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Norwegian inequality in two dimensions: Air pollution and income

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Abstract

The burdens of air pollution are not shared equally across the population. These burdens affect our health and our welfare. If we want to understand inequality of welfare in the population, not just inequality of income, these burdens need to be included. Three main theories exist to explain how the inequalities if income and environmental damages, like air pollution, affect each other. The first is the “trade-off hypothesis”, where living in a polluted area comes with a higher income, so that these two inequalities offset each other. The second, called the “market hypothesis”, explain how those with higher income can afford to live in cleaner areas, thus the two inequalities add to each other. The last is the “environmental justice hypothesis”, which explain how polluting activity is often located in less resourceful areas, where opposition to them will be smaller. Using data from the NordicWelfAir project, I explore inequality between municipalities and city districts in Norway, and with a method of implicit valuation of air pollution, I show that the damages from this pollution adds to overall inequality. Also, I find that the highest damages from air pollution are found where the income is lowest. For the three hypothesis I find evidence that all exists simultaneously in Norway.

Sammendrag

Byrdene fra luftforurensning er ikke fordelt likt I befolkningen. Disse byrdene påvirker helsa og velferden vår. Hvis vi ønsker å forstå ulikheten av velferd i befolkningen, ikke bare ulikheten i inntekt, må disse byrdene inkluderes. Tre hovedteorier finnes for å forklare hvordan ulikhet i inntekt og ulikhet i miljøskader, som luftforurensning, påvirker hverandre. Den første er «avveining hypotesen», hvor det å bo i et forurenset område kommer med en høyere inntekt, sånn at de to ulikhetene oppveier hverandre. Den andre, kalt «marked hypotesen», forklarer hvordan de med høyere inntekt har mulighet til å bo i mindre forurensede områder, på den måten vil ulikhetene forsterkes. Den tredje er «miljø rettferdighets hypotesen», som forklarer hvordan forurensende aktiviteter ofte befinner seg i mindre ressurssterke områder, der motstanden mot dem vil være svakere. Ved å bruke data fra NordicWelfAir prosjektet, utforsker jeg ulikheten mellom kommuner og bydeler i Norge, og med en metode for implisitt verdsetting av luftforurensingen, viser jeg at skadene fra denne luftforurensningen øker ulikheten. Jeg finner også at de største skadene fra luftforurensingen finner sted det det også er lavest inntekt. Når det gjelder de tre hypotesene finner jeg bevis for at alle tre eksister side om side i Norge.

Acknowledgement

This thesis completes master’s degree in economics. The degree has been a journey that has been both challenging and highly rewarding.

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Finally, I would like to thank my wife and kids, for their support and their patience, and especially for enduring my long monologues about economics at the dinner table.

All errors in this thesis are my own.

-Audun

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1 Introduction

Traditionally, economics prime concern is efficiency. However, in the wake of Thomas Piketty's book "Capital in the Twenty-First Century" (Piketty & Goldhammer 2014), equity has gained importance. Nobel prize winning economist Robert Shiller has said: *"the most important problem we are facing now, today, I think, is rising inequality in the United States and elsewhere in the world" (Digital Journal 2013)*. Inequality considerations in economics are usually concerned with the distribution of income or wealth, but human wellbeing (and thus welfare) is also affected by environmental quality. Thus, the distribution of environmental quality should also be accounted for when assessing inequality.

7 million people worldwide are estimated to die prematurely each year due to air pollution (World Health Organization 2019). In the European Union the corresponding number is around 500 000 people, and for Norway alone 1550 people die prematurely each year (European Environment Agency 2018). Since we have reason to believe that the burden of air pollution is not shared equally across the population, the question of damages from air pollution also becomes a question of inequality. Adding the distribution of air quality to the distribution of income provide a more complete picture of inequality in welfare terms.

This thesis aims to analyze both these aspects of inequality and explore whether air pollution (and the implied damages to public health and ecosystem services) increase or decrease inequality stemming from the income distribution. Two particular research questions, which will be analyzed are: i) Do the poor become worse off when air quality is included in the inequality analysis (and more general: how different parts of the income distribution are affected by air pollution), ii) are there differences in how different income groups are exposed to air pollution in urban versus rural areas.

The analyses performed in this thesis are inspired by the works of Bouvier (2014), both with regards to methods and the distribution hypotheses. The three hypotheses Bouvier (2014) uses are both competing and supplementary to each other. The “trade-off hypotheses” implies that inequality becomes smaller when including environmental quality as it is thought that living in a polluted area comes with higher wage as a compensation. The “market hypothesis”, implies that people with high income can afford to buy a place to live in a less polluted area, and thus inequality increases as “the rich” escape the damages from pollution. The “environmental justice hypothesis”, states that pollution tend to be located where the poor or less resourceful people live as they are less able to fight against it.

While Bouvier (2014) explores the state of Maine in the United States. I will test the same three hypotheses in Norway. Exploring a different and much more egalitarian country than the US will make for an interesting comparison. Comparted to Bouvier (2014), I attempt to take the analysis one step further, by exploring where in the income distribution changes take place when air pollution is included in the inequality analysis and whether there are differences between urban and rural areas in this respect.

The rest of the thesis is organized as follows: First a review of relevant theory for this thesis, including the three main hypotheses for environmental inequality. Then I present the inequality measures I use. Following that I present the way I handle the data and explain the pollutants included in my analysis. In part 3 I present and discuss the results, with first numerical then graphical presentation. I close with part 4, which is my conclusion and policy implications.

2 Theory and Method

Environmental equality is important for the welfare of people, Boyce et al. (2016) identifies three reason why it is so important;

I. The normative principle that everyone has a right to a clean environment. This principle places an intrinsic value on the equality of environmental quality, and it implies that the environmental rights of some should not take precedence over the environmental rights of others.
II. Environmental equality is important for equality of opportunity. Children are a particularly vulnerable group to the impacts of pollution, and a child's life chance can be significantly affected by environmental quality (Currie 2011).
III. Equality of outcome is affected through impacts on property values, days lost from work, productively and health costs.

2.1 Distribution Hypotheses

Exploring the link between pollution and income there are several competing hypotheses. Bouvier (2014) identifies three that have relevance for this thesis. The hypotheses can be seen as both competing and supplementary to each other. While one might dominate in one situation, another hypothesis might dominate elsewhere. I believe we need to consider all three to acquire a more complete understanding of this issue.

2.1.1 Trade-off hypothesis

The “trade-off hypothesis” suggests that individuals are confronted with a choice of where to live, and with this choice follow job opportunities and pollution levels. An individual that choose a lower pollution level would then “trade-off” some level of income opportunity. Alternatively, this individual could choose to live in an area with higher income levels but also with higher pollution. It then comes down to how much individuals value environmental quality and how much they value wage income. As a result, individuals move to areas according to their preferences. Cropper and Arriaga-Salinas (1980) use this approach to estimate the willingness to pay for cleaner air by using differences in air quality and wages across US cities.

The idea of compensating wage differentials has been around at least since Adam Smith’s time. He wrote: “THE whole of the advantages and disadvantages of the different employments of labour and stock must, in the same neighbourhood, be either perfectly equal or continually tending to equality” (Smith 1817). If one choice of employment is simply better than another choice, then everyone will select this better choice. Therefore, for people to be employed in different jobs, the sum of the positive and negative sides should be the same. The same idea applies to pollution. If there is a disadvantage, pollution in this case, this should be compensated with, for example higher wage.

Several studies find evidence for the Trade-off hypothesis. For instance Bayless (1982) finds that university professors receive a higher salary in areas with more total suspended particulates (TSP); about 1-2% increase in salary with one standard deviation increase in TSP. Cole et al. (2009) analyse the wages in pollution intense industries . They find that there is a small, one quarter of a percent, wage premium for people working in a “dirty” industry. However, this rises to over fifteen percent for those working in the five dirtiest industries.

The effect of this hypothesis would be that we get less inequality than with income alone, as those with higher incomes also carry the highest environmental costs. Thus, if we compensate for these environmental costs we should get a more equal income distribution.

2.1.2 Market hypothesis

The “Market hypothesis” indicates that richer individuals will end up in the cleaner areas. Similar to the Trade-off hypothesis, this works through the market, but with quite opposite results. According to the Market hypothesis, individuals with higher income can afford to live in cleaner areas, while individuals with lower income cannot afford to live in such areas, and thus end up living in more polluted places.

Hanna (2007) explores this by conducting a hedonic analysis of wages and housing values and emissions. She finds a negative relationship between pollution and non-wage income, which supports the Market Hypothesis. However, she does not find evidence for pollution affecting wages.

According to this hypothesis, we get increased inequality because the rich escape the cost of pollution, while everyone else get their welfare reduced by it. However, one could argue that this is simply an expression of preferences through the market, and that no injustice has taken place.

2.1.3 Environmental justice hypothesis

The third hypothesis is the Environmental Justice hypothesis. This hypothesis suggests somewhat the same as the Market Hypothesis, namely that the rich live in cleaner areas and the poorer in less clean areas. The basis of how this happens, however, is very different. Here it is thought that the sources of pollution will be placed in areas where opposition to them will be low, typically a poor or otherwise less resourceful area. For instance, if a company wish to set up a new factory that will cause pollution it is more likely to choose a site where opposition to this pollution will be low, typically a poor area, rather than a site where the opposition will be stronger, typically a richer area.

This idea originates from the United States in the 1980s. One of the first reports on this issue was United Church of Christ. Commission for Racial Justice (1987). They discovered that toxic waste dumps are more likely to be placed in areas where ethnic minorities are dominant. This fueled protests and lawsuits of environmental justice. In the early 1990s, this led to President Clinton issuing an executive order, saying that:

"…To the greatest extent practicable and permitted by law, and consistent with the principles set forth In the report on the National Performance Review, each Federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations in the United States and its territories and possessions … " (Executive Order 1994).

Consequently, the environmental justice issue became an integrated part of American politics and decision making. Some, however, would argue that not much have been achieved. The report marking the 20th anniversary of the 1987 United Church of Christ report finds that not much have changed in 20 years (Bullard et al. 2008).

While environmental justice has been debated for several decades in America, it is relatively new in Europe. One reason for the delay among Europeans to adopt such ideas might be the heavy emphasis on race in the American debate, which is a less debated issue in Europe. In Europe, race is less emphasised and more is focused on social conditions and income differences, see for instance (Laurent 2011). This shift in focus in Europe from ethnicity to other social factors is supported by Germani et al. (2014). They look at air pollution in Italy and finds no evidence of environmental discrimination based on ethnicity, however female household heads and a high concentration of children are found to be important factors.

2.2 The inequality measures

There are a number of different inequality measures, each with their own set of strengths and weaknesses. While we could wish that one measure was simply superior in every situation, that is not the case. Often, and in this case, we have to use several measures to understand the whole picture. In this thesis, I will use two indexes and several ratios to explain the inequality, both of income and of environmental damages. In the next section, I will explain the foundations of these measures.

2.2.1 The Gini index

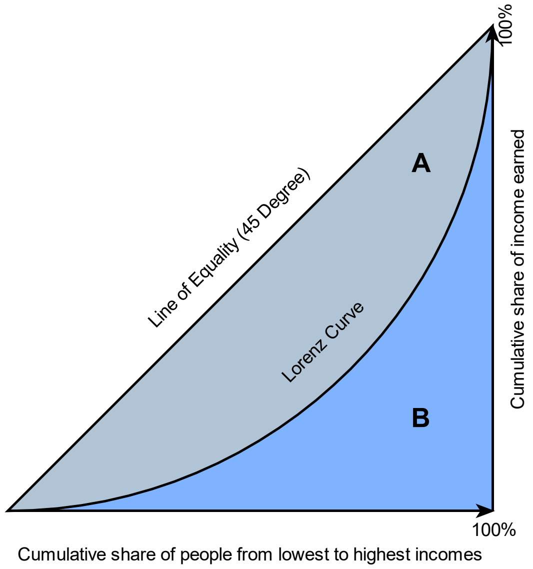

Figure 1 The Lorenz curve Picture from: (Wikipedia)

The Gini index of inequality was created by the Italian statistician Corrado Gini over a hundred years ago (Gini 1912). It has since then become one of the most used measures of inequality. It is both relatively easy to understand and to calculate. It is based on the Lorenz curve, which was created even earlier (Lorenz 1905). In the Lorenz curve the population is ranked according to income, then a graph is drawn, which shows the cumulative income share held by each part of the population. See Figure 1. The Gini coefficient is simply the area A divided by the area (A+B). This will always be a number between 0 and 1. If it is 0, the Lorenz curve is equal to the line of equality meaning that all income is shared equally. If it is 1, there is no area B and the income is not shared at all but instead held by one person, causing maximum inequality. For most practical purposes The Gini Index is somewhere in between these two extremes. In most cases, the Gini index is used to measure inequality of income or wealth, but it has also been used for many other purposes. It has for instance been used to assess inequality among universities (Halffman & Leydesdorff 2010), in medicine – to study the case of selectivity of Kinase Inhibitors (Graczyk 2007) - and to assess the “fairness” of how internet routers deal with flows of data traffic (Shi & Sethu 2003).

The Gini index can be approximated by the following equation:

$$Gini = 1 - \sum_{i=1}^{n} (X_i - X_{i-1})(Y_i + Y_{i-1})$$

Where X_i is a cumulative share of population, Y_i is a cumulative share of income and i is an index of households from 1 to n, n being the total population of the sample. The data is sorted in terms of income, with those having the lowest income being assigned i = 1.

In this thesis, I modify the standard equation, to take into account that the data is on a municipality and city district level, not on a household level. I use:

$$Spatial\ Gini = 1 - \sum_{j=1}^{n} (Z_i - Z_{i-1})(V_i + V_{i-1})$$

Where Z is a cumulative share of population in each spatial zone, V is a cumulative share of median household incomes in the spatial zones, and j is an index of spatial zones from 1 to n, n being the total number of spatial zones in the dataset. The data is still sorted in terms of income, with the spatial zone with the lowest income being assigned j = 1.

In addition, I use number of households in each spatial zone as a weight, in effect increasing n, from the number of spatial zones to the number of households, but each household inside the same zone being identical.

2.2.2 Atkinson index

Another inequality index, that I will use, is the Atkinson index. It takes its name from its creator Antony B. Atkinson who published the article “On the measurement of inequality” (1970), in which the index is presented. He draws on the similar named article, published half a century earlier, “The measurement of the inequality of incomes” (Dalton 1920). What Dalton and Atkinson both highlight is that underlying any inequality measure is some form of idea of a social welfare, and that by reducing inequality we can increase social welfare. How this change in inequality affects social welfare could then be summarized in a social welfare function.

Atkinson proposes a function that only depends on one parameter: ε. This parameter is often called the inequality aversion parameter. The choice of this parameter reflects how much we dislike inequality. ε ranges from 0 to ∞. If we choose 0, we have no problem with inequality and would gain no social welfare from a redistribution of income, and this would give an Atkinson index of 0 no matter then income distribution. On the other end, a choice of ∞ would mean that we accept no inequality, and the Atkinson index would be 1 regardless of income distribution.

This choice of an inequality aversion parameter and a social welfare function - means that the Atkinson index take the step from a purely descriptive tool to something normative. So, a given Atkinson index value can be interpreted both descriptive as well as normative. A Gini index of 0.15 can be useful in comparing with other Gini indexes, but in itself, it tells us very little. The Atkinson index can of course be used in the same way, but additionally an Atkinson index of 0.15 for a chosen ε would tell us that we could achieve the same level social welfare with 15% lower total income than we have now, given that we have complete equal income instead. A higher value for the Atkinson index for a given ε would then mean we have more to gain from redistribution.

Another convenient property of the Atkinson index is that the choice of ε affects the sensitivity to changes in different areas of the income distribution. A $\varepsilon = 1$ would be neutral in terms of sensitivity. A $\varepsilon < 1$ would mean that it is more sensitive to changes in the higher parts of the income distribution; that is changes in the income to the rich. While a $\varepsilon > 1$ would mean that it is more sensitive to changes in the bottom of the distribution, that is with the income of the poor. Thus, when looking at changes to the Atkinson index it is often useful to calculate it with several different ε to look at where the change is happening.

The Atkinson index is not used as much as the Gini index, but it has also been used for a variety of purposes. It is often used as a supplement to other inequality measures such as the Gini, especially in order to get a ranking preference of intersecting Lorenz curves (Aaberge 2007), or to look at changes in different parts of the distribution.

But, it has also been used in other areas than inequality economics. For instance, it has been used to improve data clustering when handling big data(Kant & Ansari 2016)

The Atkinson index can be calculated with the following equation:

$$A(\varepsilon) = 1 - \frac{y_{EDE}}{\bar{y}}$$

Here yEDE Equally Distributed Equivalent income the level of income that if given to everyone in society would give as much total welfare as the current income distribution does. $\bar{y}$ is the mean of the current income distribution.

We can calculate this Equally Distributed Equivalent with the following equation:

$$y_{EDE} = [\frac{1}{n}\sum_{i=1}^{n} y_i^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}$$

Where yi is the income of household i, ε is the inequality aversion parameter and n is the total number of households.

If we want to calculate the Atkinson index directly, we can insert the equation for y_{EDE} into our first equation:

$$A(\varepsilon) = 1 - \frac{1}{\bar{y}}\,[\frac{1}{n}\sum_{i=1}^{n} y_i^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}$$

Here, just as before, yi is the income of household i, $\bar{y}$ is the mean income in the population, ε is the inequality aversion parameter and n is the total number of households in the data.

Just as with the Gini index, I modify the Atkinsons index to take into account that the data is on a municipality and city district level, and not on a household or individual level as is the norm.

$$Spatial\ A(\varepsilon) = 1 - \frac{1}{\bar{v}}\,[\frac{1}{n}\sum_{i=1}^{n} v_i^{1-\varepsilon}]^{\frac{1}{1-\varepsilon}}$$

Here vi is the median income in zone i, $\bar{v}$ is the mean of the median incomes, ε is the inequality aversion parameter, and n is the total number of zones in the data. Again, I use the number of households in each zone as a weight, in effect increasing n, from the number of spatial zones to the number of households, but each household in in the same zone being identical.

2.2.3 Simple measures of inequality

In addition to the two complex inequality measures -the Gini and Atkinson indexes - I will also use some simple ratios, namely the p90/p10, p90/p50 and p10/p50 ratios. These ratios are relatively easy to use and understand and can give valuable insight, especially when combined with more complex measures. In the official statistics for Norway and for the OCED, the p90/p10 is one of the measures that are published (OECD 2019; Statistics Norway 2018).

The p90/p10 ratio is calculated by taking the income of the household that has higher income than exactly 90% of the population and dividing it on the income of the household that has higher income than only 10% of the population. If you have more income than 90% of the population then you are relatively rich, but not the richest, and if you have higher income than 10% of the population then you are relatively poor, but not the poorest. This measure is a measure of comparing the rich to the poor, while avoiding the extremes at each side. In Norway in 2016 the p90/p10 was 3,0 (Statistics Norway 2018), meaning that this representative household (that had higher income than 90% of the population) of the rich was making 3 times as much as this representative household of the poor (that has higher income than just 10% of the population).

The other ratios can be calculated in similar ways. But p90/p50 would then be comparing a rich household to a household from middle class. And p50/p10 would be comparing a household from the middle class to a household that is poor.

When exploring a change in the Gini or Atkinson indexes, these ratios can be used to analyse where in the income distribution the change is more prominent.

2.2.4 Valuation of environmental damages

Economists have tried to put a monetized value on environmental damages for many years. The methods used vary, and so do the estimates. For Sweden, Carlsson and Johansson-Stenman (2000) uses a Contingent Valuation Method (CVM) to find a mean willingness to pay for a 50% reduction in harmful substances at 2000SEK/year (about $250). In a study of ten European countries Welsch (2006) uses reported subjective well-being and historical reductions in pollution to find an implicit valuation of environmental damages. The reductions of NO_2 in Western Europe in the 1990sWelsch value at around $750/year. For the US, Bayer et al. (2009) uses a discrete-choice approach to hedonic pricing to find a median household willingness to pay between $149 and $185 for a one unit improvement of air quality.

This is just a few examples, but they illustrate the complexity of the issue. Studies measure different aspects of the environment, and different methods have been used. And, even when controlling for currency rates and price growth, the values they find vary a lot. Some are in favor of scrapping the idea of putting monetized value on environmental damages. (Ackerman & Heinzerling 2001)

The most common approach however, is a damage function approach. Here you start with a change in emission, in this case an emission of air pollution. Then we see or model how this disperses and how it reaches people and ecosystems. After that we need to find out the health effects of those it those it reaches, through a dose-response function and the effects it has on ecosystems. Lastly, we try to value those effects. We can use this to either find a value for each person exposed, or for each unit of emission. This type of calculations have been done for Norway, for instance by The Norwegian Public Roads Administration (2018), however this values are given in a way that they are not easily compatible with the annual mean concentrations I use for this thesis.

I believe it is important to acknowledge that this is a difficult issue, and that there are cases where it is very important to put a very exact price on a damage effect, and there are cases where the exact price is of less importance. My main research question is not related to a case where this exact price is important. However, it is important to put some value on the damage, in order to connect it to income. A convenient method for putting a value on the damages cause by air pollution in the case of Norway seems to be the one of implicit valuation, developed by Bouvier (2014).

2.2.5 Environmental adjusted index's

While the Gini index is quite old, the idea of a Gini adjusted for an environmental context is more recent. Perhaps the first was Ruitenbeek (1996), who adjusts the Gini to include income from traditional ecological use and thus creates an "ecologically adjusted index".

More recently a method of adjusting income inequality for environmental damages was developed by Bouvier(2014). She creates an adjusted income index using a form of implicit valuation of the damages. She uses the distribution of income and environmental damages to put an implicit value on the damages caused, letting one standard deviation of income equal one standard deviation of damages. Thus, pretending that if you got one standard deviation worth of extra damages and one standard deviation worth of increased income your welfare would stay the same. By calculating several inequality measures with plain income and after adjusting for environmental damages, she compares them to see if the environmental damages are additive or subtractive to inequality. The size of the change is of less importance than the direction in this method, as the valuation of the damages is not assumed to be exact. One could easily change the weight put on the damages vs the income to something you view as more correct, but this would only affect the size of the change, not the direction.

Mathematically, we do this by first standardizing the pollution concentration:

$$sPM2.5_i = \frac{PM2.5_i - \mu_y}{\sigma_y}$$

Her $sPM2.5_i$ is the standardized median concentration of $PM_{2.5}$ in the i municipality or city district, $PM2.5_i$ is the median $PM_{2.5}$ concentration zone i, μ_y is the arithmetic mean of the median $PM_{2.5}$ concentration, taken over all municipalities and city districts. σ_y is the standard deviation of the median $PM_{2.5}$ concentration, taken over all municipalities and city districts. For NO_2 we do the same:

$$sNO2_i = \frac{NO2_i - \mu_u}{\sigma_u}$$

Here, $sNO2_i$ is the standardized median concentration of NO_2 in the i municipality or city district, NO2i is the median NO_2 concentration in the i municipality or city district, μ_u is the arithmetic mean of the median NO_2 concentrations, taken over all municipalities and city districts and σ_u is the standard deviation of the median NO_2 concentration, taken over all municipalities and city districts.

We now have a standardized measure of concentrations of $PM_{2.5}$ and NO_2, with a mean of zero and a standard deviation of 1. This we can then use to adjust the income to acquire an environmentally adjusted income. For income adjusted for $PM_{2.5}$ damages we then calculate:

$$adjINCPM2.5_i = INCOME_i + sPM2.5_i * (-\sigma_t)$$

Here $adjINCPM2.5_i$ is median household income adjusted for $PM_{2.5}$ damages for municipality or city district i, $INCOME_i$ is the median household income after tax, $sPM2.5_i$ is the standardized median $PM_{2.5}$ concentration and σ_t is the standard deviation of median household income after tax. Notice the negative attached to the standard deviation, as a high standardized median $PM_{2.5}$ concentration should have a negative income adjustment. For NO_2 it becomes much the same:

$$adjINCNO2_i = INCOME_i + sNO2_i * (-\sigma_t)$$

Here $adjINCNO2_i$ is median household income adjusted for NO_2 damages for municipality or city district i, $INCOME_i$ is the median household income after tax, $sNO2_i$ is the standardized median NO_2 concentration and σ_t is the standard deviation of median household income after tax.

These two last equations are important and perhaps not intuitive, so let me explain them again with words. We get the adjusted income for a zone (left side of the equation) by taking the median household income for that zone and adding the product of two factors (right side of the equation). The first is the standardized pollution concentration for that zone (can be either positive or negative), the second is the standard deviation of the household income (but negative). A theoretical municipality with a median household income of 400 000 NOK, and one standard deviation below the mean in pollution concentration would then get an adjusted income of 452 293.54 NOK (400 000 NOK + (-1) * (-52 293.54). The standard deviation of median household income is 52 293.54 NOK. Since this theoretical municipality had less than the average pollution concentration it was adjusted upward.

This method has some advantages when exploring inequality. For instance, when adjusting the income, the mean stays the same, since I add a standardized value that has a mean of zero. This makes comparison between income before and after adjustment easier. Also, since I subtract from those with lower than average environmental quality, but add to those above average, it is easier to see both the groups, both the “winners” and the “losers” when it comes to environmental quality.

2.3 Data and data management

I have received air pollution data from the NordicWelfAir project, which are used in this thesis. The project uses the EVA (Economic Valuation of Air pollution) model. This is an integrated model, which calculates the distribution of several air pollution components from different pollution sources, taking into account the non-linear atmospheric chemistry. For details of this model see Brandt et al. (2013). One big advantage of the data from the EVA model is that it includes mobile emission sources, like traffic. Much of the work done, in the US at least, rely only on reported emissions from fixed emission sources(Bouvier 2014; Boyce et al. 2016). The air pollution concentration data is annual mean concentrations on a 1 x 1 km grid, covering all populated parts of Norway for the year 2016. The data from the EVA model will be taken as given, as I have no premises for doing any corrections to it.

To carry out the analyses I first need to convert the pollution concentration data to a format I had income data for, namely municipality and city districts. I use maps of the administrative units in Norway that I acquired from GeoNorge. The newest maps are available on the web (GeoNorge), but I am using a map for 2016, which is available upon request.

I use the software QGIS in order to link this data, as well as to create the maps presented in this thesis. When converting the data from the 1 x 1 km grid to municipality and city districts I find the median of the annual mean concentrations, within each zone.

Data on income, households and all other non-pollution data is collected from Statistics Norway.

The calculations of the inequality measures are done using STATA and the add-on ineqdeco (Jenkins 1999).

2.3.1 Spatial scope and scale

Since I am part of the NordicWelfAir project, I have access to concentration data for the entire Nordic region. However, I have chosen to focus only on Norway for this thesis. Considering the lack of knowledge about these issues, in particular of the Nordic countries, I hope that my thesis can be a guideline and inspiration for other analyses on Sweden, Denmark, and Iceland, both separately, combined, and comparative analyses.

While time constraints are part of the decision to only focus on Norway, limiting the scope enables an in-depth and detailed analysis of this issue it, that could be lost with a wider scope

For this thesis, a spatial scale of municipalities and city districts has been chosen. That means that the 4 biggest cities in Norway, that have formal city districts, have been removed and replaced by their city districts. When adding the city districts the cities themselves must be removed to avoid double counting. This is the finest spatial grid that have official income statistics publicly available for the whole country.

2.3.2 Choice of income type

For municipalities and city districts in Norway different income and wealth data is available, and a choice of what to use must be made. Both income and wealth are often used in inequality studies. In this thesis, I will combine economic data to pollution data; a type of pollutant that can be thought of as a flow pollutant. Income data therefore fits better in the analysis.

Furthermore, I must choose between median or mean, income before or after tax and individual or household. I choose median household income after tax. The use of median is to avoid a few high incomes to affect the value too much. I use household income because it best represents actual living standard as there are individuals who do not have income, but who live with high-income partners. I look at income after tax because we are more interested in actual purchasing power, as that is what affects the population's welfare. All analysis in this thesis using income will use this median household income after tax, for the year 2016.

2.4 Choice of pollutants

The air is full of pollutants, and any and all of them could have made an interesting study. However, the method of using environmental adjusted inequality measures is best suited for studying only two dimensions at once, and one is already taken by income. Therefor any analysis will have to be for one pollutant at a time. I have chosen to focus on the two most deadly pollutants, and the two that usually have the most focus, PM2.5 and NO2. For more information about the other pollutants included in the EVA model, and some inequality measures calculated for them, see Appendix B.

2.4.1 Particulate matter 2.5 µm

The air pollution with "the most blood on its hands" is particulate matter with a size smaller than 2.5 µm in diameter, usually called $PM_{2.5}$. This is category of pollutants that is defended by size and not by chemical compassion. So, all particles with a dimeter smaller than 2.5 µm are included in this measure.

2.5 µm is a very small size, compared to most things. For instance, a human hair typically has a diameter of 50-70 µm and a fine grain of beach sand is around 90 µm in diameter. See Figure 2 for comparison. This means the particles are so small that we can inhale them without even noticing, and they can get far into our lungs and sometimes even into our bloodstream.

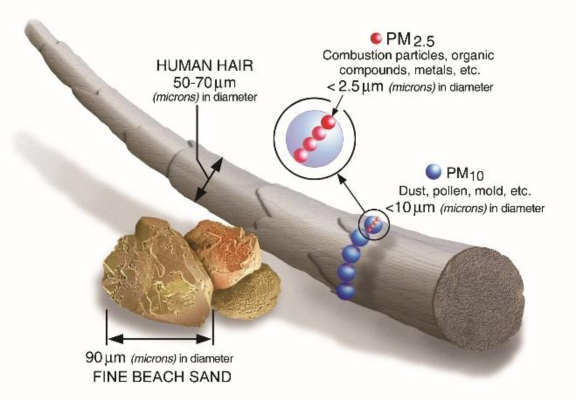

Figure 2: Size of PM2.5 Source: (EPA)

Effects on human health can be found both for short-term and long-term exposure. In Europe, around 400 000 premature deaths each year is estimated to be caused by $PM_{2.5}$ alone. (European Environment Agency 2018) The most common reason for premature death attributed to $PM_{2.5}$ is Heart disease and stroke, followed by lung diseases and lung cancer (World Health Organization 2014). It can also have many non-fatal effects like reduced lung function, respiratory infections, aggravated asthma, reduced fertility, increased risk of type 2 diabetes, obesity and Alzheimer's disease (European Environment Agency 2018). There is no evidence of any safe levels of exposure, so all concentrations above zero has the potential for harm. Particularly in the vulnerable groups, that include those with pre-existing lung or heart disease as well as elderly people and children (World Health Organization 2013).

Norway has generally less $PM_{2.5}$ than many European countries (European Environment Agency 2018), still some cities have problems with meting national guidelines. The main sources are exhaust from combustion engines, fuelwood and particles transported over long distances (Norwegian Institute of Public Health 2017). Heavy industry is generally not a strong component in Norway, but in some areas, it can still have a high contribution. For short term peeks other components, like fireworks on New Year's Eve, can push levels very high, but this New Year's Eve peek have little effect on annual mean levels. Particles transported over long distances play an important part, and even for monitor stations close to roads it can contribute as much as 40% of the annual mean. Many of these particles that travel far is from outside of Norway, as much as 57%, while the rest is from mainland

Norway and offshore activity in the North Sea. 7% even have their origin in countries outside of Europe (Norwegian Institute of Public Health 2017).

Table 2-1: Guidelines and limit values for annual mean concentrations of PM2.5

Organization	Limit
WHO (guideline)	10 µg/m^3
EEA (limit)	25 µg/m^3
Norway (limit)	15 µg/m^3
Norway (air quality standard)	8 µg/m^3

There exists many guidelines and limits for what annual mean concentrations for $PM_{2.5}$ that is acceptable. In Norway we have a limit that, by law, we should stay under, at 15 µg/m3. This is stricter than the EEA limit at 25 µg/m^3. We also have an air quality standard that we strive towards at a maximum of 8 µg/m^3. This is stricter than WHO guidelines at 10 µg/m^3.

2.4.2 Nitrogen Dioxide

The air pollutant that causes the second most deaths each year is nitrogen dioxide, commonly referred to as NO_2. Together with nitrogen oxide, NO, they form a group of pollutants know as nitrogen oxides, or NO_x. This are highly reactive gases that form at very high temperatures in combustion. In the presence of O3 NO will react to from NO_2. While both NO and NO_2 is toxic to humans it is particularly NO_2 that has large health impacts.

Health effects on humans have been found both from long- and short-term exposure. In Europe it is estimated that almost 80 000 people die prematurely because of NO_2 pollution (European Environment Agency 2018). For Norway it is estimated 200 people die prematurely. They primarily affect the raspatory system and the hearth in the human body. Both long- and short-term exposure shows increased occurrence of asthma and bronchitis as well as general decrease in lung function. Particularly short-term exposure to high levels has shown an increase in cardiovascular diseases. For NO_2 there has not been shown any health effects at very small concentrations, so there may be a safe level of exposure, but it has proven hard to isolate the effects from NO_2 from other air pollutants so there is still uncertainty. (Norwegain Institue of Public Health 2019; Norwegian Environment Agency 2017).

The general levels of NO_2 is lower in Norway than in much of Europe (European Environment Agency 2018), still many Norwegian cities have difficulties with high concentrations (Norwegian Environment Agency 2017). The main source of NO_2 in Norway is from traffic, particularly from diesel engines. Other sources include emissions from ships (also diesel engines) and emissions transported over long distances (Norwegain Institue of Public Health 2019).

Several organizations have guidelines and limits for what levels of annual mean concentrations of NO_2 is acceptable, and this are summarized in Table 2-2. Unlike the guidelines and limits for $PM_{2.5}$ annual mean concentrations these are constant with each other. All set the limit or guideline at 40 μg/m³.

Table 2-2: Guidelines and limits of annual mean concentration of NO2

Organization	Limit
WHO (guideline)	40 μg/m³
EEA (limit)	40 μg/m³
Norway (limit)	40 μg/m³
Norway (air quality standard)	40 μg/m³

3 Results and discussion

In this part, I will go through the analysis, which is divided in two. First, I will go through the analysis of the different inequality measures, for the country as a whole, and for the city districts. Secondly, I will use maps for a graphical analysis.

3.1 Inequality measures analysis

3.1.1 Descriptive statistics

Table 3-1: Descriptive statistics of income and air pollution data

Variable	*Observations*	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
Median household income (NOK)	460	497 489	52 293.56	306 000	684 000
Median $PM_{2.5}$ annual mean concentration ($\mu g/m^3$)	460	4.50	1.39	2.48	9.03
Median NO_2 annual mean concentration ($\mu g/m^3$)	460	3.13	3.55	0.33	21.23

In Table 3-1 some descriptive statistics of the used data is shown. The 460 observations are the all municipalities in Norway in 2016 with the 4 biggest cities broken down into city districts. The Median $PM_{2.5}$ and median NO_2 annual mean concentrations are from the EVA model. In terms of income, the zone with the lowest median household income is 306 000 NOK, and this low score belongs to the city district of Oslo called “sentrum”. The lowest part of the income distribution is dominated by city districts, the lowest part being 5 city districts in Oslo and Bergen. On the top part of that scale is a city district in Bergen called “Ytrebygda” with a median income of 684 000 NOK. Three of the top 5 zones are city districts in Oslo, Bergen and Stavanger, and the top 8 include these city districts and municipalities bordering these cities. It is interesting to see that both the lowest and top parts are dominated by the big cities. I will discuss this further in the graphical part of this analysis.

For median $PM_{2.5}$ annual mean concentration the lowest score is 2.48μg/m^3 and it is from the municipality "Kautokeino" in the very northernmost part of Norway. The lower end of the list is very much dominated by municipalities from the northern parts of Norway. The city district with the lowest concentration is only ranked 211th of 460 zones, and this belongs to Trondheim. The zone with the highest $PM_{2.5}$ concentration is a city district in Stavanger called "Eiganes/Våland" with a median concentration of 9.03 μg/m3. Top ten highest consecrations are all found in city districts.

For Median NO_2 annual mean concentration the lowest is found in the municipality "Lebesby" also in the very northernmost part of Norway, and it has a concentration of 0.33 μg/m3. And just as with $PM_{2.5}$ the lower end of the distribution is dominated by municipalities from the northern parts of Norway. The lowest concentration in a city district is found at rank as the 333th lowest concentration. Again, this is a city district in Trondheim. The zone with the highest concentration of NO_2 is a city district in Oslo, "St. HansHaugen" with a median annual concentration of 21.23 μg/m3. Again, city districts dominate the zones with highest median concentrations. All in the top 10 being city districts, and the entire top 6 city districts in Oslo. This confirms what we already suspected, that air pollution is worse in the cities than in rural areas.

3.1.2 Income inequality

Table 3-2: Inequality measures for household income and median annual mean concentrations of $PM_{2.5}$ and NO_2

Inequality measure*	Median Household income	Median $PM_{2.5}$ concentration	Median NO_2 concentration
Gini coefficient	0.067	0.165	0.438
Atkinson index ($\varepsilon = 0.5$)	0.004	0.022	0.158
Atkinson index ($\varepsilon = 1$)	0.007	0.044	0.314
Atkinson index ($\varepsilon = 2$)	0.014	0.090	0.563
P90 / P10	1.386	2.231	11.566
P90 / P50	1.218	1.419	2.866
P50 / P10	1.138	1.678	4.032

**This is calculated at a municipality and city district level, using number of households as weights*

For a closer examination of the distribution of income, $PM_{2.5}$ and NO_2 we can look at Table 3-2 and how they score on the different inequality measures. The levels of inequality for median household income might surprise some, as they seem very low compared to what is common for income inequality. The official level of income inequality measured by the Gini coefficient is 0.261, or 0.242 if excluding students (calculated with household equivalent income (EU-scale) and after tax) (Statistics Norway 2018). The difference here is the detail level, 0.261 is at an actual household level, while 0.067 is median household income but at a municipality and city district level. Using medians of municipalities and city districts we remove the high and low values that are within that municipality, therefore it is not surprising that we find a much lower Gini coefficient when looking between municipalities. We see the same for the P90 / P10 measure that Statistics Norway reports as 3.0 (or 2.8 when excluding student households) while between municipalities and city districts this become 1.386. These low values serve as a reminder that this analysis is between spatial zones, not between households.

For the pollutants $PM_{2.5}$ and NO_2 we find that the median annual mean concentration between municipalities and city districts are more unequally distributed than median income and that NO_2 is more unequally distributed than $PM_{2.5}$. This holds for all inequality measures used, and we can also see that the Lorenz curves in Figure 3 do not cross. That NO_2 is more unequally distributed than $PM_{2.5}$ fits well with what we know about how much of the $PM_{2.5}$ concentrations come from long distance import to Norway, while NO_2 is more locally produced.

It is also interesting to compare the Gini for the pollutants calculated from the 1 x 1 km grid and the Gini calculated from municipalities and city districts. In Table 0-1 (in the appendix) we find the values from the 1 x 1km grid, and from Table 3-2 we find the values calculated between municipalities and city districts. For $PM_{2.5}$ we have 0.150 at 1 x 1 km grid level and 0.165 at municipalities and city district level. For NO_2 we have 0.437 at 1 x 1 km grid level and 0.438 at municipality and city district level. Compared to income we see that when changing scale, we get much smaller changes in Gini coefficient, even if it is not fully comparable, as we do not have income at the 1x1km grid. We also see that when going from a finer detailed level to a less detailed level the Gini's actually goes up. In itself, this does not tell us much, but it is interesting to see that the pollutants and income behave differently when changing the scale.

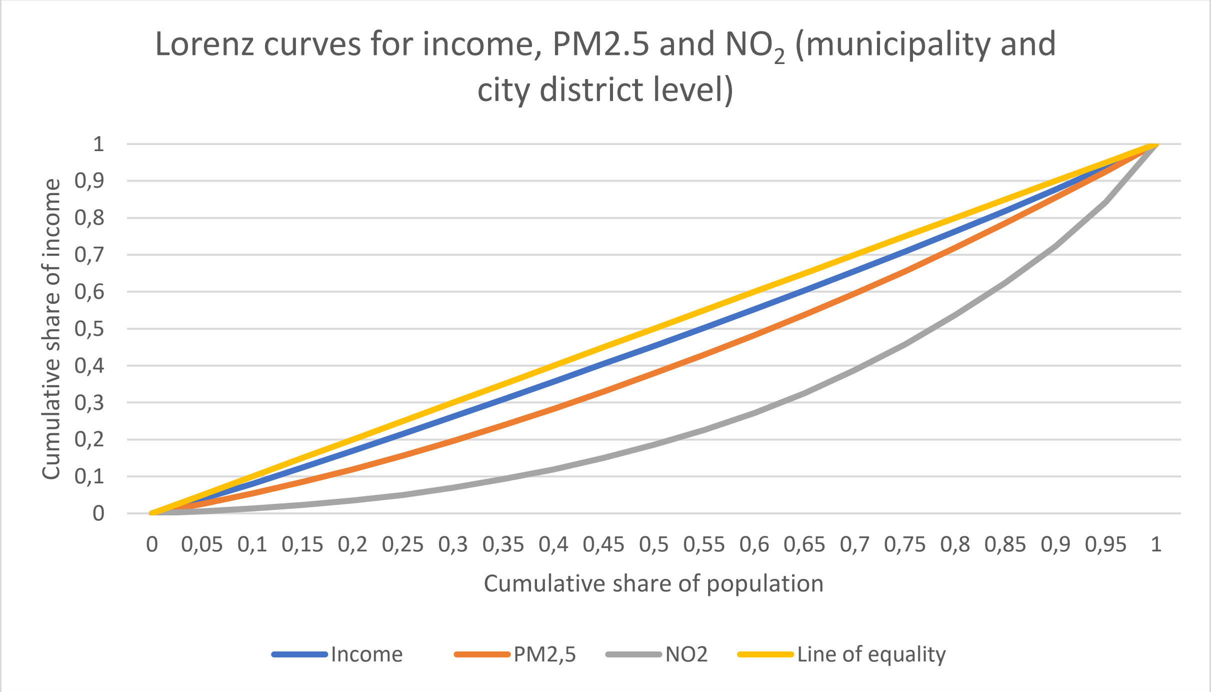

Figure 3: Lorenz curves for median household Income and median annual mean concentrations for $PM_{2.5}$ and NO_2, calculated between municipalities and city districts.

3.1.3 Income adjusted for environmental damages

As described in chapter 2.2.5 I use a method of implicit valuation to adjust for environmental damages. The descriptive statistics for the incomes adjusted for air pollutant concentrations are summarized in Table 3-3.

Table 3-3: descriptive statistics for unadjusted income, and income adjusted for concentrations of $PM_{2.5}$ and NO_2

Variable	*Observations*	*Mean*	*Standard deviation*	*Minimum*	*Maximum*
Median household income (NOK)	460	497 489	52 293.56	306 000	684 000
Income adjusted for $PM_{2.5}$ (NOK)	460	497 489	57 027.73	163 380	637 934
Income adjusted for NO_2 (NOK)	460	497 489	64 583.66	485 58	641 882

This method will by design not change the mean values and we can see they stay the same in both adjustments. However, the standard deviation increases after both adjustments, compared to how they were before, and more so for NO_2 than for $PM_{2.5}$, meaning that the adjusted income distributions are less focused around the mean than the unadjusted income. It is also interesting to see that both minimum and maximum values go down, with minimum values decreasing more than the maximum.

Adjusting for $PM_{2.5}$ concentrations gives us 202 municipalities and city districts, containing 1 698 549 households, that are adjusted down, with an average adjustment of -48 302 NOK. The highest adjustment being - 170 935 NOK for the city district in Stavanger that has the highest median $PM_{2.5}$ annual mean concertation. The lowest ranking zone after $PM_{2.5}$ adjustment is still “Sentrum”, the city district in Oslo, that also ranked lowest in median household income. However, the adjusted income is almost halved to only 163 380 NOK.

While 202 zones were adjusted downwards 258 zones, containing 641 440 households, were adjusted upward, with an average of 37 818 NOK, and the highest adjustment being 76 351 NOK. This highest adjustment of course belonging to the municipality “Kautokeino” that had the lowest median $PM_{2.5}$ concentration. The municipality that has the highest income after adjustments is “Skaun” right outside of Trondheim.

Adjusting for NO_2 concentrations gives us 132 municipalities or city districts containing 1 498 926 households that are adjusted down with an average of -63 517 NOK. The highest adjustment is - 266 728 NOK and that adjustment is for the zone with the highest NO_2 concentrations “St. HansHaugen” in Oslo. The zone with the lowest adjusted income after adjusting for NO_2 concentrations is still “Sentrum” in Oslo, having also the second highest adjustment for NO_2, with only 48 558 NOK in adjusted income. This adjustment leaves “Sentrum” with less than 1/6th of its unadjusted income.

While 132 zones are adjusted down that leaves 328 municipalities or city districts, containing 841 063 households, to be adjusted upwards with an average of 25 562 NOK. The highest positive adjustment is 41 317 NOK and belongs to the municipality with the lowest NO_2 concentration “Lebesby”. After adjusting for NO_2 concentrations the municipality with the highest adjusted income is “Bjerkheim” in the southwest of Norway, with an adjusted income of 641 882 NOK.

For both $PM_{2.5}$ and NO_2 the adjusted minimum and maximum values are lower than the unadjusted values. So, both at the very bottom and very top of the income distribution zones are adjusted downwards. This fits well with what we saw earlier in terms of both the lower end and top of the income distribution being dominated by city districts or municipalities close to cities, and that both pollutants are primarily a city problem.

3.1.4 Inequality with adjusted income

Table 3-4: Inequality measures for unadjusted income and for income adjusted for concentrations of $PM_{2.5}$ and NO_2

Inequality measure	Median Household income	Income adjusted for $PM_{2.5}$	Income adjusted for NO_2
Gini coefficient	0.067	0.099 (+ 48%)	0.112 (+ 67%)
Atkinson index ($\varepsilon = 0.5$)	0.004	0.009 (+ 125%)	0.016 (+ 300%)
Atkinson index ($\varepsilon = 1$)	0.007	0.019 (+ 171%)	0.036 (+ 414%)
Atkinson index ($\varepsilon = 2$)	0.014	0.042 (+ 200%)	0.092 (+ 557%)
P90 / P10	1.386	1.648 (+ 18%)	1.762 (+27%)
P90 / P50	1.218	1.148 (- 6%)	1.136 (- 7%)
P50 / P10	1.138	1.435 (+26%)	1.550 (+36%)

This is calculated at a municipality and city district level, using number of households as weights. In parentheses is the change from unadjusted income.

The adjusted incomes distributions for $PM_{2.5}$ and NO_2 can be used to calculate environmental adjusted inequality measures. The measures are summarized in Table 3-4.

The effects for both adjustments are similar, but more extreme for NO_2 than for $PM_{2.5}$. Both the Gini coefficient and the Atkinson index, for all chosen levels of inequality aversion (ε), increase. The change can seem quite high, but we need to remember that the method of implicit valuation used here is not meant to give an exact valuation, so the level of change is also not meant to be an exact reflection of the real world. The important thing here is that the direction of the changes should be robust.

Both the Gini coefficient and the Atkinson index increase, which is a clear indication that inequality is more severe when having adjusted for environmental damages. We can say that the inequality from air pollution is additive, rather than subtractive, to income inequality.

Furthermore, the multiple inequality measures I have calculated can say something about where in the distribution this change is most severe. Since the P90 / P10 ratio increases, we know that the rich part of the distribution is better off compared to the poorer part. However, the P90 / P50 ratio goes down slightly, which means that the rich are a little worse off compared to the middle of the distribution. Finally, the P50 / P10 ratio also goes up, meaning the middle-income part of the distribution are better off compared to the low-income part.

This tells us that the rich and the middle-income parts pull ahead from the poor. This is also supported by the Atkinson index. Since the changes in the Atkinson index are larger the higher the choice of inequality aversion (ε) the bigger part of the change is in the lower part of the distribution. This is again supported by the Lorenz curves shown in Figure 4. Here, the lines are furthest from the unadjusted income in the lowest part.

All points in the same direction: the poorest municipalities and city districts also suffer the most damages from $PM_{2.5}$ and NO_2 pollution.

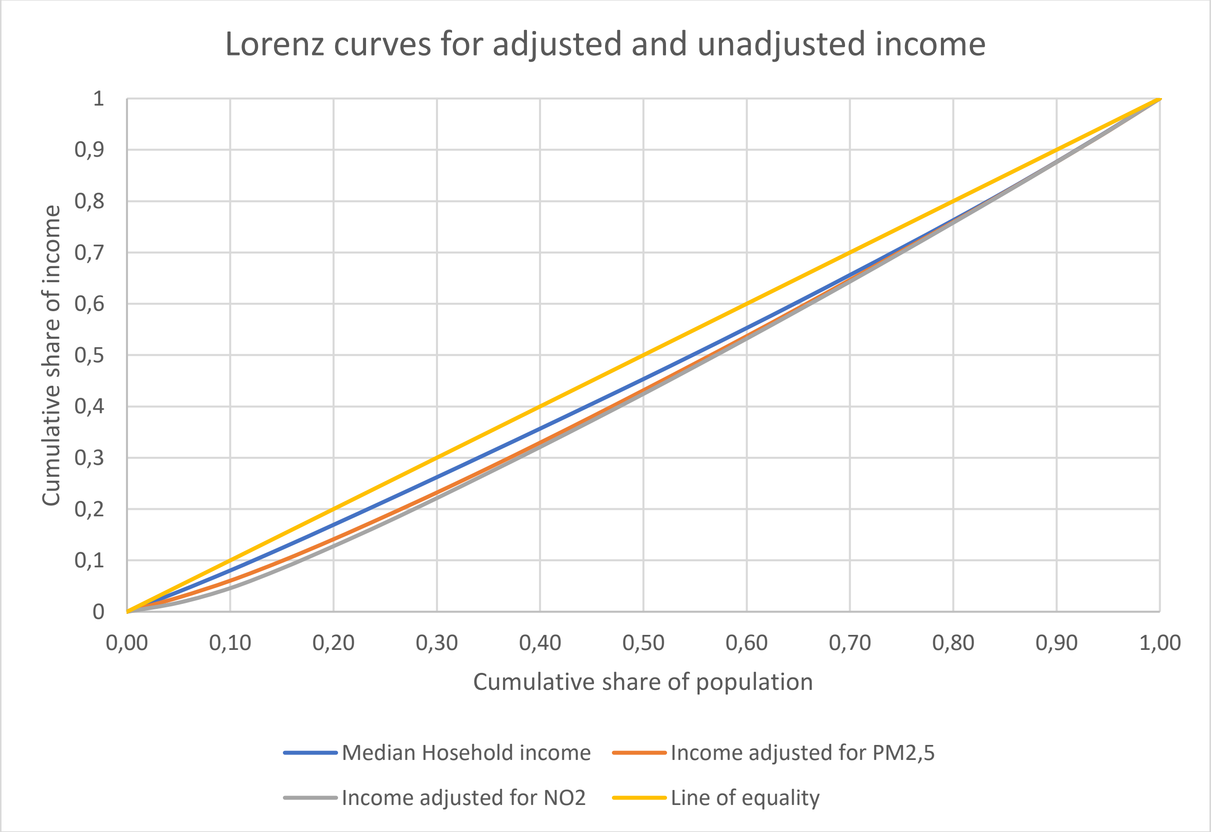

Figure 4: Lorenz curves for unadjusted income and income adjusted for concentrations of $PM_{2.5}$ and NO_2

3.1.5 Non-cumulative income distribution

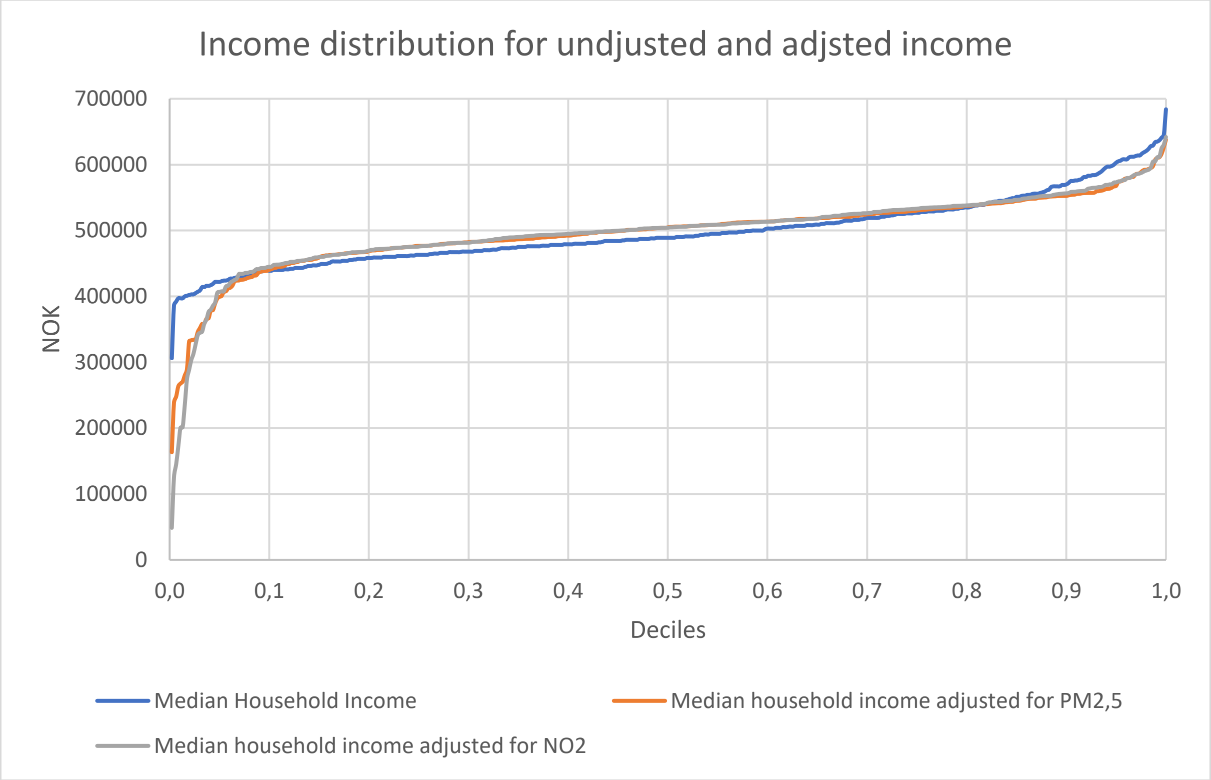

Figure 5: Non-cumulative income distribution for median household income and median household income adjusted for $PM_{2.5}$ *and* NO_2

The Lorenz curves show the cumulative income distribution, and they can be very fine tools, but sometimes the non-cumulate distribution can explain more. Figure 4 and Figure 4Figure 5 shows the same data, but the first is with cumulative Lorenz curves, while the last is a non-cumulative graph. The last show very well where the changes happen. The lower parts of the distribution are lowered significantly, and the top part a little less, while the majority in the middle is adjusted slightly upwards.

This fits well with what we learned from the ratios, the lower parts of the distribution are hurt the most, while the part that gains the most is the middle. However, what this graph shows is that much of the change, and the most severe changes happen outside of what the P 90 / P 10 can capture, it happens in the very tails of the distribution. Particularly the changes in the first decile is disturbing, it shows how the poor zones are the once that are really affected negatively.

3.2 Separating the City Districts

3.2.1 Income inequality in city districts and the rest of the municipalities

It is also interesting to divide the zones into separate parts by considering urban areas and the rest of the country separately. One convenient way of doing this is to separate out the municipalities that we have already split into city districts and analyze the city districts isolated. I explore first the 4 biggest cities in Norway isolated, and second, the rest of the municipalities. The 4 biggest cities have a total of 36 city districts, with a total of 599 005 households. The rest of the municipalities consists of 424 municipalities with a total of 1 740 984 households. So, these city districts contain about 1/4th of the households in Norway.

Table 3-5: Inequality measures for median household income for the whole country combined, the City Districts and rest of the municipalities

	Median household income		
Inequality measure	*The whole country combined*	*The City Districts*	*The Rest of the municipalities*
Gini coefficient	0.067	0.091 (+ 36%)	0.055 (- 18%)
Atkinson index ($\varepsilon = 0.5$)	0.004	0.006 (+ 50%)	0.002 (- 50%)
Atkinson index ($\varepsilon = 1$)	0.007	0.013 (+ 80%)	0.005 (- 29%)
Atkinson index ($\varepsilon = 2$)	0.014	0.025 (+ 79%)	0.009 (- 36%)
P90 / P10	1.386	1.542 (+ 11%)	1.298 (- 6%)
P90 / P50	1.218	1.275 (+ 5%)	1.194 (- 2%)
P10 / P50	1.138	1.209 (+ 6%)	1.087 (- 4%)

This is calculated at a municipality and city district level, using number of households as weights. In parentheses is the difference from the whole country combined.

The unadjusted Median Household Income data shows that we have overall more income inequality between the city districts than between the rest of the municipalities. The combined data shows less inequality than with the City Districts, but more than the rest of the municipalities. This fits well with the examples above of city districts being present both at the top and at the lower part of the income distribution.

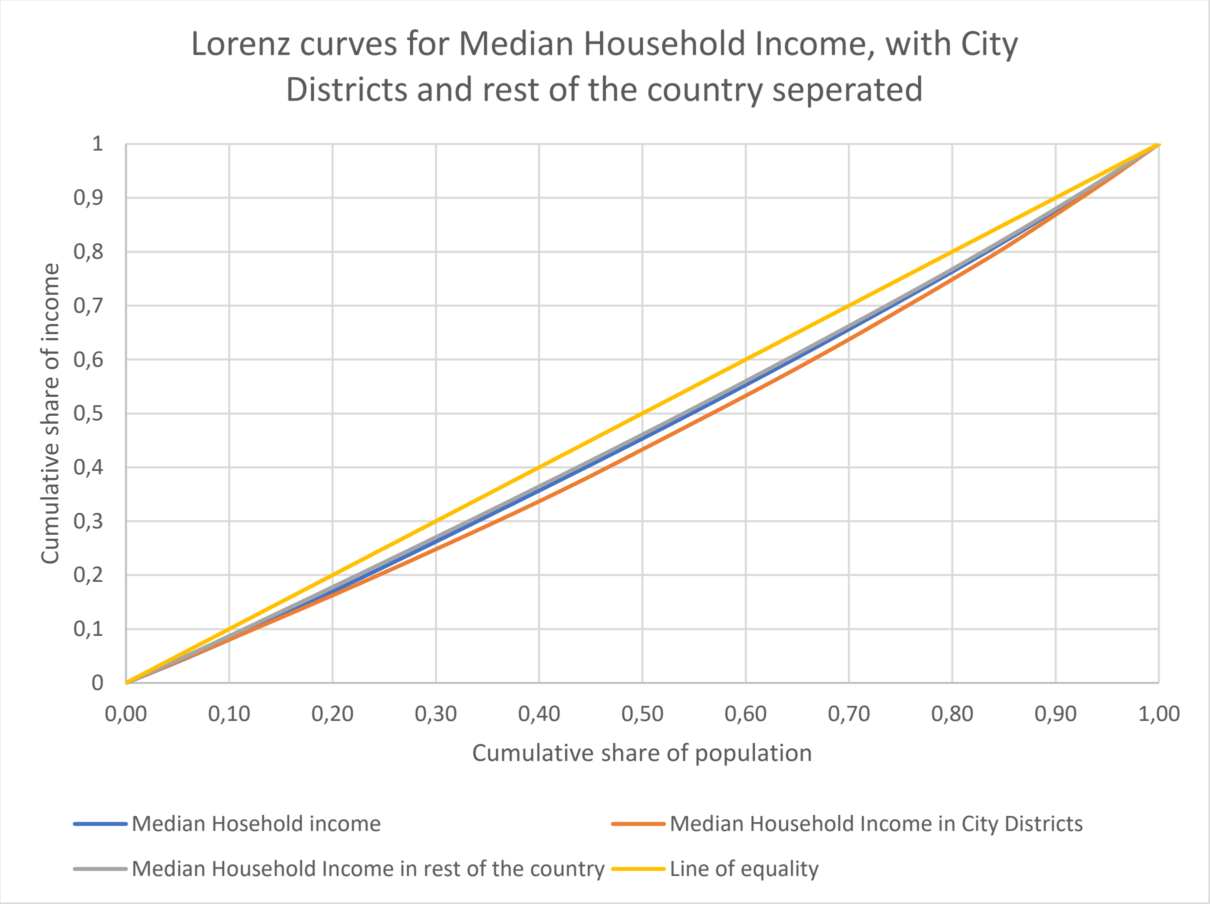

Figure 6: Lorenz curves for Median household income for the whole country combined, the City Districts and rest of the municipalities

3.2.2 Inequality after adjusting for $PM_{2.5}$ in City Districts and the rest of the municipalities

Table 3-6: Inequality measures for income adjusted for $PM_{2.5}$ concentrations, for the whole country, the City districts and rest of the municipalities

	Median household income adjusted for $PM_{2.5}$ concentrations		
Inequality measure	*The whole country*	*The City Districts*	*The Rest of the municipalities*
Gini coefficient	0.099	0.149 (+ 51%)	0.061 (- 38%)
Atkinson index ($\varepsilon = 0.5$)	0.009	0.017 (+ 89%)	0.003 (- 67%)
Atkinson index ($\varepsilon = 1$)	0.019	0.034 (+ 79%)	0.006 (- 68%)
Atkinson index ($\varepsilon = 2$)	0.042	0.067 (+ 60%)	0.012 (- 71%)
P90 / P10	1.648	1.977 (+ 20%)	1.337 (- 19%)
P90 / P50	1.148	1.422 (+ 24%)	1.122 (- 2%)
P50 / P10	1.435	1.390 (- 3%)	1.192 (- 17%)

This is calculated at a municipality and city district level, using number of households as weights. In parentheses is the difference compared to the whole country.

A comparison of City Districts and the rest of the country after I have adjusted for $PM_{2.5}$ concentrations show much the same as when I did the same for unadjusted income. There is higher inequality within the city districts than between the municipalities in the rest of the country.

It is also interesting to compare Table 3-6 with numbers that are adjusted with Table 3-5 that have unadjusted income numbers. We can then also see that adjusting for $PM_{2.5}$ concentrations give higher inequality measures in both City Districts and the rest of the municipalities.

Figure 7: Lorenz curves for median household income adjusted for $PM_{2.5}$ *concentrations, for the whole country, the City districts and rest of the municipalities*

3.2.3 Inequality after adjusting for NO_2 in City Districts and the rest of the municipalities

Table 3-7: Inequality measures for income adjusted for NO_2 concentrations, for the whole country, the City districts and rest of the municipalities

	Median household income adjusted for NO_2 concentrations		
Inequality measure	*The whole country*	*The City Districts*	*The Rest of the municipalities*
Gini coefficient	0.112	0.214 (+ 91%)	0.054 (- 52%)
Atkinson index $(\varepsilon = 0.5)$	0.016	0.039 (+ 144%)	0.002 (- 86%)
Atkinson index $(\varepsilon = 1)$	0.036	0.081 (+ 125%)	0.005 (- 86%)
Atkinson index $(\varepsilon = 2)$	0.092	0.172 (+ 87%)	0.010 (- 89%)
P90 / P10	1.762	3.031 (+ 72%)	1.274 (- 28%)
P90 / P50	1.136	1.455 (+ 28%)	1.107 (- 3%)
P50 / P10	1.550	2.083 (+ 35%)	1.151 (- 26%)

This is calculated at a municipality and city district level, using number of households as weights. In parentheses is the difference compared to the whole country.

Splitting the median household income adjusted for NO_2 concentrations into City Districts and rest of the municipalities gives much the same picture as with $PM_{2.5}$, but the differences compared to the combined data are bigger. Once again, the inequality measures are highest between the City Districts and the lowest in the rest of the municipalities.

It is here extra interesting to compare Table 3-7 with Table 3-5. For the City Districts, we see the expected with the inequality measures increasing after adjusting for NO_2 concentrations. But when considering the rest of the municipalities the Gini coefficient decreases slightly from 0.055 to 0.054, after adjusting for NO_2 concentrations. The Atkinson index stays almost the same. This can indicate that the rest of the municipalities is more equal adjusting for NO_2 concentrations. This is something we see only for NO_2 and not for $PM_{2.5}$, this is probably due to a higher share of $PM_{2.5}$ annual mean concentrations being transported over long distances, while NO2 is more concentrated in the cities.

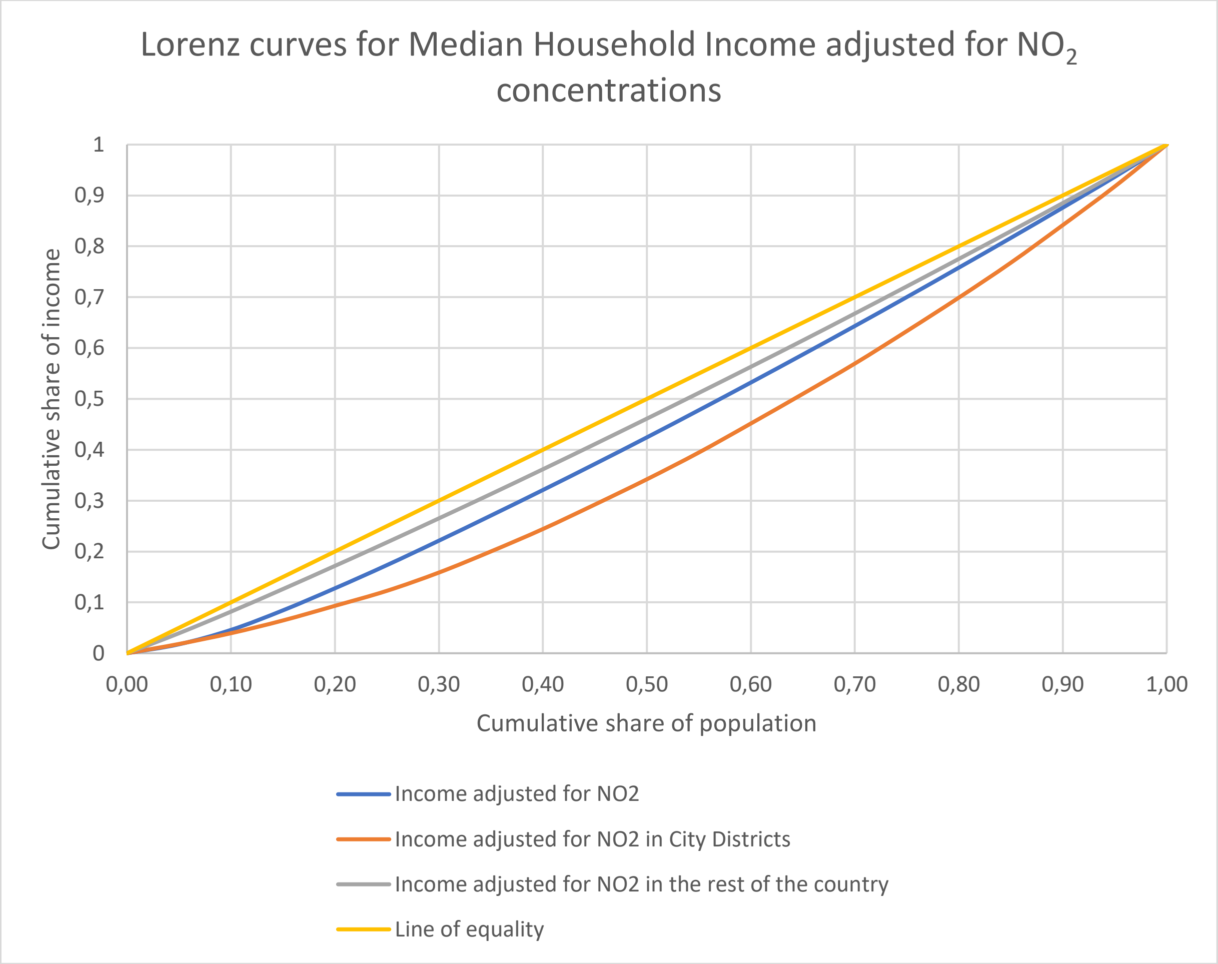

Figure 8: Lorenz curves for median household income adjusted for NO2 concentrations, for the whole country, the City districts and rest of the municipalities

3.3 Graphical presentation

Here I will use maps created in qGIS to show visually the link between income and environmental quality, still using median $PM_{2.5}$ and NO_2 concentrations as well as median household income.

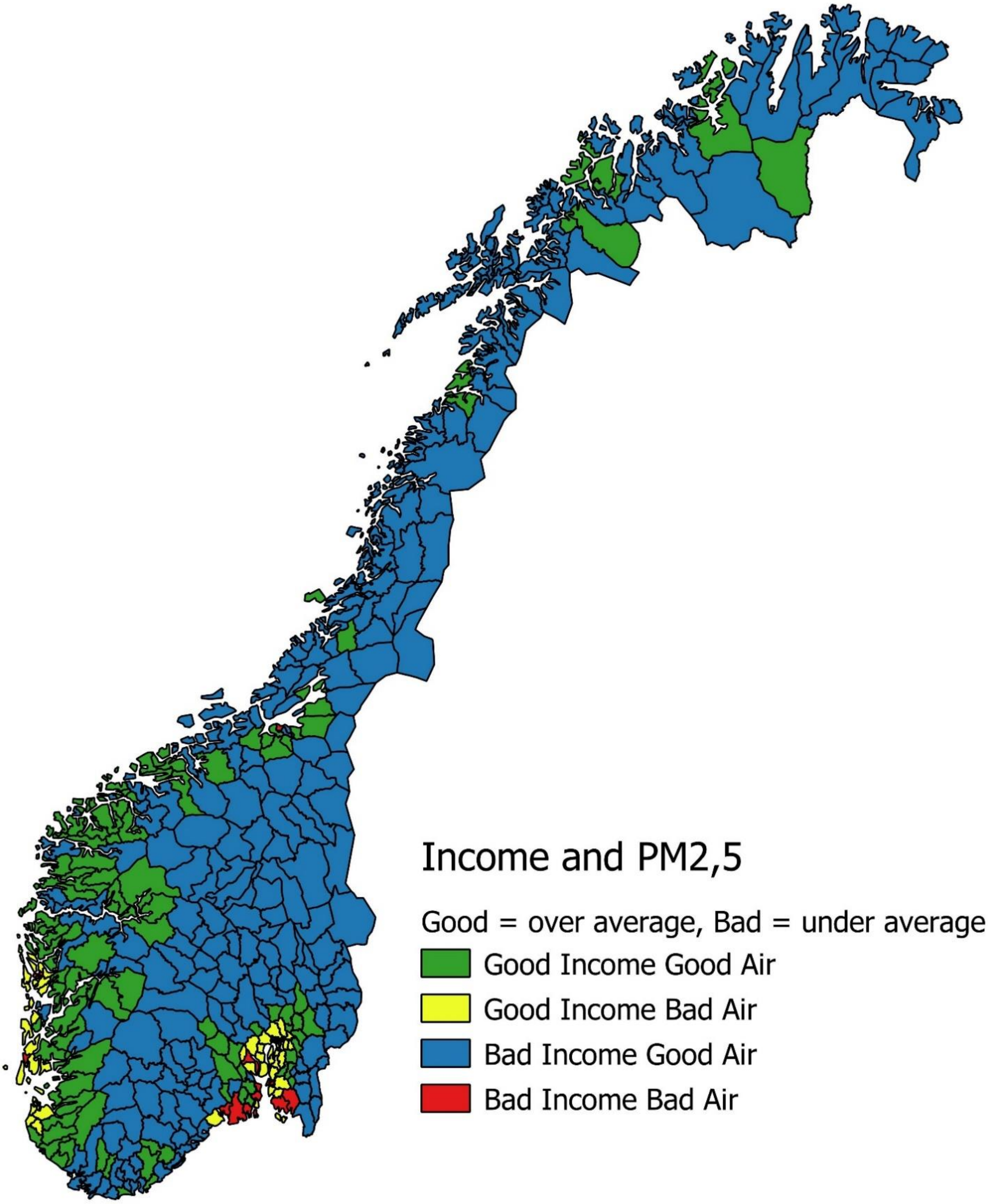

Figure 9: Map of Norway with median household income and $PM_{2.5}$ annual mean concentrations, with municipalities split into 4 groups. The green group has higher than average median household income, and better air quality than average. The yellow group has higher than average median household income, but worse air quality than average. The Blue group has lower median household income than average, but better air quality than average. Red group has lower median household income than average, and worse air quality than average. (air quality refers to annual mean concentrations of $PM_{2.5}$)

Figure 9 shows a map of Norway, which has the City Districts and municipalities divided into 4 categories, based on whether they are over or under average in median household income, and $PM_{2.5}$ concentrations. The average median household income is 505 146 NOK[1] so any City District or municipality with a higher median household income than this is here considered advantaged, while anyone with less can be considered disadvantaged. For median $PM_{2.5}$ concentration the average is 5.62 µg/m3 so anybody with a smaller concentration is considered advanced in this dimension, while any zone with a higher concentration can be considered disadvantaged.

The red zones on the map are those municipalities or city districts that are disadvantaged in both dimensions. This is just 30 zones, but they contain 569 247 households, almost 1/4th of the households in Norway.

The green zones are municipalities or city districts that are advantaged in both dimensions, with better than average income and less than average $PM_{2.5}$ concentrations. There are 115 of these zones and they contain 442 206 households, less than 1/5th of the households in Norway.

The yellow zones are municipalities or city districts that are advantaged in the income dimension but disadvantaged in the $PM_{2.5}$ concentration dimension. This category contains 60 zones with a total of 573 969 households, almost 1/4th of the households in Norway.

The blue zones are municipalities or city districts that are disadvantaged in the income dimension but advantaged in the $PM_{2.5}$ concentration dimension. Here we find the most zones, 255, and the most households, 754 567, almost 1/3rd of the households in Norway.

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[1] Earlier reported average median household income differ from this number because the previous number was calculated using number of households as weights, while this is unweighted.

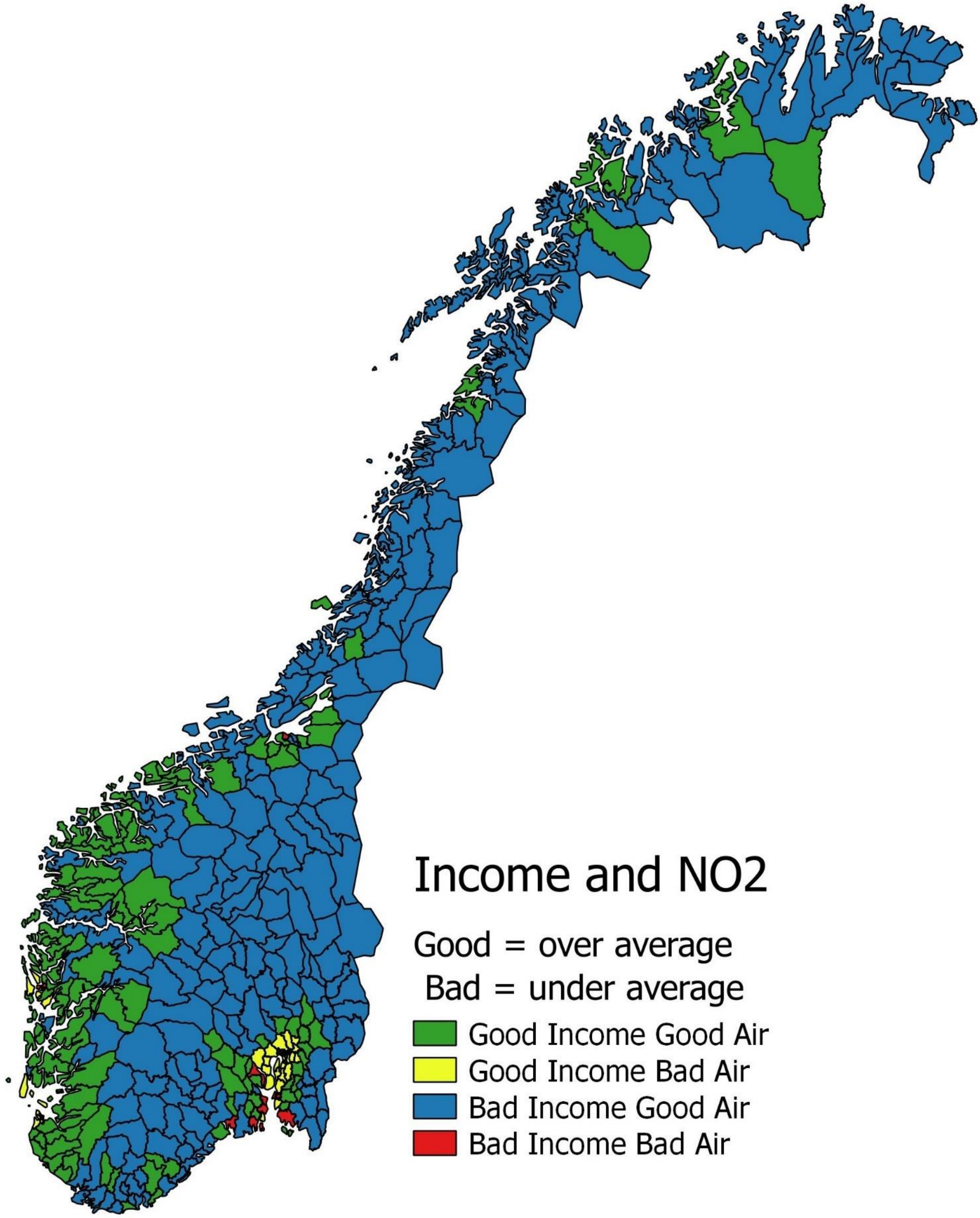

Figure 10: Map of Norway with median household income and NO$_2$ annual mean concentrations, with municipalities split into 4 groups. The green group has higher than average median household income, and better air quality than average. The yellow group has higher than average median household income, but worse air quality than average. The Blue group has lower median household income than average, but better air quality than average. Red group has lower median household income than average, and worse air quality than average. (air quality refers to annual mean concentrations of NO$_{2.5}$)

In this map $PM_{2.5}$ is replaced with NO_2, yet we are still exploring two dimensions in one map. The average median household income is still 505 146 NOK, while the average median NO_2 concentration is 6.21 µg/m3.

The red zones on this map are municipalities or city districts that are disadvantaged in both dimensions. For NO_2 this consists of 27 zones with a total of 507 306 households, a little over 1/5th of the households in Norway.

The green zones are municipalities or city districts that are advantaged in both dimensions; having higher than average income, and less than average concentrations of NO_2. This group consists of 136 zones with a total of 577 113 households, about 1/4th of the households in Norway.

The yellow zones are municipalities or city districts that are advantaged in the income dimension but disadvantaged in the NO_2 concentration dimension. There are 39 of these zones, containing 439 062 households, less than 1/4th of the households in Norway.

The blue zones are municipalities or city districts that are disadvantaged in the income dimension but advantaged in the NO_2 concentration dimension. There are 258 zones in this category, containing 816 508 households, over 1/3rd of the households in Norway.

Overall the map looks very similar for both $PM_{2.5}$ and NO_2 concentrations. 24 more zones are considered better than average for pollution concentrations for NO_2 than for $PM_{2.5}$ but for both the clear majority of zones have less than average concentrations of this air pollutants.

Taking into consideration the three hypotheses of environmental inequality, we can see if these categories we just explored fits into any of them. The environmental justice hypothesis, which suggests that pollution follows the already disadvantaged fits well with our red category, where people are disadvantaged in both dimensions. The zones in green match well with the “market hypothesis”, which indicates that households with high income can afford to live in a less polluted area. The yellow and blue zones fit well with the “trade-off hypothesis”, which argues that there is a wage premium for living in a polluted area.

So, all three hypotheses can find support here, and from this map none of them seem to have particularly more support than the others. This is much in line with Bouvier (2014) findings, which are based on the same methods. However, if we combined this with what we learned from Figure 4, the support for the market hypothesis might be weakened, as the very riches of the zones are also adjusted downwards. The way these maps are created does not show us that we find the zones with the highest median income as yellow on this map, not as green. This find is something I leave to further research to explore further.

3.3.1 The “ring shape” around some big cities

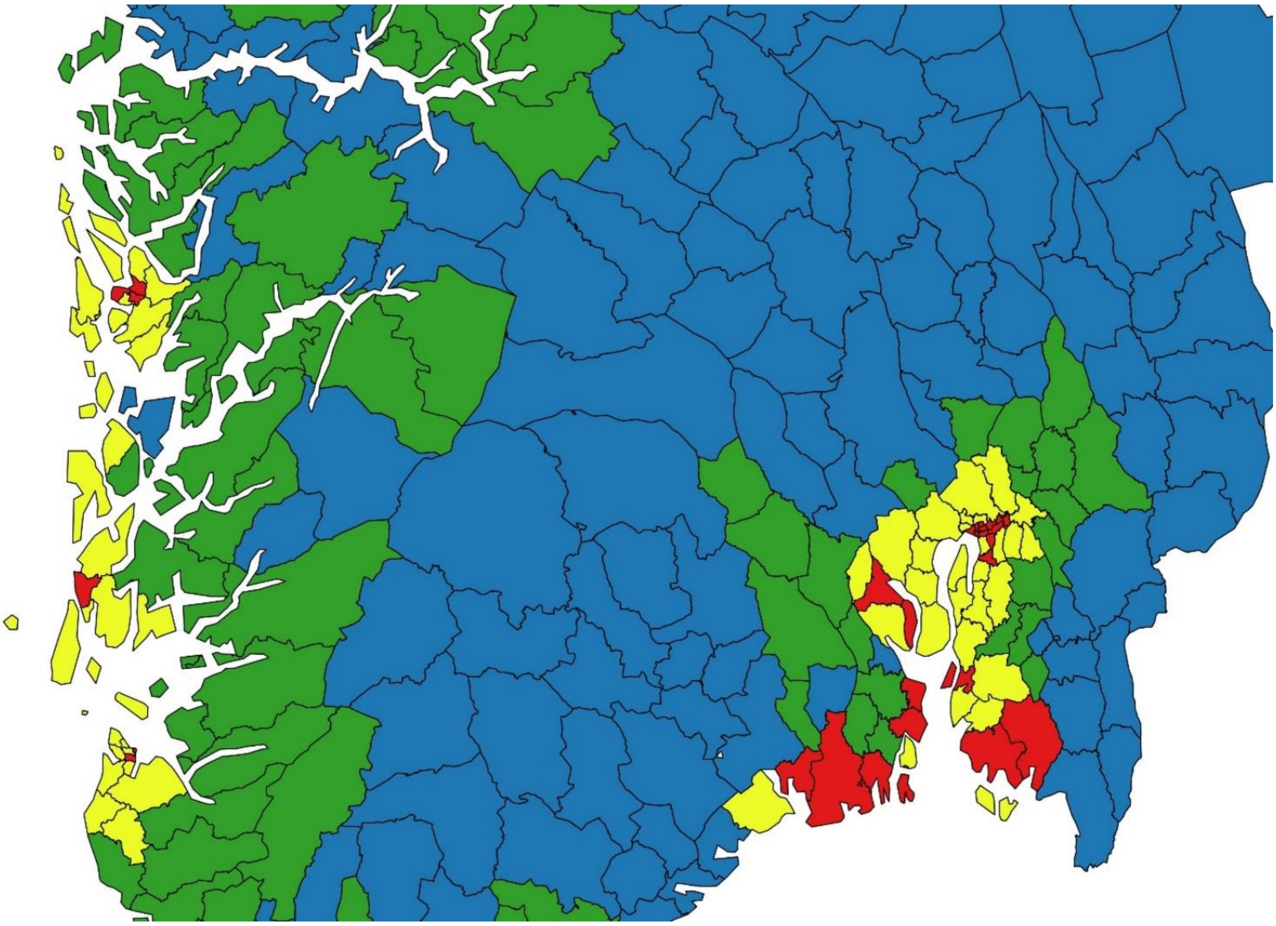

Figure 11: Zoomed in map showing "ring" shapes around some of the big cities

Maps for both $PM_{2.5}$ and NO_2 and indicate a ring pattern around the bigger cities. The population in the he city center is often disadvantaged in both dimensions, indicated with the color red. The red centers are surrounded by a “yellow ring”, in which the population is advantaged in the income dimension but disadvantaged in air quality. Outside this “yellow ring” we find many green municipalities, where they are advantaged in both dimensions. Furthest away from the city centers most municipalities? are colored in blue, where the population is advantaged in the pollution dimension, but disadvantaged in the income dimension. This pattern is not detectable in a zoomed-out map yet is clear in this detailed map in Figure 11. Figure 12 shows an illustration of this ring pattern.

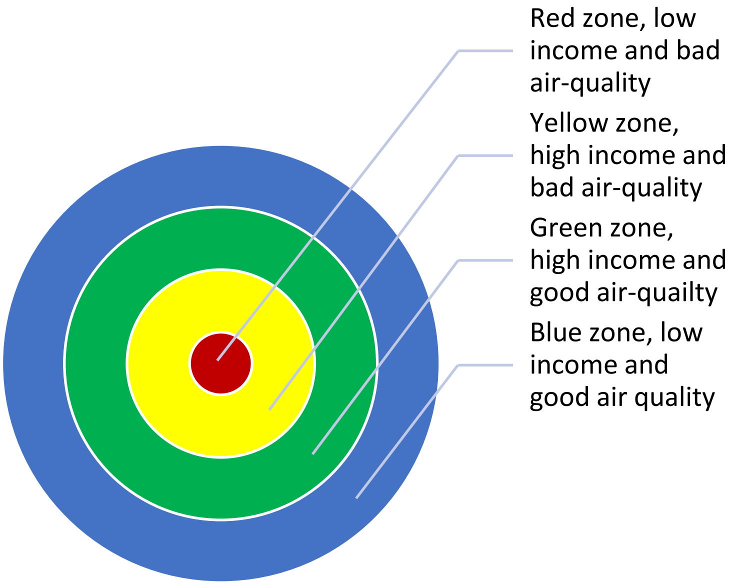

Figure 12: Illustration of the ring pattern found around some big cities

4 Conclusion and policy implications

In this thesis I have shown that inequality in air pollution is additive, rather than subtractive, to the income inequality between municipalities and city districts in Norway. This means that we end up with more inequality when accounting for air pollution levels. I also find that the inequality, both for income and for air pollution, is more severe in the urban than the rural areas. However, I cannot reject any of the three hypotheses from Bouvier (2014) (and discussed in chapter 2.1.), as all seem to be present, but in different municipalities.

It is important to remember that these findings rely on inequality across medians (in terms of income and air pollution levels) within municipalities and city districts. The choice of a different spatial scale could easily influence results. As was pointed out by Stroh et al. (2005) and Boyce et al. (2016) the choice of spatial scope can give different, and even contradicting results. Further research should look at this from a different spatial scope to see how sensitive the results are to the spatial scope of the analysis.

There are three main policy implications from this work: The first is that there is more inequality in Norway than income inequality can capture. This is relevant for any inequality debate. The measures used for the debate are probably already too low, tax evasion for instance makes inequality higher than the official statistics suggests (Alstadsæter et al. 2017). With more than one factor suggesting that inequality is more severe than we thought a real debate about how to report inequality might be needed.

The second point is that some municipalities and city districts have high air pollution levels and an already low net median household income. These municipalities and city districts should be a focus point for national policies that reduce air pollution levels, as they might be unable to do this alone. It is, however, good news for these parts of the country that much of the Norwegian welfare state is organized at the state level, and this means the municipalities are not alone in handling the costs that stem from this pollution, for instance hospital admissions. The effects of the extensive welfare state in Norway has not been included in this analysis and would be an interesting study for further research.

The third and last point is that air pollution levels, unlike income, is a “bad” and not a “good”. With income inequality it is usually a goal to distribute the income in the society more equal, or to increase the income of the poor more than that the income of the rich, to gain a more equal income distribution. If we increase air pollution in parts of the country that have low levels now, we would decrease inequality, but it would be a meaningless goal. Just as income is a “good” and increasing it can increase welfare, air pollution levels is a “bad” and the goal must be to reduce it, to increase welfare.

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Appendix

Appendix A: Gini calculations

In this thesis I present the following formula for calculating the Gini index.

$$Gini = 1 - \sum_{i=1}^{n} (X_i - X_{i-1})(Y_i + Y_{i-1})$$

This is but one of many ways to calculate the gini index. I chose to present this as I find it the most intuitive, and easily readable. The STATA package I use for the actual calculations use a different formula:

$$Gini = 1 + \left(\frac{1}{n}\right) - \left[\frac{2}{\bar{Y} * n^2}\right] \sum_{i=1}^{n} [(n - i + 1) * Y_i]$$

Where Yi is the income of household i, $\bar{Y}$ is the mean income for all households. n is the number of households. Again, sorted with increasing household incomes, with the household having the lowest income having i = 1.

The differences between the results from the two are minor, and the higher n the smaller the differences between these approximations become. With the n that is used for my analyzes there should be no noticeable difference. Therefor I chose to use the first in the thesis even if it is not full correct, but I include the real formula here for reference.

Appendix B: more types of air pollution from the EVA model

The data I have from the NordicWelfAir project use include a wide range of pollutants. While my thesis focuses on two key pollutant, some calculations was also done on the other pollutants included. I include this here because the differences in distribution between them are quite interesting, but not really relevant in my thesis. All (except SOMO35) measured in μg/m3 and are annual mean values for the year 2016. Table 0-1**Feil! Fant ikke referansekilden.** includes the full list. Since 1 µg/m3 of one pollutant does not affect humans the same way as 1 µg/m3 of another, direct comparison of levels means little.

Table 0-1 : Air pollutants from the NordicWelfAir project all (except SOMO35) measured in µg/m3 annual mean values for the year 2016, with mean std. dev, min, max, Gini and p90/p10

air pollutant	*mean*	*std. Dev*	*min*	*max*	*Gini*	*p90/p10*
$PM_{2.5}$	4.33	1.18	2.38	20.22	0.15	1.96
PM_{10}	6.06	1.70	3.20	21.77	0.16	2.03
NO_2	2.53	2.39	0.33	27.78	0.44	7.25
o_3	63.51	3.79	36.99	71.64	0.03	1.16
somo35	1460.72	499.30	134.76	2981.89	0.19	2.37
so4	0.64	0.09	0.49	0.85	0.08	1.43
no3	0.69	0.23	0.31	1.22	0.19	2.66
nh4	0.18	0.23	0.04	0.32	0.18	2.78
bc	0.16	0.09	0.08	1.00	0.26	3.00
oc	0.35	0.18	0.14	1.10	0.27	3.59
soa	0.19	0.06	0.08	0.32	0.19	2.80
ss	1.63	0.46	0.88	3.35	0.16	2.06
co	122.11	8.37	115.09	208.76	0.03	1.14
so2	0.18	0.23	0.05	6.56	0.46	5.83
NO_x	2.85	2.92	0.35	40.12	0.46	7.66

$PM_{2.5}$ is particulate matter with maximum size of 2.5 mµ, PM_{10} is particulate matter with maximum size of 10 µm, NO_2 is nitrogen dioxide, O^3 is ozone, somo35 is the yearly sum of daily maximum of 8-hour running average of 0_3 over 35 ppb, so4 is sulphate, no3 is nitrate, nh4 is ammonia, bc is black carbon, oc is organic carbon, soa is secondary organic aerosols, ss is sea salt, co is carbon monoxide, so2 is sulphur dioxideand NOx is nitrogen oxides.

Some of these abbreviations might be confusing, so let me clarify what they are. $PM_{2.5}$ and pm10 is a group of pollutants defined by the size. They are particles that are less than 2.5 or less than 10 µm in size. 1µm is one thousandth of a millimeter, so these are really small particles. For comparison, the average diameter of a human hair is 50-70 µm. For more on $PM_{2.5}$ see chapter 2.4.1. NOX is nitrogen oxides, with

NO_2 being nitrogen dioxide. This is a type of gas usually created by combustion vehicles and is toxic to humans. For more on NO_2 see chapter 2.4.2.

O_3 is ground level ozone, and SOMO35 is “the yearly sum of the daily maximum of 8-hour running average of O_3 over 35 ppb”. So, the two measure ozone in different ways. Ozone can give negative health impacts that can vary a lot between individuals. In Norway, most ozone is transported to us from other European countries (Norwegian Environment Agency 2018). In my data the level of ozone is negatively correlated with the other pollutants, which means that it is lower in the cities and high elsewhere.

SO_x are Sulphur oxides, with SO_2 being sulphur dioxide and SO_4 (or SO_4^{2-}) being sulphate. Sulphur oxides have direct human health consequences, but also affect the acidity of the atmosphere and from acid rain. Acid rain and SO_2 emissions used to be on the forefront of the environmental agenda but are not as pressing as they used to be. This is probably both due to other environmental concerns demanding more focus, but also due to successful international cooperation in reducing emissions. The UNECE Convention on Long-rage Transboundary Air Pollution and later the Gothenburg Protocol has been particularly successful in reducing SO_2 emissions (UNECE).

NO_3 is nitrate and NH_4 is ammonia, usually associated with fertilizers and with water pollution. Also present in the atmosphere and is toxic.

BC is black carbon, and is the product of incomplete combustion, forming when there is insufficient oxygen. It is the dominant absorber of visible solar radiation in the atmosphere, contributing to global warming. After carbon dioxide it might be the second strongest contributor (Ramanathan & Carmichael 2008). It is also directly harmful to humans and it is a particulate matter and is thus also part of the $PM_{2.5}$ and pm10 categories.

OC is organic carbon, is also a type of particulate matter, and is typically very small, between 0.7 and 0.22 μm, well below the limits for $PM_{2.5}$. In short organic carbon is the part of the carbon particulate matter that is not black carbon, or in other words the part that don’t absorb light.

SOA is secondary organic aerosols. A part of particulate matter that is composed of compounds formed from the atmospheric transformation of organic species. Also, part of the $PM_{2.5}$ and pm10 category.

SS is sea salt. Sea salt is a particulate matter and can be a significant contributor to pm10 and $PM_{2.5}$. It is also a part of particulate matter that is very difficult to reduce, due to it coming from sea spray.

CO is carbon monoxide. It is a colourless and odourless gas that can be harmful to humans, but it dissolves quickly into CO_2. It is also part of the chemical process that creates ground level ozone.

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