education mitigates the misconception to some degree. School A also show some differences between genders, as 17% of the boys and 29% of girls chose this option. This changes at schools B and C, where boys chose this option more often. Although these differences are noticeable, their significance are uncertain. However, it is also uncertain if the students know that the concentrations of water vapour is dependent on temperature and thus on CO_2 level or not. Hence, students could refrain from selecting water vapour as it does not cause the greenhouse effect by itself.

Methane does also have few responses, even though it is a very potent greenhouse gas. Even though methane is more potent then CO_2, the concentration of methane is considerably smaller than CO_2. Two possible reasons why so few selected methane could be either they did now think methane made a noticeable difference to the greenhouse effect, or they did not know methane is a greenhouse gas.

Next, the incorrect results. The three incorrect option were options (b), (e) and (f).These results show that few students consider dust and particles to cause the greenhouse effects. In contrast to the results from Koulaidis and Christidou (1999), which reported misconceptions that students believe dust and particles cause climate change. Thus, students participating in this survey can separate greenhouse gases from dust and particles.

The results show that 33% of participants believe oxygen contributes as a cause to the greenhouse effect, which is a clear indication of a misconception. On a more positive view, 67% of the student do not believe oxygen is a cause of the greenhouse effect. However, the fact that 33% of students think oxygen contributes to the greenhouse effects is higher then expected and gives reason for concern about their understanding of the greenhouse effects. One possible reason for these results is that these students mix the concept of photosynthesis with the greenhouse effect. Thus, oxygen gets incorrectly mixed with CO_2 and thought of as an greenhouse gas, even though it is not. If there is a misconception between the greenhouse effects and photosynthesis, it does not depend on gender or level of education as the response were similar across all schools and genders.

Lastly, the result of option (e) "ozone". Ozone received slightly less responses than oxygen. However, the result is higher then expected. This result could support the results found in question 12 that some student have misconceptions between the greenhouse effect similar to results documented in high school students by Rajeev Gowda et al. (1997) and Boyes et al. (1993). Another possibility could be students choosing this option on the basis that ground level ozone contributed to the greenhouse effect. However, this correlation between the greenhouse effect and the ozone layer comes with a high degree of uncertainty as no specific question in the survey referred to the ozone layer. The only grounds to base such a misconception present with the participants are the similarities between the models presented by Rajeev Gowda et al. (1997) and the high responses rate to option (a) in question 12, as well the response rate to option (e) "ozone in question 19.

4.8.3 Q20: Can you write what you think causes the greenhouse effect?

Results and discussion

In total, three participants selected option (h) "other" in question 19. Thus, only these three participants were given question 20. All three participants came from school A and consisted of one boy and two girls. One written answer was "the sun", another answer was "other greenhouse gases", and the last was "do not know". Unfortunately, no conclusion concerning misconceptions can be drawn from these responses due to the small sample size.

4.9 Humans changing the climate, and willingness to stop the change

4.9.1 Q21: Are humans capable of changing the climate?

Results

The results in Figure 4.16 show that 68% of participants chose option (d), which means they agree that humans are capable of changing the climate. Option (c) "somewhat agree" received 23% of responses.

Discussion

When combining the results, all schools have a response rate of approximately 90% or above, which means that students in lower secondary and upper secondary school largely agree that humans can change the climate. These results show that students are aware of climate change and the possibility of humans changing the climate. Thus, few participants showed signs of misconceptions concerning man made climate change.

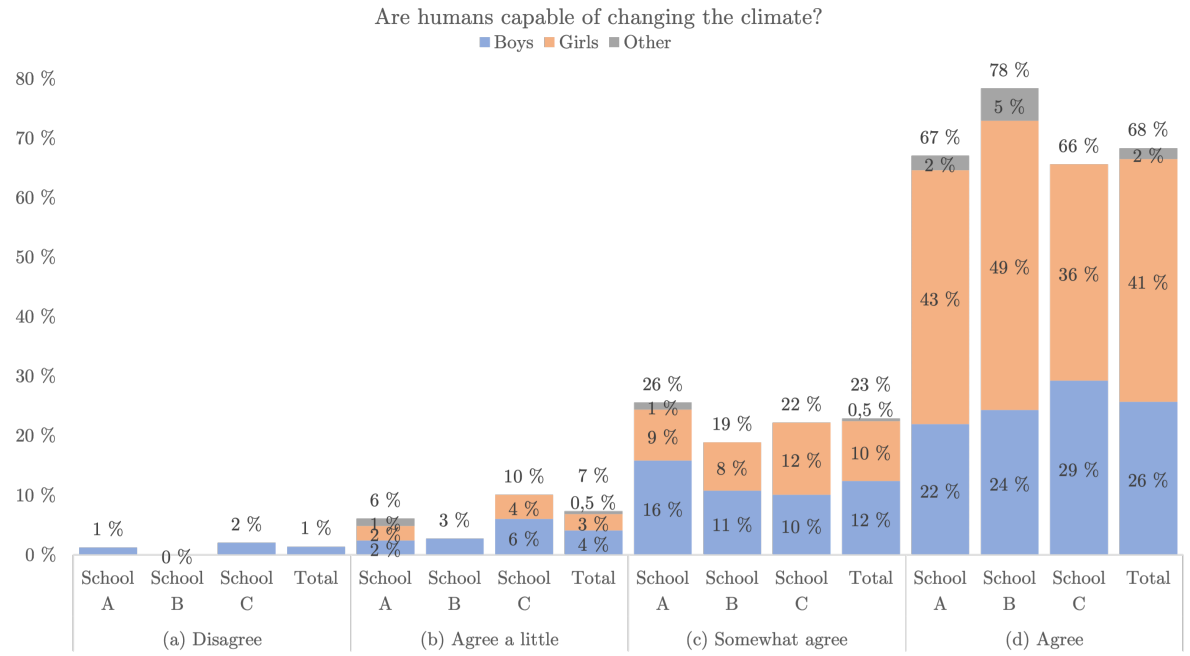


Figure 4.16: Results to questions 21 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.29 and A.30.

4.9.2 Q22: Are you willing to change your way of life to stop climate change?

Results

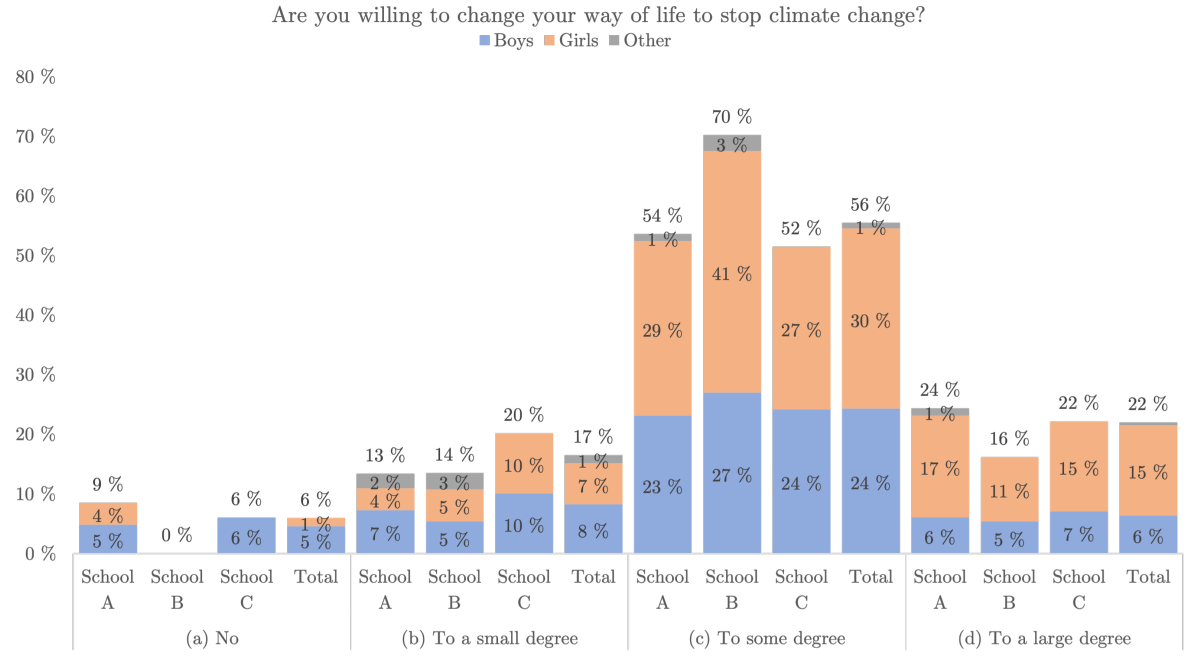


Figure 4.17: Results to questions 22 in the survey, shown in percentage of responses to each option. The number of responses and percentage is presented in Tables A.31 and A.32.

The results in Figure 4.17 show few participants not willing to change their way of life as in total 6% of participants chose option (a) "no". Otherwise, the rest of the participants were willing to change their way of life to a small, some or a big degree, to stop climate change. Most participants chose option (c) "to some degree", with 56% of students selecting this option. The distribution among schools was largely even except for some deviations. School B had a higher response rate to option (c) and a lower rate to option (d).

Discussion

These results show that students are positive and willing to change their way of life to stop climate change. However, these results could suffer from some bias, as there is a possibility that participants respond to what they believe is expected of them. If these students are willing to take the word into action is uncertain.

5 Conclusion

In conclusion, the results from the survey show that students possess misconceptions in some areas of the carbon cycle, while having good conceptual understanding of others. Areas where the students show clear understanding were the ocean acidification effect on marine life, burning of fossil fuels contributing to CO_2 emissions, the greenhouse effects being a natural process and that humans are able to change the climate.

The misconceptions the students were shown to possess were varied across multiple areas of the carbon cycle and differentiated with levels of education. Areas where the misconception was dependent of level of education was the solubility of CO_2 in water and how CO_2 affects the pH level of the water. In the case of solubility, both lower secondary and upper secondary school students think that CO_2 dissolves better in hot water than in cold water. However, the education level difference between the students who think CO_2 dissolve better in cold water was large. Very few students in lower secondary school think CO_2 dissolves better in cold water. In the case of pH, most students in upper secondary school understand that CO_2 makes water more acidic, while students in lower secondary school struggle with the concept of CO_2 and pH. Thus higher levels of educations seem to mitigate misconceptions concerning the solubility of CO_2 and how it affects the pH of water.

Misconceptions that were not dependent on education level were more prevalent among students. Such misconceptions include students only regarding photosynthesis as natural carbon capture. Most students do not include oceanic capture or long term carbon capture as oil and natural gas as natural processes. Another misconception found among student were the struggle of separating other environmental issues which is not a part of the carbon cycle. Such issues include an increase in oceanic plastic and air pollution.

The gender distribution of the results varied from school to school. In total, these variations seem cancelled out overall across the participating schools. No misconception were more prevalent in either gender. Thus the results from gender based misconceptions remain inconclusive.

As some previously described misconceptions were confirmed, others were disproved, and some results were inconclusive. Misconceptions concerning biofuels, burning of wood, and forest wild fires appear contradicting. Perhaps the questions were not clear enough, thus leading to students misinterpretation or misunderstanding the question. The same goes for how an increase in CO_2 affects plant growth and if the greenhouse effect is natural or not. The responses from the students are not consistent across questions. Another inconclusive misconception is the misconceptions between the greenhouse effect and the ozone layer. There are indicators of students having trouble differentiating between the different processes. However, these are just indicators and not consistent data to prove the presence of such a misconception.

The results of the survey give an indication of the misconceptions students in lower secondary and upper secondary school possess concerning the carbon cycle. However, the representation of the demographic were not a random representation. Thus no conclusion on behalf of the entire

population can be drawn, and further studies need to be conducted.

6 Further studies

This study leaves many questions to be unanswered. For example, what is the origin of the misconceptions students are found to possess? A qualitative study is better suited to answer this question. Interviews with students could give deeper insight into the reasoning behind their responses. Thus, the student would give their own explanation of the concepts they find too complex and abstract to understand. Interviewing students will also eliminates the uncertainty of them not understanding the given questions in the survey.

Many of the studies cited and compared with this study were conducted in the 1990s and early 2000s. There are similarities between then and now. What other research on misconceptions concerning the carbon cycle has been conducted in recent years? Thus, further studies with more recent comparisons are needed.

Lastly, do the results found in this study represent all students in lower and upper secondary school? Do misconceptions depend on the region of residence in Norway? Is there any difference in misconceptions between students of different social circles or households? How do parental factors like household income or parental education level affect students' misconceptions? These questions are just some examples of possible areas of further studies concerning misconceptions about the carbon cycle.

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A Appendix

A.1 Survey questions in norwegian

1. Ønsker du å delta på spørreundersøkelsen?
   (a) Ja
   (b) Nei
2. Kjønn?
   (a) Gutt
   (b) Jente
   (c) Annet
   (d) Ønsker ikke å oppgi
3. Hvilken skole går du på?
   (a) Skole A
   (b) Skole B
   (c) Skole C
4. Hvilken ungdomsskole gikk du på?
   - *Skriftlig kortsvar*
5. Løser CO_2 seg best i kaldt eller varmt vann?
   (a) Varmt vann
   (b) Kaldt vann
   (c) Temperatur påvirker ikke løselighet
   (d) CO_2 løser seg ikke i vann
   (e) Vet ikke
6. Dersom CO_2 løser seg i vann, har det påvirkning på pH i vannet?
   (a) Lavere pH (surere)
   (b) Høyere pH (mer basisk)
   (c) Ingen endring i pH
   (d) Vet ikke
7. Kan økt CO_2 konsentrasjon i havet være positivt for liv i havet?
   (a) Sant
   (b) Usant
   (c) Både og
   (d) Vet ikke
8. Hvilke av disse alternativene kan betegnes som naturlig karbonfangst?

(a) Løselighet i vann
(b) Fotosyntese (plantevekst)
(c) Olje
(d) Naturgass
(e) Vet ikke

9. Hvilke av alternativene er kilder til menneskeskapt CO_2 utslipp?

(a) Gass fra planter
(b) Transport (biler, båter og fly)
(c) Industri
(d) Sur nedbør
(e) Plast i havet
(f) Gasser fra dyr
(g) Kjernekraftverk
(h) Vannkraftverk
(i) Oljeproduksjon
(j) Brenning av ved
(k) Biodrivstoff
(l) Skogbrann
(m) Død av dyrearter
(n) Landbruk
(o) Avfall/søppel
(p) Ingen
(q) Vet ikke
(r) Annet

10. Har du et annet eksempel på menneskeskapt CO_2 utslipp?

- *Skriftlig kortsvar*

11. Biodrivstoff fører til økt CO_2 i den naturlig CO_2 syklusen?

(a) Ja
(b) Nei
(c) Vet ikke

12. Hvordan fordeler CO_2 seg i atmosfæren?

(a) I det øverste laget i atmosfæren
(b) I et lag midt i atmosfæren
(c) I den nederste laget i atmosfæren
(d) Jevn fordelt i hele atmosfæren
(e) Vet ikke

13. Økt CO_2 gir dårligere luftkvalitet utendørs?

    (a) Sant
    (b) Usant
    (c) Vet ikke

14. CO_2 er den drivhusgassen det er mest av i atmosfæren?

    (a) Sant
    (b) Usant
    (c) Vet ikke

15. Økt CO_2 i atmosfæren vil føre til økt plantevekst?

    (a) Sant
    (b) Usant
    (c) Vet ikke

16. Drivhuseffekten vil reduseres ved planting av flere trær?

    (a) Sant
    (b) Usant
    (c) Vet ikke

17. Er drivhuseffekten naturlig?

    (a) Ja
    (b) Nei
    (c) Vet ikke

18. Er drivhuseffekten menneskeskapt?

    (a) Ja
    (b) Nei
    (c) Vet ikke

19. Hva forårsaker drivhuseffekten?

    (a) Metan
    (b) Støv og partikler
    (c) CO_2
    (d) Vanndamp
    (e) Ozon
    (f) Oksygen
    (g) Solstrålet
    (h) Annet
    (i) Vet ikke

20. Kan du skrive hva du tror forårsaker drivhuseffekten?

- *Skriftlig kortsvar*

21. Er mennesker i stand til å endre klimaet?

    (a) Uenig
    (b) Litt enig
    (c) Noe enig
    (d) Enig

22. Er du villig til å endre måten du lever på for å hindre klimaendringer?

    (a) Nei
    (b) I liten grad
    (c) I noen grad
    (d) I stor grad

A.2 Survey questions in english

1. Do you want to participate in the survey?
   (a) Yes
   (b) No
2. Gender?
   (a) Boy
   (b) Girl
   (c) Other
   (d) Does not want to answer
3. What school to you go to?
   (a) School A
   (b) School B
   (c) School C
4. Which lower secondary school did you attend?
   - *Written short answer*
5. Does CO_2 dissolve better i cold or hot water?
   (a) Hot water
   (b) Cold water
   (c) Temperature does not affect solubility
   (d) CO_2 does not dissolve in water
   (e) Do not know
6. If CO_2 dissolves in water, does it affect the pH of the water?
   (a) Lower pH (more acidic)
   (b) Higher pH (more alkaline)
   (c) No change i pH
   (d) Do not know
7. Can an increase in CO_2 concentration in the ocean be beneficial to ocean life?
   (a) True
   (b) False
   (c) Both
   (d) Do not know
8. Which of these options can be denoted as natural carbon capture?
   (a) Solubility in water
   (b) Photosynthesis (plant growth)

(c) Oil
(d) Natural gas
(e) Do not know

9. Which of these options are sources to human made CO_2 emissions?

(a) Gas for plants
(b) Transportation (cars, boats and planes)
(c) Industry
(d) Acidic rain
(e) Ocean plastics
(f) Gases from animals
(g) Nuclear power plants
(h) Hydro power plants
(i) Oil production
(j) Burning of wood
(k) Biofuels
(l) Forest fires
(m) Death of species
(n) Farming
(o) Waste/trash
(p) None
(q) Do not know
(r) Other

10. Do you have another example of human made CO_2 emissions?

- *Written short answer*

11. Biofuel results in an increase of CO_2 in the natural CO_2 cycle?

(a) True
(b) False
(c) Do not know

12. How does CO_2 distribute in the atmosphere?

(a) In the top layer of the atmosphere
(b) In a layer in the middle of the atmosphere
(c) In the lowest layer in the atmosphere
(d) Evenly distributed in the whole atmosphere
(e) Do not know

13. An increase of CO_2 results in worse air quality outdoors?

(a) True

(b) False
(c) Do not know

14. CO_2 is the most abundant greenhouse gas in the atmosphere?

(a) True
(b) False
(c) Do not know

15. An increase in CO_2 in the atmosphere results in increased plant growth?

(a) True
(b) False
(c) Do not know

16. The greenhouse effect will be reduced by planting more trees?

(a) True
(b) False
(c) Do not know

17. Is the greenhouse effect natural?

(a) Yes
(b) No
(c) Do not know

18. Is the greenhouse effect man-made?

(a) Yes
(b) No
(c) Do not know

19. What causes the greenhouse effect?

(a) Methane
(b) Dust and particles
(c) CO_2
(d) Water vapour
(e) Ozone
(f) Oxygen
(g) Solar rays
(h) Other
(i) Do not know

20. Can you write what you think causes the greenhouse effect?

- *Written short answer*

21. Are humans capable of changing the climate?

    (a) Disagree
    (b) Agree a little
    (c) Somewhat agree
    (d) Agree

22. Are you willing to change your way of life to stop climate change?

    (a) No
    (b) To a small degree
    (c) To some degree
    (d) To a large degree

A.3 Participant information

Vil du delta i forskningsprosjektet

Kartlegging av elevers misoppfatning til karbonsyklusen.

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å kartlegge elevers misoppfatninger og hverdagsforestillinger knyttet til karbonsyklusen. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål
Denne undersøkelsen er en del av masteroppgave ved lektorutdanningen i realfag ved Universitetet i Stavanger. Formålet med undersøkelsen er å kartlegge elevers misoppfatninger og hverdagsforestillinger knyttet til karbonsyklusen og CO_2 i atmosfæren og i havet. Spørsmålene er basert på problemstillinger fra tidligere forskning. Derfor vil resultatene fra denne undersøkelsen måles opp mot lignende undersøkelser gjort nasjonalt og internasjonalt.

Problemstillingen som jeg ønsker å kunne besvare er «hvilke misoppfatninger om karbonsyklusen finnes hos elever ved 10. trinn og VG1?» og «hvilke tiltak kan gjøres for å forhindre at slike misoppfatninger?». Undersøkelsen består av opptil 20 spørsmål. Spørsmålene i undersøkelsen er undersøker forståelsen til CO_2 sin løselighet i vann, CO_2 og pH, naturlig karbonfangst prosesser, kilder til CO_2, CO_2 i atmosfæren, drivhuseffekten og forholdet mellom mennesker og klima.

Undersøkelsen skal ikke brukes til annet enn data til masteroppgaven.

Hvem er ansvarlig for forskningsprosjektet?
Magne O. Sydnes ved Universitetet i Stavanger er masterveileder og er ansvarlig for prosjektet. Undersøkelsen gjennomføres av Eirik Midbøe Lunde, masterstudent.

Hvorfor får du spørsmål om å delta?
Utvalget til spørreundersøkelsen er elever ved 10. trinn og VG1. Grunnen til at du blir spurt om å delta på undersøkelsen er at din lærer viste interesse for at klassen kunne bli med. Der er opp til 7 klasser på 10. trinn og 4 klasser på VG1 som blir spurt om å delta på undersøkelsen. Altså kan det være opp mot 300 elever som deltar.
Hva innebærer det for deg å delta?
Å delta i på denne undersøkelsen betyr at du skal svare på opp til 20 spørsmål. Data samles inn via et digitalt spørreskjema i Nettskjema. Hvis du velger å ta del i undersøkelsen vil det ta 10-15 minutter å gjennomføre. Svarene dine blir registrert elektronisk.

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg. I starten av undersøkelsen kan du velge å svare «nei» på at du vil være med på undersøkelsen. Da blir du tatt videre til slutten av undersøkelsen hvor du kan sende inn svaret ditt. Ved å svare nei, skal du ikke svare på noen fler spørsmål. Deltakelse vil ikke påvirke din skolegang eller vurdering i faget.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Spørreundersøkelsen er anonym, vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket. Data blir lagret bak innloggingssperre med passord og kryptert. De som har tilgang til data, er masterstudent Eirik Midbøe Lunde og veileder Magne Olav Sydnes.

Resultatene av spørreundersøkelsen vil bli publisert som del av en masteroppgave fra UiS. De opplysningene som kan bli publisert er skole og kjønn.

Hva skjer med personopplysningene dine når forskningsprosjektet avsluttes?
Prosjektet vil etter planen avsluttes ca. 7. September 2022.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke. På oppdrag fra Universitetet i Stavanger har Personverntjenester vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke opplysninger vi behandler om deg, og å få utlevert en kopi av opplysningene
- å få rettet opplysninger om deg som er feil eller misvisende
- å få slettet personopplysninger om deg
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger

Hvis du har spørsmål til studien, eller ønsker å vite mer om eller benytte deg av dine rettigheter, ta kontakt med:

- Eirik Midbøe Lunde (eirik.m.lunde@uis.no)
- Magne O. Sydnes (magne.o.sydnes@uis.no)

Med vennlig hilsen

Magne O. Sydnes.
Prosjektansvarlig
(Forsker/veileder)

Eirik Midbøe Lunde
Masterstudent

A.4 Survey results

Table A.1: The number of responses to question 5.

Does CO_2 dissolve best i cold or hot water?					
Option	School	Boy	Girl	Other	Total
(a)	A	13	17	0	30
	B	6	4	0	10
	C	23	15	0	38
	Total	42	36	0	78
(b)	A	4	6	0	10
	B	2	3	0	5
	C	20	19	0	39
	Total	26	28	0	54
(c)	A	5	8	2	15
	B	1	6	0	7
	C	3	5	0	8
	Total	9	19	2	30
(d)	A	3	4	1	8
	B	3	2	1	6
	C	1	3	0	4
	Total	7	9	2	18
(e)	A	9	9	1	19
	B	2	6	1	9
	C	0	10	0	10
	Total	11	25	2	38

Table A.2: The percentage of responses to question 5.

Does CO_2 dissolve best i cold or hot water?					
Option	School	Boy	Girl	Other	Total
(a)	A	16%	21%	0%	37%
	B	16%	11%	0%	27%
	C	23%	15%	0%	38%
	Total	19%	17%	0%	36%
(b)	A	5%	7%	0%	12%
	B	5%	8%	0%	14%
	C	20%	19%	0%	39%
	Total	12%	13%	0%	25%
(c)	A	6%	10%	2%	18%
	B	3%	16%	0%	19%
	C	3%	5%	0%	8%
	Total	4%	9%	1%	14%
(d)	A	4%	5%	1%	10%
	B	8%	5%	3%	16%
	C	1%	3%	0%	4%
	Total	3%	4%	1%	8%
(e)	A	11%	11%	1%	23%
	B	5%	16%	3%	24%
	C	0%	10%	0%	10%
	Total	5%	11%	1%	17%

Table A.3: The number of responses to question 6.

If CO_2 dissolves in water, does it affect the pH of the water?					
Option	School	Boy	Girl	Other	Total
(a)	A	6	9	0	15
	B	4	7	0	11
	C	37	34	0	71
	Total	47	50	0	97
(b)	A	13	9	2	24
	B	3	5	1	9
	C	6	12	0	18
	Total	22	26	3	51
(c)	A	3	8	1	12
	B	4	4	0	8
	C	1	1	0	2
	Total	8	13	1	22
(d)	A	3	10	0	13
	B	3	5	1	9
	C	3	5	0	8
	Total	9	20	1	30

Table A.4: The percentage of responses to question 6.

If CO_2 dissolves in water, does it affect the pH of the water?					
Option	School	Boy	Girl	Other	Total
(a)	A	9%	14%	0%	23%
	B	11%	19%	0%	30%
	C	37%	34%	0%	72%
	Total	24%	23%	0%	46%
(b)	A	20%	14%	3%	38%
	B	8%	14%	3%	24%
	C	6%	12%	0%	18%
	Total	11%	13%	2%	26%
(c)	A	5%	13%	2%	19%
	B	11%	11%	0%	22%
	C	1%	1%	0%	2%
	Total	4%	7%	1%	11%
(d)	A	5%	16%	0%	20%
	B	8%	14%	3%	24%
	C	3%	5%	0%	8%
	Total	5%	10%	1%	15%

Table A.5: The number of responses to question 7.

Can an increase in CO_2 concentration in the ocean be beneficial to life in the ocean?					
Option	School	Boy	Girl	Other	Total
(a)	A	2	3	0	5
	B	2	2	0	4
	C	2	2	0	4
	Total	6	7	0	13
(b)	A	19	33	4	56
	B	7	10	0	17
	C	40	42	0	82
	Total	66	85	4	155
(c)	A	12	3	0	15
	B	3	6	0	9
	C	5	7	0	12
	Total	20	16	0	36
(d)	A	1	5	0	6
	B	2	3	2	7
	C	0	1	0	1
	Total	3	9	2	14

Table A.6: The percentage of responses to question 7.

Can an increase in CO_2 concentration in the ocean be beneficial to life in the ocean?					
Option	School	Boy	Girl	Other	Total
(a)	A	2%	4%	0%	6%
	B	5%	5%	0%	11%
	C	2%	2%	0%	4%
	Total	3%	3%	0%	6%
(b)	A	23%	40%	5%	68%
	B	19%	27%	0%	46%
	C	40%	42%	0%	83%
	Total	30%	39%	2%	71%
(c)	A	15%	4%	0%	18%
	B	8%	16%	0%	24%
	C	5%	7%	0%	12%
	Total	9%	7%	0%	17%
(d)	A	1%	6%	0%	7%
	B	5%	8%	5%	19%
	C	0%	1%	0%	1%
	Total	1%	4%	1%	6%

Table A.7: The number of responses to question 8.

Which of these options can be denoted as natural carbon capture?					
Option	School	Boy	Girl	Other	Total
(a)	A	6	2	0	8
	B	4	6	0	10
	C	15	7	0	22
	Total	25	15	0	40
(b)	A	25	29	1	55
	B	9	15	1	25
	C	38	34	0	72
	Total	72	78	2	152
(c)	A	8	10	1	19
	B	5	5	0	10
	C	16	15	0	31
	Total	29	30	1	60
(d)	A	8	8	1	17
	B	6	11	1	18
	C	19	14	0	33
	Total	33	33	2	68
(e)	A	1	7	0	8
	B	1	2	1	4
	C	1	8	0	9
	Total	3	17	1	21

Table A.8: The percentage of responses to question 8.

Which of these options can be denoted as natural carbon capture?					
Option	School	Boy	Girl	Other	Total
(a)	A	7%	2%	0%	10%
	B	11%	16%	0%	27%
	C	15%	7%	0%	22%
	Total	11%	7%	0%	18%
(b)	A	30%	35%	1%	67%
	B	24%	41%	3%	68%
	C	38%	34%	0%	73%
	Total	33%	36%	1%	70%
(c)	A	10%	12%	1%	23%
	B	14%	14%	0%	27%
	C	16%	15%	0%	31%
	Total	13%	14%	0.5%	28%
(d)	A	10%	10%	1%	21%
	B	16%	30%	3%	49%
	C	19%	14%	0%	33%
	Total	15%	15%	1%	31%
(e)	A	1%	9%	0%	10%
	B	3%	5%	3%	11%
	C	1%	8%	0%	9%
	Total	1%	8%	0.5%	10%

Table A.9: The number of responses to question 9.

Which of these options are sources to human made CO_2 emissions?					
Option	School	Boy	Girl	Other	Total
(a)	A	3	1	0	4
	B	3	0	0	3
	C	3	1	0	4
	Total	9	2	0	11
(b)	A	32	40	4	76
	B	10	19	2	31
	C	46	50	0	96
	Total	88	109	6	203
(c)	A	31	38	4	73
	B	11	17	2	30
	C	47	50	0	97
	Total	89	105	6	200
(d)	A	4	4	0	8
	B	5	3	0	8
	C	9	14	0	23
	Total	18	21	0	39
(e)	A	24	25	0	49
	B	4	12	0	16
	C	23	28	0	51
	Total	51	65	0	116
(f)	A	6	7	0	13
	B	3	2	0	5
	C	8	3	0	11
	Total	17	12	0	29
(g)	A	15	24	2	41
	B	4	11	1	16
	C	25	42	0	67
	Total	44	77	3	124
(h)	A	7	5	1	13
	B	2	4	0	6
	C	7	16	0	23
	Total	16	25	1	42
(i)	A	30	37	4	71
	B	9	18	2	29
	C	45	49	0	94
	Total	84	104	6	194
(j)	A	30	21	3	54
	B	8	12	1	21
	C	39	43	0	82
	Total	77	76	4	157
(k)	A	13	16	1	30
	B	2	10	0	12
	C	23	13	0	36
	Total	38	39	1	78

(l)	A	15	11	3	29
	B	4	8	1	13
	C	17	17	0	34
	Total	36	36	4	76
(m)	A	8	4	0	12
	B	0	2	0	2
	C	8	10	0	18
	Total	16	16	0	32
(n)	A	20	10	1	31
	B	4	9	0	13
	C	22	23	0	45
	Total	46	42	1	89
(o)	A	20	30	2	52
	B	7	16	0	23
	C	33	39	0	72
	Total	60	85	2	147
(p)	A	1	0	0	1
	B	0	0	0	0
	C	0	0	0	0
	Total	1	0	0	1
(q)	A	1	2	0	3
	B	2	2	0	4
	C	0	1	0	1
	Total	3	5	0	8
(r)	A	1	0	0	1
	B	0	0	0	0
	C	0	0	0	0
	Total	1	0	0	1

Table A.10: The percentage of responses to question 9.

Which of these options are sources to human made CO_2 emissions?					
Option	School	Boy	Girl	Other	Total
(a)	A	4%	1%	0%	5%
	B	8%	0%	0%	8%
	C	3%	1%	0%	4%
	Total	4%	1%	0%	5%
(b)	A	39%	49%	5%	93%
	B	27%	51%	5%	84%
	C	46%	51%	0%	97%
	Total	40%	50%	3%	93%
(c)	A	38%	46%	5%	89%
	B	30%	46%	5%	81%
	C	47%	51%	0%	98%
	Total	41%	48%	3%	92%
(d)	A	5%	5%	0%	10%
	B	14%	8%	0%	22%
	C	9%	14%	0%	23%
	Total	8%	10%	0%	18%
(e)	A	29%	30%	0%	60%
	B	11%	32%	0%	43%
	C	23%	28%	0%	52%
	Total	23%	30%	0%	53%
(f)	A	7%	9%	0%	16%
	B	8%	5%	0%	14%
	C	8%	3%	0%	11%
	Total	8%	6%	0%	13%
(g)	A	18%	29%	2%	50%
	B	11%	30%	3%	43%
	C	25%	42%	0%	68%
	Total	20%	35%	1%	57%
(h)	A	9%	6%	1%	16%
	B	5%	11%	0%	16%
	C	7%	16%	0%	23%
	Total	7%	11%	0.5 %	19%
(i)	A	37%	45%	5%	87%
	B	24%	49%	5%	78%
	C	45%	49%	0%	95%
	Total	39%	48%	3%	89%
(j)	A	37%	26%	4%	66%
	B	22%	32%	3%	57%
	C	39%	43%	0%	83%
	Total	35%	35%	2%	72%
(k)	A	16%	20%	1%	37%
	B	5%	27%	0%	32%
	C	23%	13%	0%	36%
	Total	17%	18%	0.5 %	36%

(l)	A	18%	13%	4%	35%
	B	11%	22%	3%	35%
	C	17%	17%	0%	34%
	Total	17%	17%	2%	35%
(m)	A	10%	5%	0%	15%
	B	0%	5%	0%	5%
	C	8%	10%	0%	18%
	Total	7%	7%	0%	15%
(n)	A	24%	12%	1%	38%
	B	11%	24%	0%	35%
	C	22%	23%	0%	45%
	Total	21%	19%	0%	41%
(o)	A	24%	37%	2%	63%
	B	19%	43%	0%	62%
	C	33%	39%	0%	73%
	Total	28%	39%	1%	67%
(p)	A	1%	0%	0%	1%
	B	0%	0%	0%	0%
	C	0%	0%	0%	0%
	Total	0%	0%	0%	0.5 %
(q)	A	1%	2%	0%	4%
	B	5%	5%	0%	11%
	C	0%	1%	0%	1%
	Total	1%	2%	0%	4%
(r)	A	1%	0%	0%	1%
	B	0%	0%	0%	0%
	C	0%	0%	0%	0%
	Total	0%	0%	0%	0.5 %

Table A.11: The number of responses to question 11.

Biofuels result in an increase of CO_2 in the natural CO_2 cycle?					
Option	School	Boy	Girl	Other	Total
(a)	A	16	25	1	42
	B	3	12	1	16
	C	16	16	0	32
	Total	35	53	2	90
(b)	A	12	11	2	25
	B	7	2	0	9
	C	13	17	0	30
	Total	32	30	2	64
(c)	A	6	8	1	15
	B	4	7	1	12
	C	18	19	0	37
	Total	28	34	2	64

Table A.12: The percentage of responses to question 11.

Biofuels result in an increase of CO_2 in the natural CO_2 cycle?					
Option	School	Boy	Girl	Other	Total
(a)	A	20%	30%	1%	51%
	B	8%	32%	3%	43%
	C	16%	16%	0%	32%
	Total	16%	24%	1%	41%
(b)	A	15%	13%	2%	30%
	B	19%	5%	0%	24%
	C	13%	17%	0%	30%
	Total	15%	14%	1%	29%
(c)	A	7%	10%	1%	18%
	B	11%	19%	3%	32%
	C	18%	19%	0%	37%
	Total	13%	16%	1%	29%

Table A.13: The number of responses to question 12.

How does CO_2 distribute in atmosphere?					
Option	School	Boy	Girl	Other	Total
(a)	School A	14	16	2	32
	School B	2	6	1	9
	School C	12	15	0	27
	Total	28	37	3	68
(b)	School A	3	3	0	6
	School B	2	2	0	4
	School C	4	5	0	9
	Total	9	10	0	19
(c)	School A	7	10	2	19
	School B	6	7	1	14
	School C	13	7	0	20
	Total	26	24	3	53
(d)	School A	5	12	0	17
	School B	2	5	0	7
	School C	7	9	0	16
	Total	14	26	0	40
(e)	School A	5	3	0	8
	School B	2	1	0	3
	School C	11	16	0	27
	Total	18	20	0	38

Table A.14: The percentage of responses to question 12.

How does CO_2 distribute in atmosphere?					
Option	School	Boy	Girl	Other	Total
(a)	School A	17%	20%	2%	39%
	School B	5%	16%	3%	24%
	School C	12%	15%	0%	27%
	Total	13%	17%	1%	31%
(b)	School A	4%	4%	0%	7%
	School B	5%	5%	0%	11%
	School C	4%	5%	0%	9%
	Total	4%	5%	0%	9%
(c)	School A	9%	12%	2%	23%
	School B	16%	19%	3%	38%
	School C	13%	7%	0%	20%
	Total	12%	11%	1%	24%
(d)	School A	6%	15%	0%	21%
	School B	5%	14%	0%	19%
	School C	7%	9%	0%	16%
	Total	6%	12%	0%	18%
(e)	School A	6%	4%	0%	10%
	School B	5%	3%	0%	8%
	School C	11%	16%	0%	27%
	Total	8%	9%	0%	17%

Table A.15: The number of responses for question 13

How does CO_2 distribute in atmosphere?					
Option	School	Boy	Girl	Other	Total
(a)	School A	28	37	4	69
	School B	12	16	2	30
	School C	41	42	0	83
	Total	81	95	6	182
(b)	School A	4	5	0	9
	School B	1	4	0	5
	School C	4	5	0	9
	Total	9	14	0	23
(c)	School A	2	2	0	4
	School B	1	1	0	2
	School C	2	5	0	7
	Total	5	8	0	13

Table A.16: The percentage of responses for question 13

How does CO_2 distribute in atmosphere?					
Option	School	Boy	Girl	Other	Total
(a)	School A	34%	45%	5%	84%
	School B	32%	43%	5%	81%
	School C	41%	42%	0%	84%
	Total	37%	44%	3%	83%
(b)	School A	5%	6%	0%	11%
	School B	3%	11%	0%	14%
	School C	4%	5%	0%	9%
	Total	4%	6%	0%	11%
(c)	School A	2%	2%	0%	5%
	School B	3%	3%	0%	5%
	School C	2%	5%	0%	7%
	Total	2%	4%	0%	6%

Table A.17: The number of responses for question 14

CO_2 is the most abundant greenhouse gas in the atmosphere?					
Option	School	Boy	Girl	Other	Total
(a)	School A	17	28	1	46
	School B	4	14	1	19
	School C	24	21	0	45
	Total	45	63	2	110
(b)	School A	9	12	3	24
	School B	6	5	1	12
	School C	19	21	0	40
	Total	34	38	4	76
(c)	School A	8	4	0	12
	School B	4	2	0	6
	School C	4	10	0	14
	Total	16	16	0	32

Table A.18: The percentage of responses for question 14

CO_2 is the most abundant greenhouse gas in the atmosphere?					
Option	School	Boy	Girl	Other	Total
(a)	School A	21%	34%	1%	56%
	School B	11%	38%	3%	51%
	School C	24%	21%	0%	45%
	Total	21%	29%	1%	50%
(b)	School A	11%	15%	4%	29%
	School B	16%	14%	3%	32%
	School C	19%	21%	0%	40%
	Total	16%	17%	2%	35%
(c)	School A	10%	5%	0%	15%
	School B	11%	5%	0%	16%
	School C	4%	10%	0%	14%
	Total	7%	7%	0%	15%

Table A.19: The number of responses for question 15

An increase in CO_2 in the atmosphere results in increased plant growth?					
Option	School	Boy	Girl	Other	Total
(a)	School A	15	5	0	20
	School B	4	4	0	8
	School C	9	5	0	14
	Total	28	14	0	42
(b)	School A	14	34	3	51
	School B	8	15	2	25
	School C	32	36	0	68
	Total	54	85	5	144
(c)	School A	5	5	1	11
	School B	2	2	0	4
	School C	6	11	0	17
	Total	13	18	1	32

Table A.20: The percentage of responses for question 15

An increase in CO_2 in the atmosphere results in increased plant growth?					
Option	School	Boy	Girl	Other	Total
(a)	School A	18%	6%	0%	24%
	School B	11%	11%	0%	22%
	School C	9%	5%	0%	14%
	Total	13%	6%	0%	19%
(b)	School A	17%	41%	4%	62%
	School B	22%	41%	5%	68%
	School C	32%	36%	0%	69%
	Total	25%	39%	2%	66%
(c)	School A	6%	6%	1%	13%
	School B	5%	5%	0%	11%
	School C	6%	11%	0%	17%
	Total	6%	8%	0%	15%

Table A.21: The number of responses for question 16

The greenhouse effect will be reduced by planting more trees?					
Option	School	Boy	Girl	Other	Total
(a)	School A	22	28	2	52
	School B	7	9	0	16
	School C	32	28	0	60
	Total	61	65	2	128
(b)	School A	7	14	2	23
	School B	4	8	1	13
	School C	12	16	0	28
	Total	23	38	3	64
(c)	School A	5	2	0	7
	School B	3	4	1	8
	School C	3	8	0	11
	Total	11	14	1	26

Table A.22: The percentage of responses for question 16

The greenhouse effect will be reduced by planting more trees?					
Option	School	Boy	Girl	Other	Total
(a)	School A	27%	34%	2%	63%
	School B	19%	24%	0%	43%
	School C	32%	28%	0%	61%
	Total	28%	30%	1%	59%
(b)	School A	9%	17%	2%	28%
	School B	11%	22%	3%	35%
	School C	12%	16%	0%	28%
	Total	11%	17%	1%	29%
(c)	School A	6%	2%	0%	9%
	School B	8%	11%	3%	22%
	School C	3%	8%	0%	11%
	Total	5%	6%	0%	12%

Table A.23: The number of responses for question 17

Is the greenhouse effect natural?					
Option	School	Boy	Girl	Other	Total
(a)	School A	27	35	4	66
	School B	10	18	1	29
	School C	41	37	0	78
	Total	78	90	5	173
(b)	School A	5	8	0	13
	School B	3	2	1	6
	School C	5	8	0	13
	Total	13	18	1	32
(c)	School A	2	1	0	3
	School B	1	1	0	2
	School C	1	7	0	8
	Total	4	9	0	13

Table A.24: The percentage of responses for question 17

Is the greenhouse effect natural?					
Option	School	Boy	Girl	Other	Total
(a)	School A	33%	43%	5%	80%
	School B	27%	49%	3%	78%
	School C	41%	37%	0%	79%
	Total	36%	41%	2%	79%
(b)	School A	6%	10%	0%	16%
	School B	8%	5%	3%	16%
	School C	5%	8%	0%	13%
	Total	6%	8%	0%	15%
(c)	School A	2%	1%	0%	4%
	School B	3%	3%	0%	5%
	School C	1%	7%	0%	8%
	Total	2%	4%	0%	6%

Table A.25: The number of responses for question 18

Is the greenhouse effect man made?					
Option	School	Boy	Girl	Other	Total
(a)	School A	6	16	0	22
	School B	4	3	1	8
	School C	10	11	0	21
	Total	20	30	1	51
(b)	School A	26	26	3	55
	School B	9	17	1	27
	School C	34	34	0	68
	Total	69	77	4	150
(c)	School A	2	2	1	5
	School B	1	1	0	2
	School C	3	7	0	10
	Total	6	10	1	17

Table A.26: The percentage of responses for question 18

Is the greenhouse effect man made?					
Option	School	Boy	Girl	Other	Total
(a)	School A	7%	20%	0%	27%
	School B	11%	8%	3%	22%
	School C	10%	11%	0%	21%
	Total	9%	14%	0.5 %	23%
(b)	School A	32%	32%	4%	67%
	School B	24%	46%	3%	73%
	School C	34%	34%	0%	69%
	Total	32%	35%	2%	69%
(c)	School A	2%	2%	1%	6%
	School B	3%	3%	0%	5%
	School C	3%	7%	0%	10%
	Total	3%	5%	0.5 %	8%

Table A.27: The number of responses for question 19

What causes the greenhouse effect?					
Option	School	Boy	Girl	Other	Total
(a)	School A	18	15	0	33
	School B	7	6	0	13
	School C	29	15	0	44
	Total	54	36	0	90
(b)	School A	7	3	0	10
	School B	2	0	0	2
	School C	5	5	0	10
	Total	14	8	0	22
(c)	School A	25	28	3	56
	School B	11	11	1	23
	School C	34	38	0	72
	Total	70	77	4	151
(d)	School A	6	13	1	20
	School B	7	7	0	14
	School C	23	20	0	43
	Total	36	40	1	77
(e)	School A	9	10	2	21
	School B	5	5	0	10
	School C	16	14	0	30
	Total	30	29	2	61
(f)	School A	12	15	1	28
	School B	3	7	1	11
	School C	14	18	0	32
	Total	29	40	2	71
(g)	School A	25	29	3	57
	School B	6	14	1	21
	School C	19	28	0	47
	Total	50	71	4	125
(h)	School A	1	2	0	3
	School B	0	0	0	0
	School C	0	0	0	0
	Total	1	2	0	3
(i)	School A	2	5	0	7
	School B	1	4	1	6
	School C	6	7	0	13
	Total	9	16	1	26

Table A.28: The percentage of responses for question 19

What causes the greenhouse effect?					
Option	School	Boy	Girl	Other	Total
(a)	School A	22%	18%	0%	40%
	School B	19%	16%	0%	35%
	School C	29%	15%	0%	44%
	Total	25%	17%	0%	41%
(b)	School A	9%	4%	0%	12%
	School B	5%	0%	0%	5%
	School C	5%	5%	0%	10%
	Total	6%	4%	0%	10%
(c)	School A	30%	34%	4%	68%
	School B	30%	30%	3%	62%
	School C	34%	38%	0%	73%
	Total	32%	35%	2%	69%
(d)	School A	7%	16%	1%	24%
	School B	19%	19%	0%	38%
	School C	23%	20%	0%	43%
	Total	17%	18%	0.5 %	35%
(e)	School A	11%	12%	2%	26%
	School B	14%	14%	0%	27%
	School C	16%	14%	0%	30%
	Total	14%	13%	1%	28%
(f)	School A	15%	18%	1%	34%
	School B	8%	19%	3%	30%
	School C	14%	18%	0%	32%
	Total	13%	18%	1%	33%
(g)	School A	30%	35%	4%	70%
	School B	16%	38%	3%	57%
	School C	19%	28%	0%	47%
	Total	23%	33%	2%	57%
(h)	School A	1%	2%	0%	4%
	School B	0%	0%	0%	0%
	School C	0%	0%	0%	0%
	Total	0.5 %	1%	0%	1.4%
(i)	School A	2%	6%	0%	9%
	School B	3%	11%	3%	16%
	School C	6%	7%	0%	13%
	Total	4%	7%	0.5 %	12%

Table A.29: The number of responses for question 21

Are humans capable of changing the climate?					
Option	School	Boy	Girl	Other	Total
(a)	School A	1	0	0	1
	School B	0	0	0	0
	School C	2	0	0	2
	Total	3	0	0	3
(b)	School A	2	2	1	5
	School B	1	0	0	1
	School C	6	4	0	10
	Total	9	6	1	16
(c)	School A	13	7	1	21
	School B	4	3	0	7
	School C	10	12	0	22
	Total	27	22	1	50
(d)	School A	18	35	2	55
	School B	9	18	2	29
	School C	29	36	0	65
	Total	56	89	4	149

Table A.30: The percentage of responses for question 21

Are humans capable of changing the climate?					
Option	School	Boy	Girl	Other	Total
(a)	School A	1%	0%	0%	1%
	School B	0%	0%	0%	0%
	School C	2%	0%	0%	2%
	Total	1%	0%	0%	1%
(b)	School A	2%	2%	1%	6%
	School B	3%	0%	0%	3%
	School C	6%	4%	0%	10%
	Total	4%	3%	0.5%	7%
(c)	School A	16%	9%	1%	26%
	School B	11%	8%	0%	19%
	School C	10%	12%	0%	22%
	Total	12%	10%	0.5%	23%
(d)	School A	22%	43%	2%	67%
	School B	24%	49%	5%	78%
	School C	29%	36%	0%	66%
	Total	26%	41%	2%	68%

Table A.31: The number of responses for question 22

Are you willing to change your way of life to stop climate change?					
Option	School	Boy	Girl	Other	Total
(a)	School A	1	0	0	1
	School B	0	0	0	0
	School C	2	0	0	2
	Total	3	0	0	3
(b)	School A	2	2	1	5
	School B	1	0	0	1
	School C	6	4	0	10
	Total	9	6	1	16
(c)	School A	13	7	1	21
	School B	4	3	0	7
	School C	10	12	0	22
	Total	27	22	1	50
(d)	School A	18	35	2	55
	School B	9	18	2	29
	School C	29	36	0	65
	Total	56	89	4	149

Table A.32: The percentage of responses for question 22

Are you willing to change your way of life to stop climate change?					
Option	School	Boy	Girl	Other	Total
(a)	School A	1%	0%	0%	1%
	School B	0%	0%	0%	0%
	School C	2%	0%	0%	2%
	Total	1%	0%	0%	1%
(b)	School A	2%	2%	1%	6%
	School B	3%	0%	0%	3%
	School C	6%	4%	0%	10%
	Total	4%	3%	0.5 %	7%
(c)	School A	16%	9%	1%	26%
	School B	11%	8%	0%	19%
	School C	10%	12%	0%	22%
	Total	12%	10%	0.5 %	23%
(d)	School A	22%	43%	2%	67%
	School B	24%	49%	5%	78%
	School C	29%	36%	0%	66%
	Total	26%	41%	2%	68%