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Quantification of the effect that Green Roofs have on ambient CO_2 concentrations -

Västra Hamnen, Malmö

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Abstract

Living in the Anthropocene epoch, climate change is a fact and the rising temperatures due to increasing greenhouse gases are only one of the many consequences. The carbon dioxide levels and greenhouse gases are of international concern, but something must be done on a local scale for it to be improved globally. Green areas and ecological corridors are now a modern and fashionable way of doing this. These innovative approaches, such as green roofs, are one of the many experiments in trying to improve the environment.

This report aims to quantify the effects that green roofs have on ambient carbon dioxide concentrations by looking into the green roofs in Västra Hamnen in Malmö, Sweden. By doing so, it is possible to see that atmospheric carbon dioxide levels could not be substantially reduced by the means of the 70 000 m^2 big green roof area alone. They do not sequester enough carbon for them to be substantial for off-setting anthropogenic emissions from a power plant. They do however balance out the carbon emissions from 16 cars per year.

There are still uncertainties and difficulties regarding green roofs and carbon sequestration, therefore, further experiments and studies are encouraged in this topic.

Keywords: *Green Roofs • Carbon Sequestration • Ambient Carbon Dioxide • Climate Change • Anthropogenic Emissions • Malmö*

Populärvetenskaplig sammanfattning

Att klimatet på jorden förändras och går mot varmare temperaturer är det nog igen som undkommit att höra. Därför riktar sig denna rapport till att undersöka och redovisa för hur mycket kol de gröna taken i Västra Hamnen i Malmö kan sekvestrera, inlagra, från luftens koldioxid. Detta, för att förhoppningsvis kunna använda gröna tak som en metod för att begränsa klimatförändringarna.

Resultatet från denna rapport visar på att de gröna taken i Västra Hamnen, på ca 70 000 m^2, sekvestrerar upp till 13 ton kol på ett år. Detta kan jämföras med hur mycket kol ett kraftverk i Malmö släpper ut under ett år. Då visar resultaten att dessa gröna tak tar bort endast 0,018 % av det kol som kraftverket släpper ut.

Om man istället likställer upptaget av kol med det kol som en bil släpper ut under ett år, så landar det på 16 gånger så mycket. Alltså tar de gröna taken i Västra Hamnen upp den mängden kol som 16 bilar släpper ut på ett år. Men om man slår ut detta på hur många bilägare det finns i området så blir resultatet ynka 0,64 %.

Dessa resultat pekar då alltså på att användningen, av gröna tak, för att enbart begränsa klimatförändringarna, inte är tillräcklig. Det kan såklart, tillsammans med många andra tillvägagångssätt, användas för att hjälpa klimatet, men endast gröna tak gör ingen större skillnad för det globala klimatet.

Att hitta nytänkande lösningar på klimatförändringarna är någonting som förhoppningsvis kommer att utforskas vidare. Alltså finns det stora utvecklingsmöjligheter inom detta område och det uppmärksammas att fortsätta undersöka nya lösningar.

Nyckelord: *Gröna tak* • *Kol inlagring* • *Kol sekvestrering* • *Klimatförändringar* • *Antropogena utsläpp* • *Malmö*

Table of Content

1. Introduction

Living in the Anthropocene epoch, climate change is a fact and the rising temperatures due to increasing Greenhouse gases (GHG from now on) are only one of the many consequences (Raupach and Canadell 2010). Since the industrialization, atmospheric carbon dioxide (CO_2 hereinafter) levels increased rapidly because of the burning of fossil fuels that released carbon (as of now referred to as C), which was buried formerly as coal or oil, into the air (Costello et al. 2009). This led to a much higher amount of GHG in the atmosphere, which caused the temperature to rise due to the "trapped" solar rays that could not be reflected back into space, but rather bounced back to the earth's surface. Out of many GHG (CO_2, CH_4, N_2O and many others) CO_2 is therefore the main contributor to the globally increasing temperatures (IPCC 2014). The release of CO_2 is, as mentioned above, mainly caused by burning fossil fuels (besides cement production and land use change) and therefore tightly linked to human activity such as transportation, heating/cooling and power production (IPCC 2014). Most of these activities co-located to population, hence large cities are usually also large emitters of CO_2 (IPCC 2014).

The CO_2 levels and GHG are of global concern, but something must be done on a local scale for it to be improved on a global scale. By the year 2045, Sweden's total net GHG emissions should be zero in order for the Swedish government's climate goals to be reached (Naturvårdsverket (a and b) n.d.). Therefore, new techniques and developments are focused on making the environments in the cities better by implementing new ways of lowering the emissions and bringing the vegetation into the cities (Gunther 2018). Green areas and ecological corridors is now a modern way of doing this. These innovative methods are something that really is appropriate in time, considering the changing climate. Green roofs are one of the many ways to bring nature into the city. A green roof is a roof that has a vegetation surface instead of other regular building materials. Even though it is not a modern method, it has been used for centuries in various parts of the world for isolation and protection against harsh weather, it is still something new for the urban areas (SMHI 2015).

Due to this being a new approach, there is limited research on what the green roofs actually contribute to, in addition to increasing the green areas in urban environments. Therefore, this report aims to quantify the effects that green roofs have on ambient CO_2 concentrations. Thus, the following research questions have been investigated: Can atmospheric CO_2 levels be meaningfully reduced by the means of green roofs? Can the CO_2 sequestration by the green roofs actually make up for the emissions that one average car in Sweden emits over a year? As well as, can the CO_2 sequestration even measure/be compared at all to the CO_2 emissions from a power plant? This will be investigated by zoning into a smaller district in the third biggest city in Sweden, Västra Hamnen in Malmö.

Null hypothesis (H_0): The roofs will take away CO_2, but it will not be substantial for off-setting anthropogenic emissions from a power plant, but they are likely to off-set an average car's emissions over a year.

Alternative hypothesis (H_A): The roofs will take away CO_2, and it will be satisfactory for the implementation of greens roofs in means of compensating the power plants emissions as well as one car's emissions for a year.

1.1. Limitations of this study

In this study, the focus lies on the questions whether or not it is worthwhile to implement green roofs on the sole purpose for it to sequester a substantial amount of the ambient CO_2. This study will not go into detail in the CO_2 emissions that were released in the process of building the green roofs, nor will it account for the CO_2 amount that is saved from the isolation and energy savings that comes from implementing green roofs, i.e. the effect green roofs have on the energy balance of the buildings. This research lies solely on the question if green roofs can reduce ambient CO_2 concentrations by such amounts to off-set emissions from human activities.

This study is limited to the investigation of the uptake of CO_2 by plants on the green roofs in Malmö. It is also limited in the way that the CO_2 measurements were retrieved from a previous study and not based on sampled experiment results.

The different types of photosynthesis or other processes will not be described in this report nor will the methods for retrieving the global CO_2 measurements. For further information about this, please see Khan Academy (n.d.) and Dlugokencky and Tans (2018).

1.2. Background

The following paragraphs will give some more information and essentials about the key components in this report.

1.2.1. Green roofs

Green roofs are, as mentioned before, a quite innovative approach to improve the environment in urban areas. There are three different types of green roofs; intensive, semi-intensive and extensive (Li and Yeung 2014). They differ in both the soil depth and thus also in what kind of vegetation can possibly grow on the roof. The soil depth for intensive green roofs vary between 15 cm to over 1 m while for extensive green roofs the soil depth is usually between 4 – 15 cm. The intensive green roofs require a bit more maintenance, with the different vegetation that needs more upkeep. They cost somewhat more than extensive green roofs, so the latter is ergo more common and will therefore be given the main focus in this report (Li and Yeung 2014; Rowe 2011).

The green roofs have many different applications in the urban areas such as reducing the urban heat island effect and lowering the energy consumption (Rowe 2011). This is accomplished by decreasing the heat and air condition demand by isolating the buildings in winter and by not absorbing the energy from solar radiation and heating up the building during summer (Getter et al. 2009). The albedo of a green roof is generally higher than for a regular building, hence, the green roof does not absorb and store as much heat as the regular roofs, it is rather reflected back to the atmosphere, keeping the building cooler. The urban heat island effect is reduced by the green roofs as a result of the transpiration process by plants (Li and Yeung 2014). Other positive effects are the decrease of runoff and reduction of air pollutants such as O_3 (ozone) and NO_2 (nitrogen dioxide) through uptake by plants (Li and Yeung 2014). And as Li and Yeung (2014) states, "Green roofs can also reduce the effects of acid rain by raising the pH value from 5 to 6 in rain water to over 7 to 8 in runoff water.".

The vegetation on green roofs is generally composed of plants that are very drought tolerant and plants that do not require more than ca 15 cm substrate depths (extensive roofs). Therefore, the most common plants used on green roofs are succulents such as the sedum species. Their roots are relatively shallow, they can store water and they have crassulacean acid metabolism (CAM) which makes them suitable for arid climates (dry conditions) (Li and Yeung 2014). CAM is a type of photosynthesis where the plants open their stomata during the night to let CO_2 in. CO_2 is then fixed into organic acid and stored until the following day. During daytime the plants do not have to open their stomata, risking losing water, but can use the organic acid and sunlight to photosynthesize (Khan Academy n.d.).

1.2.2. Carbon cycle

The natural carbon cycle describes how C moves in and between the 4 different reservoirs, or spheres: the atmosphere, biosphere, lithosphere and hydrosphere. On top of that is the anthropogenic perturbation, that is, like land use changes, a major source, by releasing CO_2 into the atmosphere, by burning fossil fuel. The sinks, that takes away CO_2 from the atmosphere, can be plants, for instance (NOAA/ESRL (a) n.d.). The CO_2 is taken up by photosynthetic organisms that use the CO_2 in the photosynthesis where C is transformed into starch molecules. Some of the C is then released again to the atmosphere through respiration and the rest of the C molecules, which are naturally found in the plants tissue, are sequestered in the soil when the plants die and decay. The soil can act as a C sink because the C that is kept as coal or oil (fossil fuels), from plants and organisms that has decayed and been compressed for millions of years, is only released to the atmosphere again if they are burned. And this is where human impact enters the carbon cycle and disturbs the natural exchanges by producing a net increase of CO_2 when burning the fossil fuels. The remaining parts of the carbon cycle can be seen in Figure 1 below.

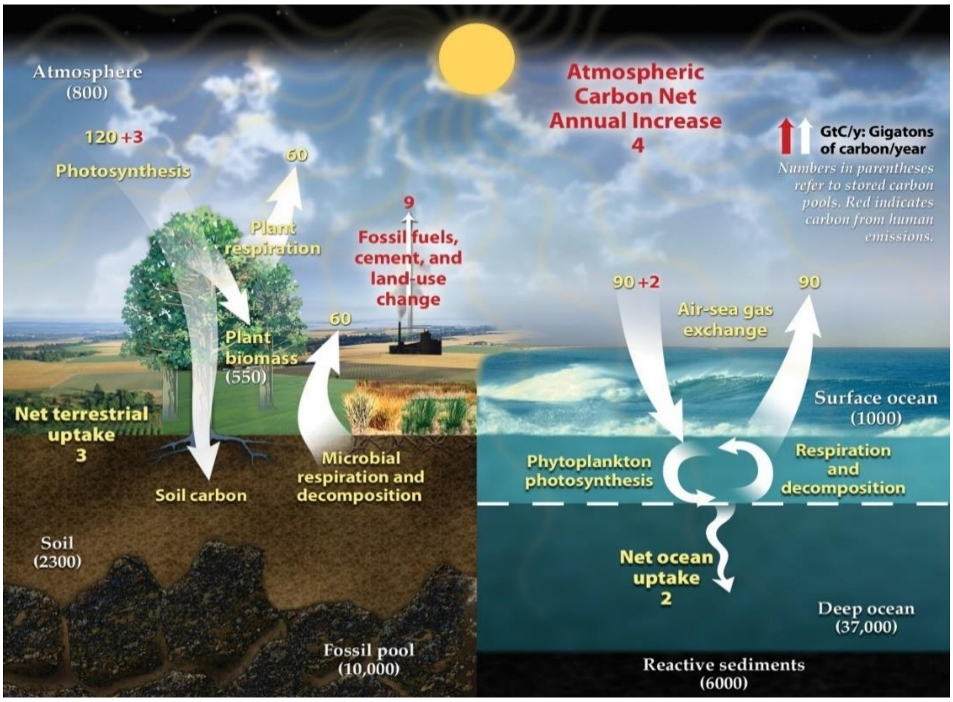

Figure 1*: The fast carbon cycle. It shows the C movement between the different spheres. The red is the human impact and the yellow is the natural fluxes, all in gigaton C/year. (Figure from: U.S. DOE. 2008, genomicscience.energy.gov)*

The global atmospheric CO_2 concentration at the beginning of the industrial revolution was measured, from air trapped in ice cores, to be 280 ppm, whereas the current global CO_2 concentration in the atmosphere is now above 400 ppm (NOAA/ESRL (b) n.d.). The local values vary depending on the location, the seasons, closeness to hot spots like power plants and closeness to clean air high up in the mountains or near the coast. Seen in Figure 2 is the global monthly mean CO_2 trend from 1980 onwards.

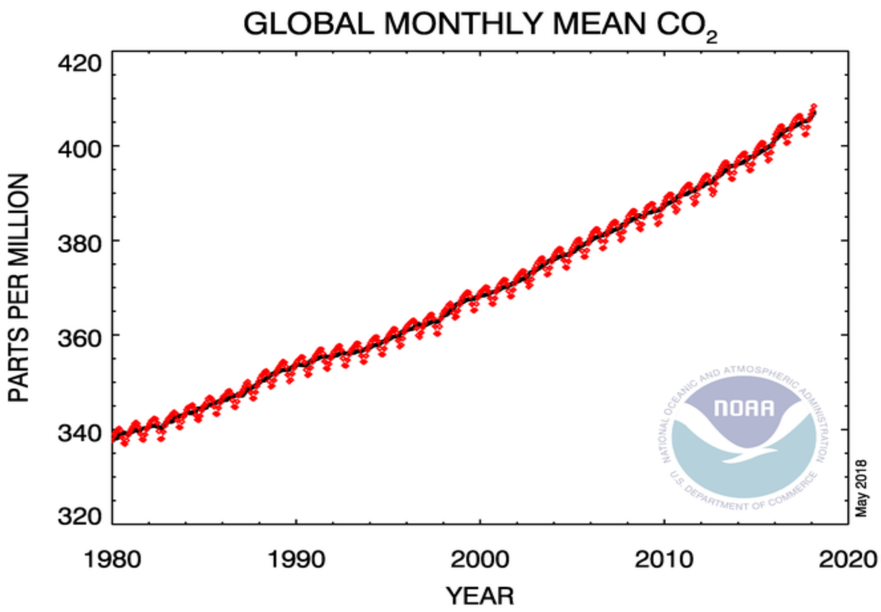

***Figure 2**: Showing the global monthly mean CO2 in ppm from 1980 until today (Figure from: Dlugokencky and Tans 2018).*

1.3. Study area

Malmö is Sweden's third biggest city and is located in the most southwestern part of the country, right by the coast to Öresund. Västra Hamnen in Malmö is the result from a group of projects, one of which is called Bo01 from 2001, and they were intended as a contribution towards a sustainable city development (Malmö Stad (b) n.d.). They were designed to extend the nature into the city. The area is made up of residential buildings, but there are also some company and industrial buildings as well. The area is 187 hectares big with a population of 6 835 and is situated right by the Öresund sea, as seen in Figure 4 (Malmö Stad (c) n.d.). It is proximately a third of the people in Malmö that owns a car (364 out of 1000 people in 2016), so in Västra Hamnen it would result in 2488 car owners (Malmö Stad (a) n.d.).

2. Materials and Methods

To be able to calculate how much the green roofs in Västra Hamnen in Malmö actually do take away when looking at the CO_2 concentration in the city/district, the green roofs had to be digitized in order to calculate the area covered by green roof. Then the measured amount of the sequestered CO_2 by green roofs in Michigan, as reported by Getter et al. (2009), is used to calculate the potential amount of CO_2 taken up by the green roofs in Västra Hamnen based on the total area that they covered. This area calculation was done by using ArcMap and the extrapolation of the Michigan values, to Malmö, was done using Microsoft Excel.

2.1. Data

2.1.1. Aerial orthophotographs

The data was retrieved from Lantmäteriet in the form of aerial photographs in raster format, both in RGB and IR with an altitude of 3700 m, and with a resolution of 0.25 m, from 2016 (Lantmäteriet 2016). When digitizing the roofs, the RGB image was used as a base and a kind of accuracy assessment was made. Using the IR image and Malmö Stad and Stadsbyggnadskontoret Karta with the oblique images over Västra Hamnen in order to clearly see whether or not the roofs were in fact green (Malmö Stad and Stadsbyggnadskontoret n.d.).

2.1.2. CO_2 sequestration numbers

The CO_2 sequestration values per m^2 comes from Study 2 in the research made by Getter et al. (2009). It was carried out in Michigan over a period of two years where both the above- and below biomass were sampled, every second month during growing season, as well as the substrate C content. The vegetation on the roofs was composed out of four common species from the *Sedum* family. Weeds were not included in the C analysis and were therefore plucked regularly. The result for C sequestration in the study was 187,5 g C/m^2 and year. This study was chosen because of the similarities when it comes to the most important factors such as the climate and vegetation. The climate in Michigan and the climate in Malmö is classified in the same climate zone according to the Köppen-Geiger Climate Classification, as seen in Figure 3 (Peel et al. 2007). The vegetation on the roofs, both in Michigan and in Sweden, is most commonly from the *Sedum* family (Wrede 2011). So, with similar climate and similar vegetation, the determining factors (i.e. environmental conditions) should be similar. For that reason, the numbers from Getter et al. (2009) were chosen.

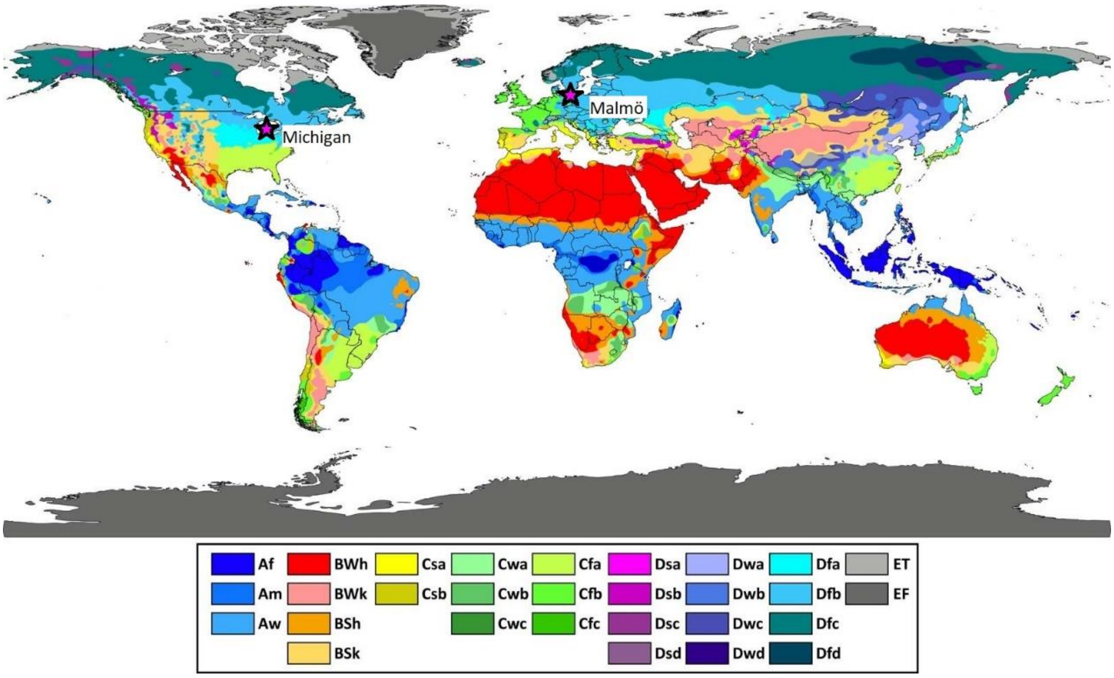

Figure 3*: The climate classification according to the Köppen-Geiger Climate Classification, the stars show the locations of Michigan and Malmö. (Figure from: Peel et al. 2007, with modification by Nike Rosenström).*

2.1.3. Power plant- and car emissions

The data for the chosen power plant comes from CARMA (Carbon Monitoring for Action 2009, carma.org) and shows that 267 330,64 tonnes of CO_2 were emitted in Malmö in 2009 from burning fossil fuels. For the car emissions, a value of 3 tonnes CO_2 per year will be used because it is stated, by Garcia (2008) that the average Swedish car driver emits about that value.

2.2. Analysis

The analysis was performed in ArcMap 10.5 as stated before by editing and digitizing the roofs on the aerial photographs and then exporting the data to Microsoft Excel for the calculations to be made. Although some intensive green roofs might be encountered, the area of those are possibly not substantial (< 5 % of the green roof area) and will therefore be treated as extensive ones when applying the CO_2 measurements on the total area of green roofs.

2.3. Procedure

1) Calculation of the percentage green roofs out of all the roofs in the area.
2) Calculating the percentage of each type of building the green roofs were situated on.
3) Calculating the total amount of C sequestration by all green roofs:

$$X * Y = Z \tag{1}$$

Where:

X = C sequestration per year (g C/m^2)

Y = the total area of green roofs (m^2)

Z = total C sequestration of the green roofs over a year (g C)

4) Calculating the CO_2 molecule weight, using Equation 2:

$$X_1 * M_1 + X_2 * \; M_2 \; = Z \tag{2}$$

Where:

X_1 = 1 (one C molecule)

M_1= molar mass of a C molecule

X_2 = 2 (two O molecules)

M_2 = molar mass of an O molecule

Z = the weight of one CO_2 molecule

5) Calculating the C weight of the CO_2 that one power plant emitted, using Equation 3.

$$(\frac{Z_1}{Z_{1+2}}) * N = Y \tag{3}$$

Where:

Z_1 = Z from Calculation 4 i.e. the weight of one C molecule

Z_2 = Z from Calculation 5 i.e. the weight of two O molecules

N = the amount of CO_2 that one power plant in Malmö emit over one year (tonnes CO_2)

Y = resulting tonnes C

6) Calculating how many percent the C sequestration took away in the means of C emissions from a power plant.
7) The procedures of 4) and 5) were used to get the numbers of C emission for a car over a year. Thereafter the total C sequestration by the green roofs are divided by the C emissions for the car to get a value of how many cars' emissions the green roofs can compensate for.

3. Results

The following section will display the results from the analysis and calculations made in forms of tables and figures, but also presented in text.

3.1. Resulting map

The green roofs found in Västra Hamnen are highlighted in pink in Figure 4, they are distributed in various parts in the area, but the majority are located in the northwestern part of the area.

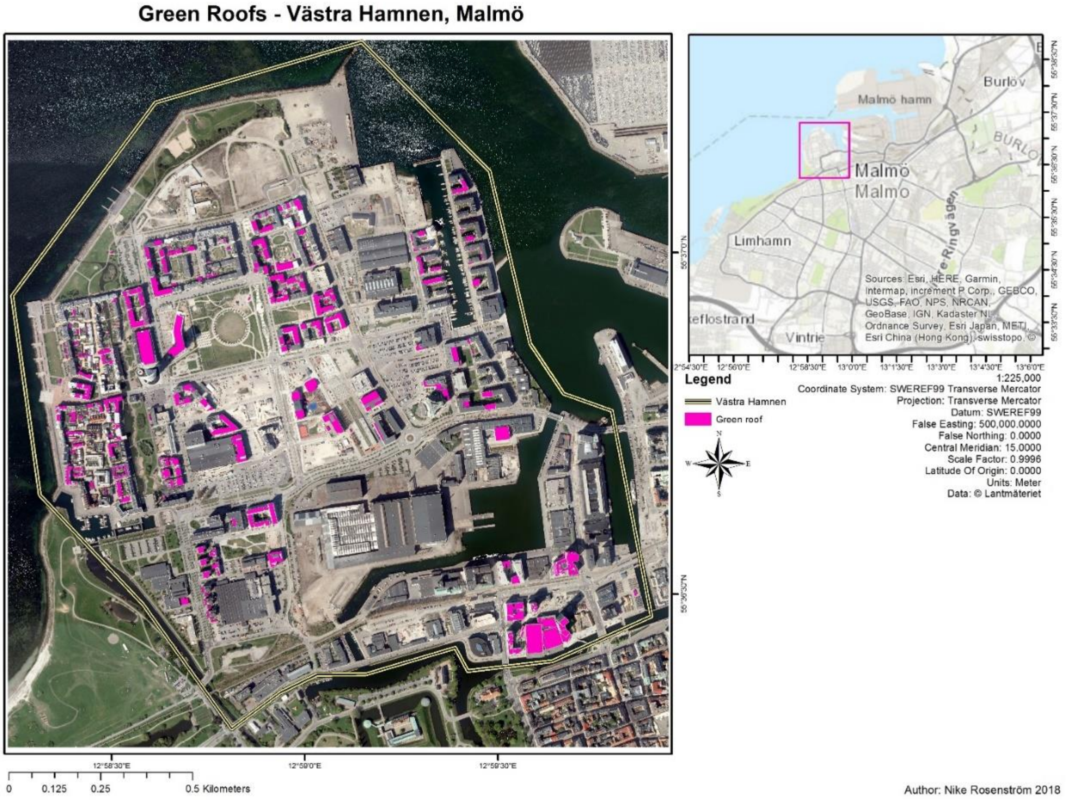

Figure 4: *The resulting map from the digitization of the green roofs in Västra Hamnen, Malmö. (Aerial photo to the left, Orthophoto raster, 0.25 m RGB © Lantmäteriet, base map to the right © Esri.) (Full page map is found in Appendix I).*

3.2. Resulting tables and calculations

3.2.1. Green roof area

Apart from Figure 4, Table 1 shows the total area of all the roofs in Västra Hamnen, and also the area of each of the green roofs on each of the different types of buildings that they are situated on. It can be seen that the total area of all the roofs are 385 471 m^2 while the whole Västra Hamnen ground area is 1 870 000 m^2, which means that all the roofs cover ca 21 % of the whole area. The regular roofs are 315 583 m^2 while the green roofs are 69 888 m^2 which is ca 17 % and ca 4 % respectively out of the whole ground area. The residential buildings are as much as 41 033 m^2 while the governmental buildings are 3 326 m^2 in size.

Table 1*: The area for each of the different types of green roofs and the regular roofs.*

Type	***Area (m2)***
Residential	41 033
Company building	19 578
Governmental building	5 951
Garden shed/bike garage/garbage room	3 326
Green roofs combined	**69 888**
Regular	315 583
Sum	**385 471**

The percentage of all the green- and regular roofs are shown in Table 2 and were derived from Calculation 1 using Equation 1. The regular roofs stand for 81,9 % of all the roofs in the area while the green roofs represent 18,1 %. What kind of buildings the green roofs are situated on are shown in Table 3 in percentage of total green roofs area, either residential buildings, company, governmental or smaller roofs as garden sheds for example. By doing Calculation 2, using Equation 1, the residential buildings cover 58,7% of all the green roofs in the area while the governmental buildings represent 8,5% of the total green roof area.

__Table 2__: Resulting percentage for green roofs and the regular roofs.

Type	***Percentage %***
Green combined	18,1
Regular	81,9
Sum	**100,0**

__Table 3__: The resulting percentages for each type of buildings the green roofs are situated on.

Type	***Percentage %***
Residential	58,7
Company	*28,0*
Governmental	8,5
Garden	*4,8*
Green combined	**100,0**

3.2.2. CO_2 sequestration

The total amount of CO_2 that is being sequestered by the green roofs in Västra Hamnen can be calculated by using Equation 1:

$$187{,}5 \text{ g C } m^{-2}yr^{-1} * 69\,888\, m^2 = 13\,103\,980 \text{ g C } yr^{-1} \sim 13.1 \text{ tonnes C } yr^{-1}$$

When using Equation 3, the molecule weight for CO_2 is calculated:

$$1 * 12{,}01 + 2 * 16{,}00 = 44{,}01 \text{ g}$$

So, the conversion from CO_2 to C results in power plant emissions of:

$$\left(\frac{12{,}01}{44{,}01}\right) * 267\,330{,}64\, tonnes\ CO2\ yr^{-1} = 72\,954{,}53\, tonnes\ Cyr^{-1}$$

$$\frac{13{,}10}{72\,954{,}53} * 100 \cong 0{,}018 = 1{,}8 * 10^{-2}\ \%$$

This shows that the green roofs in Västra Hamnen have the potential to remove 0,018 % per year of the C emissions from a power plant given the assumptions made here (as critically discussed below).

For the cars' C emission, the results are:

$$\left(\frac{12{,}01}{44{,}01}\right) * 3\ tonnes\ CO2\ yr^{-1} = 0{,}8187\ tonnes\ C y\mathrm{r}^{-1}$$

And when calculating how much the green roofs make up for from the cars' emissions:

$$\frac{13{,}10}{0{,}8187} = 16$$

This shows that the total area of green roofs in Västra Hamnen can potentially sequester 16 times as much as one car emits over a period of one year on average in Sweden, again given the assumptions made here.

If it is then related to the number of car owners in the area, which is 2 488, it can be calculated that the green roofs sequester about 0,64 % of the C emissions from all the cars in Västra Hamnen

4. Discussion

Next, the results will be analyzed and discussed furthermore, and a bigger picture will be drawn as well as sources of errors that might have influenced the results.

4.1. Analyzing the results

4.1.1. Green roof distribution

As seen in figure 4, the green roofs are quite well distributed over the whole area, there seem to be a somewhat smaller amount in the southeast corner, but otherwise the area is well defined by the green roofs. But when comparing the map to the percentage of green roofs, shown in Table 2, the fraction is not as high as expected. 18,1 % green roofs while the regular roofs stand for 81,9 % of all the roofs in the area. This might of course be due to the bigger industrial buildings, in the southeast, that has regular roofs.

For an area, that is claimed to have the focus on sustainability, the green roofs might seem to be far down the list of things to incorporate. But the fact is that the area is still under development and it is expected to continue to 2031 (Malmö Stad (d) n.d.). It is also a lot of difficulties and work to rebuild a regular roof to a green roof, such as: weak structural load of the existing roof, technical difficulties when designing and constructing the new green roof and the old age of the building (Li and Yeung 2014). These factors obviously play a part in the decision to rebuild a roof to a green roof or not.

4.1.2. Calculations

From the calculations made, it resulted in 13 ton C that was being sequestered by the total 69 888 m^2 green roofs. By the continuing calculations it is shown that it is only 0,018 % of the amount of C that one power plant in Malmö emits during a year. So, by looking at the big picture, with the power plant spewing/pouring/ejecting out C emissions, the green roofs do not off-set enough of the anthropogenic emissions for a compensation to be made. On the car's emissions on the other hand, the green roofs sequester as much as 16 times the amount that one car emits over a year. This can be compared to, either compensate for 16 cars' C emissions over a year, or a single car's

C emissions for 16 years, in only one year of C sequestration by the green roofs. Even though it might not be enough for a family, to off-set their car's emissions, by building a green roof instead of a regular roof on their house. It is, however, still relevant in addition to everything else that is being done to help the environment and climate change, that people should be aware of and gain knowledge about.

When relating the C sequestration to the cars, it is seen that the roofs sequester 0,64 % of all the C emissions from all the cars in Västra Hamnen. To put this in perspective, the roofs sequestered 0,018 % of the amount of C emission from a power plant. So, for the big picture, with the sequestration of the C emissions from a power plant, it is not satisfactory with the results. But on a smaller scale, with sequestration from emissions from cars, one should not take green roofs out of the equation. Even though the amounts, of the off-setting of anthropogenic C emissions by green roofs, are not that big, green roofs are however still something to consider for improving the environment.

4.2. Sources of error

In this section, a discussion of the assumptions made, and the potential sources of errors for calculating the C sequestration potential of the green roofs in Västra Hamnen, will be held. This is important for the research to go forward and to continue investigating and conducting experiments on this topic.

4.2.1. Transferable data

One of the biggest uncertainties are the transferability of the measured CO_2 data from Michigan to Sweden. Even though the climate, as well as the vegetation on the green roofs, are similar in a broader sense (i.e. same Köppen climate zone), there is just no assurance that the measured values would be similar to what would be measured here.

4.2.2. Intensive roofs

The intensive green roofs in the area were treated as extensive ones. This was mainly due to the uncertainty if they really were intensive ones or just extensive ones with planted, bigger vegetation in pots, as a garden landscaping design. There were however only two smaller roofs that would fall under those uncertainties and that is why the conversion to extensive ones were made. The possible error is estimated to be much less than 5 %.

4.2.3. Small roof sizes and height

The smaller roof sizes, such as the garden sheds, bike garages and public toilettes, that had green roofs might be a source of error. Because no investigation was conducted to examine if the height of the roof is of importance or not when it comes to the amount of C sequestration possible.

4.2.4. The angle of roofs

It is hard to digitize an angled roof from an aerial photograph because all roofs seem flat, but with the help from Malmö Stad Karta, it was visible that not all roofs were flat. This is then a source of error, because when digitizing an angled roof, as a flat roof, the areal surface is not as big as it is in reality. Therefore, some m^2 of roof area might have been lost in the digitizing process.

4.2.5. Vegetation

Even though the vegetation on green roofs most likely are similar in Michigan and Sweden (Li and Yeung 2014; Peel et al. 2007; Wrede 2011) there is no real knowledge unless one actually investigate it by field visits. This was not possible due to the time limitations and accessibility to the roofs.

4.2.6. Local climate

The local climate can very well influence the C sequestration by green roofs. The closeness to the ocean in Malmö or the amount of rain can affect the amount of C that a plant can sequester. The surrounding conditions, such as the amount of maintenance and shadow also contributes to smaller errors that is hard to account for if the measurements and experiment are not done in the same way.

4.2.7. C sequestration respire back to atmosphere

The C sequestration that Getter et al. (2009) measured were C stored in above- and belowground biomass and substrate organic matter. This C will successively be respired back to the atmosphere, through the decomposition of the organic material, in a couple of years. This is also enlarged by the uncertainty of how the sequestration rate increases/decreases after a couple of years. The green roofs in Michigan were not accounted for how old they were, while the age of the roofs in Västra Hamnen are between 1-17 years old at least. The age of the green roof certainly is a source of error because the lack of information on how the roof continue to sequester carbon over a longer period of time.

4.3. Future research

The research on this topic is expected to continue and be one of the more prominent approaches to the research about climate mitigation tactics. The next step is to conduct even more and bigger experiments and measure data in various parts of the world. Research with other types of vegetation on the green roofs and the placement of the green roofs, near water or deep into a country etc., is of interest.

4.4. Additional thoughts

For the climate change and temperature increase to reduce, something must be done to prevent it from increasing any further. Therefore, it is thought that everything that is done to lower the current trend, is a step towards a better climate. Every tree that is planted, every person that chooses to take the bike instead of the car and every locally produced product that is being sold, are all small things that together helps to lower the current trend. It is all the small things, that together, makes the difference.

If, in the future, the CO_2 emissions could be in balance with the sequestration or uptake of CO_2, it would be a huge step in bettering the climate. But from how the world looks and functions right now, it would not be possible.

5. Conclusion

The quantification of the effects that green roofs have on ambient CO_2 have shown to be possible to investigate. Atmospheric CO_2 levels could not be meaningfully reduced by the means of green roofs alone. They can contribute to the bettering of the environment, but they do not sequester enough C for it to be substantial for off-setting anthropogenic emissions from a power plant. They do however balance out the C emissions from 16 cars per year, or 0,64 % of the cars in Västra Hamnen. Therefore, the alternative hypothesis in this study, is rejected.

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Appendix I

Green Roofs - Västra Hamnen, Malmö