De Økonomiske Råd
Formandskabet

ECONOMY AND ENVIRONMENT, 2019
SUMMARY AND RECOMMENDATIONS

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This report from the Chairmen of the Danish Economic Council of Environmental Economics contains two chapters which focus on the distribution of environmental impacts and carbon leakage from Danish climate policies. There are two main conclusions:

In Denmark, there is a relationship between high environmental exposure and individuals with low incomes. However, the relationship found in the Danish data is very weak. On the other hand, large differences in environmental exposure are found between individuals within the same income groups, indicating that income does not contribute significantly to the explanation of differences in environmental exposure between individuals.

Denmark's overall carbon leakage rate is 45-53 per cent. The leakage rate is particularly high for the Danish quota sectors and for agriculture. Agriculture should, however, still contribute significantly to the overall reductions of greenhouse gas emissions in the non-quota sector because of socio-economic benefits related to a better aquatic environment and less air pollution.

ENGLISH SUMMARY

This report from the Chairmen of the Danish Economic Council of Environmental Economics consists of two chapters:

- Distribution of environmental exposure
- Carbon leakage resulting from Danish climate policies

The first chapter analyses the distribution of environmental exposure in Denmark using Lorenz curves and the Theil index, and these are followed by statistical descriptions and regression analyses.

The second chapter presents estimations of the overall carbon leakage rate for Denmark as well as leakage rates for various sectors of the Danish economy. The chapter discusses the consequences for Danish climate policy of adjusting for leakage.

CHAPTER I: ENVIRONMENTAL EXPOSURE AND DISTRIBUTION

The public debate about the environment and distributional effects in Denmark often focusses on the distributional effects of green taxes. However, there has not been a similar focus on the distributional aspects of environmental exposure. The relationship between income and environmental exposure has been examined in the international literature, with findings indicating that individuals with low incomes are, to a higher extent, prone to environmental exposure than those with high incomes. Similar studies have not been conducted on a national level for Denmark.

Chapter I sheds light on various aspects of environmental exposure and distribution in Denmark. First, the extent of the differences in the environmental risks that people in Denmark are exposed to is investigated. Second, whether there is a correlation between the degree of environmental exposure and income is examined. Finally, the chapter examines the socioeconomic characteristics of those who live in the most highly exposed houses and apartments.

More specifically, the analyses focus on the environmental exposure from traffic noise and air pollution due to particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2). Furthermore, analyses are conducted on the benefits of living in close proximity to nature (forests, lakes and coastal areas). There are nationwide data available for these environmental impacts that can be linked to all homes in Denmark, and further linked to register data to provide information on the income and other socioeconomic characteristics of the individuals living in the respective homes.

The results obtained in chapter I cannot be generalized to encompass types of environmental exposure that are not included in the analysis. The availability of geographically detailed nationwide data that can be linked to the individuals is the main determinant of the choice of the types of environmental exposure included in the analysis. Most similar international studies only focus on one environmental exposure, which makes the current study more comprehensive than many earlier studies.

THE DISTRIBUTION OF ENVIRONMENTAL EXPOSURES

When analysing distributional issues the Lorenz curve is often used to illustrate the degree of inequality in the distribution of income. However, the Lorenz curve can also be used to illustrate the distribution of environmental exposure among individuals. Figure A shows the Lorenz curves for air pollution ($PM_{2.5}$ and NO_2), noise and proximity to nature. For comparison, the Lorenz curve for the distribution of income is also shown. If the Lorenz curve is close to the 45-degree line, the distribution of income or environmental exposure can be considered to be equal.

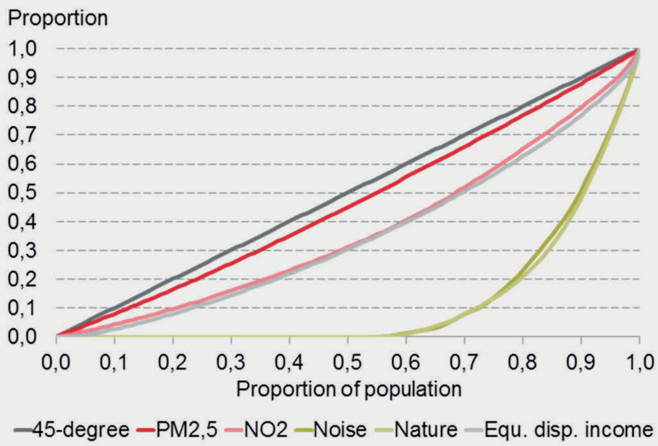
The results show large differences in distributional inequality across the different environmental exposures and proximities to nature. Relatively small differences are seen in the distribution of $PM_{2.5}$ and NO_2 between individuals. Compared to the distribution of income, $PM_{2.5}$ is more equally distributed, while NO_2 has more or less the same distribution as income. The greater inequality for NO_2 relative to $PM_{2.5}$ reflects the fact that the concentration of NO_2 varies to a greater extent with local sources, such as, e.g. power plants, traffic and shipping, while $PM_{2.5}$ is more regional in nature.

For both noise and proximity to nature, the distributional inequality between individuals is larger than for the two types of air pollution. This reflects that noise and proximity to nature are of a very local character.

There is a risk of overestimating the inequality of proximity to nature because only housing within certain distances from nature (0.6 to 1 km, depending on the type of nature) are included in the analyses. If individuals experience a value from proximity to nature further away than the defined distances, the inequality shown in the Lorenz curve might be overestimated. Similarly, smaller natural areas are not included in the analyses, which can also give rise to an overestimation of the inequality of proximity to nature between individuals.

FIGURE A **INEQUALITY IN ENVIRONMENTAL EXPOSURE**

The inequality is illustrated using Lorenz curves for air pollution ($PM_{2.5}$, NO_2), noise, proximity to nature and income.



Note: Lorenz curves are based on concentrations of air pollution, noise above 50 dB, and proximity to nature within 0.6 to 1 km from nature (depending on the type of nature). The Lorenz curve for income is calculated from the equivalent disposable income in 2016.

Source: Own calculations.

ENVIRONMENTAL EXPOSURES AND INCOME

A range of international studies investigate the relationship between environmental exposure and income. These analyses often show that individuals with low incomes are more prone to environmental exposures than individuals with high incomes.

The analyses based on the Danish data reveal only a weak relationship between environmental exposure and income. Moreover, the analyses show large differences in the distribution of environmental exposure between individuals within the same income group. As Figure A and Figure B in Box A illustrate, the difference in environmental exposure between individuals within the same income group is much larger than the difference in environmental exposure between individuals in the lowest and highest income groups. This indicates that differences in income between individuals only explain a small part of the variation in environmental exposure.

Even though the relationship between environmental exposure and income is weak in Denmark, there is a tendency for individuals with low incomes to be more prone to environmental exposure than individuals with high incomes, cf. Box A. Estimations in the current chapter show that individuals with disposable income equivalent to DKK 100,000 above the average income are less prone to environmental exposure corresponding to values of DKK 30 for $PM_{2.5}$, DKK 30 for NO_2 and DKK 5 for noise.

INDIVIDUALS WITH HIGHEST ENVIRONMENTAL EXPOSURE

In chapter I the characteristics of the most environmentally exposed housing and the characteristics of the individuals who live in this housing are examined. The most environmentally exposed housing is defined as the houses and apartments where the 10 percent of the population who are most exposed to the highest air and noise pollution live. Proximity to nature is not included in the selection of housing most prone to environmental exposure.

BOX A RELATIONSHIP BETWEEN INCOME AND ENVIRONMENTAL EXPOSURE

Figures A and B illustrate the relationship between income and the concentrations of NO_2 and noise, respectively.

The X-axis shows the equivalent disposable income divided into percentiles. The first point on the X-axis represents the one percentile of the population with the lowest income, while the point most to the right represents the one percentile of the population with the highest income. The green curves illustrate the average level of NO_2 and noise for all individuals within each of the 100 income groups.[a)] The figures show that there is a tendency towards lower income groups having higher levels of NO_2 and noise.

FIGURE A NO_2 AND INCOME

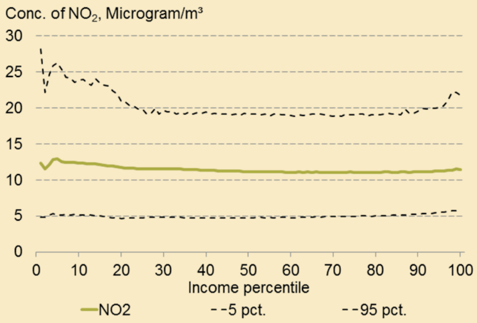
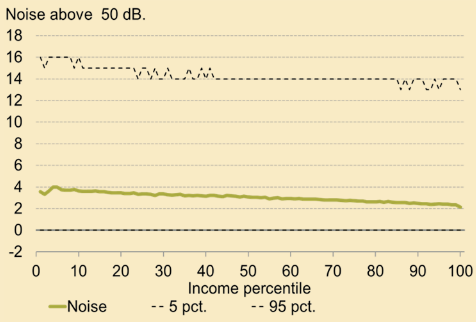


FIGURE B NOISE AND INCOME



Note: Income percentiles are calculated based on the equivalent disposable income in 2016.

Source: Own calculations based on registry data and data for air and noise pollution from Aarhus University and MOE|Tetraplan, respectively.

The dotted lines in the figures illustrate the variation in NO_2 and noise within each income group. The dotted lines show the 5 and 95 percent fraction for NO_2 and noise, which means that 90 percent of the individuals in each of the income groups are exposed to a level of NO_2 or noise within the two dotted lines. It appears that the differences in environmental exposure between individuals within the same income group are much larger than the differences between individuals in the lowest and highest income groups.

Figures illustrating the relationship between income and concentrations of $PM_{2.5}$ and between income and proximity to nature show the same tendency, cf. section I.4 in chapter 1.

a) The curves show the relationship between income and NO_2 and noise corrected for differences in level in income, NO_2 and noise in different parts of Denmark (calculated by commuting areas).

The majority of the most environmentally exposure housing is located within or near the capital of Denmark, Copenhagen, or in other larger cities. In contrast, most of the housing that is least prone to environmental exposure is located in rural areas.

By using unit values, environmental exposure per house in Denmark can be converted to costs in Danish Kroner (DKK) per year. Unit values reflect inconvenience costs related to, e.g., noise, and costs of serious health effects, including premature death. The estimated yearly cost from air and noise pollution is about DKK 4,100 higher for individuals living in housing that is most prone to environmental exposure compared to individuals living in an averagely polluted residence. This corresponds to 1.5 percent of the average equivalent disposable income of an individual in Denmark. A large share of the cost is attributable to the increased risk of premature death. The increased health risk corresponds to a loss of 40 hours of expected life per year for an individual living in the most environmentally exposed housing compared to an individual living in an averagely polluted residence.

Apartments, co-housing flats and private rental flats are, to a greater extent, represented among the housing that is most prone to environmental exposures compared to the general distribution of housing in Denmark. In contrast, not-for-profit community housing is less often among the housing that is most prone to environmental exposure compared to the general distribution of housing.

The analyses in the current chapter show small differences in socioeconomic characteristics among residents in the housing that is most prone to environmental exposure compared to residents in housing with average levels of environmental exposure, corrected for geographical differences. More specifically, the results show that individuals living alone, families without children and ethnic minorities more often live in housing with more environmental exposure. In contrast, fewer senior citizens live in housing that is more prone to environmental exposure compared to the general distribution. The international literature primarily shows that individuals with lower education more often live in housing that is prone to negative environmental exposure. In contrast, the current analysis shows that this is not the case in Denmark. The analysis shows a tendency for higher educated individuals to more often live in housing that is more prone to environmental exposures compared to the general distribution of population in Denmark.

Children are considered to be a vulnerable group in terms of being prone to environmental exposure. The current chapter investigates whether children who have grown up in the most environmentally-compromised homes have parents with socioeconomic characteristics that are different to the parents of children who grew up in other homes. Only small differences are found between the two groups of children. However, children of tertiary-educated parents are slightly overrepresented among children living in housing that is more prone to environmental exposures compared to other children.

CHAPTER II: LEAKAGE OF GREENHOUSE GAS EMISSIONS AND DANISH CLIMATE POLICY

Danish climate policy reduces CO_2e-emissions in Denmark but may, at the same time, increase CO_2e-emissions abroad.[1] This phenomenon is known as carbon leakage. Carbon leakage implies that Danish climate policy has a smaller impact on global reductions than on domestic reductions in greenhouse gas emissions.

According to its EU obligations, Denmark must reduce emissions of greenhouse gasses in the non-quota sector by 39 per cent by 2030 compared to the emissions in 2005. In addition, the Danish government has committed to a strategy of climate neutrality by 2050. The obligation for the non-quota sector and the target of climate neutrality are specifically related to emissions from the Danish territory. It has been argued that Danish climate policy should focus on *global* emissions of greenhouse gasses in addition to the focus on emissions from the Danish territory.

Chapter II presents estimations of carbon leakage rates in Denmark and discusses the consequences of taking account of the presence of leakage in the Danish climate policy.

LEAKAGE RATES FOR DENMARK

The so-called leakage rate expresses the share of domestic reductions in emissions that is replaced by increased foreign emissions. The analyses in chapter II indicate that Denmark's overall leakage rate is between 45 and 53 per cent. This implies that a national CO_2e

1) CO_2e is used to denote the emission of all greenhouse gases (including agricultural emissions of methane and nitrous oxide), converted to CO_2-equivalents.

reduction of 1 million tonnes results in a global CO_2e reduction of about 0.5 million tonnes.

The leakage rate for Denmark is calculated by imposing a tariff of DKK 100 per tonne CO_2e on all emissions in Denmark in the so-called GTAP-E model. GTAP-E includes a description of global trade flows, energy consumption and the corresponding greenhouse gas emissions, which makes the model suitable for assessing the impact of such a tariff on emissions in Denmark, as well as abroad.

There are several channels through which carbon leakage can occur. Some of these mechanisms are included directly in the default GTAP-E model, e.g., mechanisms that operate via foreign trade (e.g., CO_2e tariffs in Denmark weaken the international competitiveness of Danish CO_2e-intensive firms, so some of the CO_2e-emitting production that currently takes place in Denmark moves abroad), and via the price of fossil fuels (e.g., as CO_2e tariffs reduce Danish demand for fossil fuels, the world market price of fossil fuels is (slightly) reduced, and the consumption of fossil fuels increases abroad).

However, the leakage rate in Denmark is also largely affected by the climate policy in the EU. The EU CO_2 quota system has been designed such that climate policy that reduces emissions in the Danish quota sector has only a limited impact on the total emissions in the EU's quota sector in the long run. This contributes to a higher leakage rate in Denmark. Conversely, the CO_2e leakage in the non-quota sector is reduced by many EU countries' binding targets for their non-quota sector emissions. This lowers the overall leakage rate in Denmark. The GTAP-E model has been expanded to account for these mechanisms.

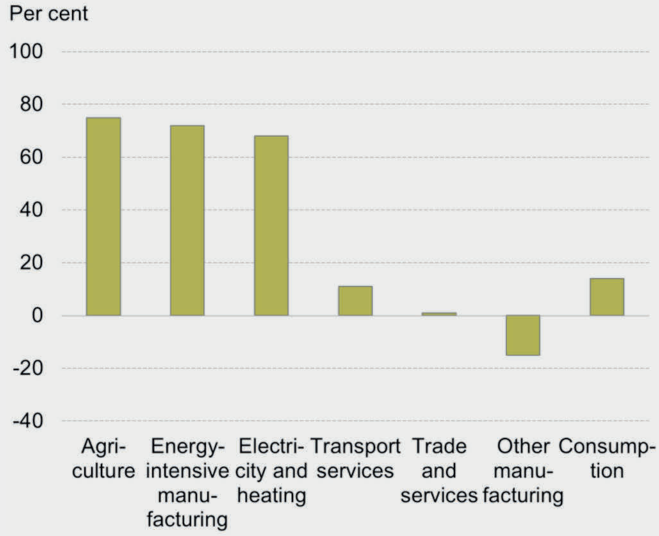
There are some other mechanisms that may affect the leakage rate but that are not included in the calculations. For example, tighter climate policy in Denmark may encourage technological development that makes it easier to reduce emissions in other countries. This would lower the leakage rate. Tighter Danish climate policy may also give rise to higher reduction targets for other countries, which would lower the leakage rate as well. However, a tighter climate policy could also reduce other countries' incentives to undertake climate policy themselves.

LEAKAGE RATES FOR VARIOUS SECTORS

The calculations indicate large differences in the leakage rates for various sectors of the Danish economy, see Figure B.

FIGURE B LEAKAGE RATES FOR SECTORS

The leakage rates are high for agriculture and for sectors covered by the EU quota system (energy-intensive manufacturing and electricity and heating).



Note: The figure shows the leakage rates in a scenario where the long run effects of permanent climate policy are considered. The chapter includes estimates of leakage rates under different assumptions and adjustments in the model.

Source: Own calculations.

The leakage rates are high for the energy-intensive manufacturing and the electricity and heating sectors, all of which are subject to the EU quota system. The leakage rates are relatively high for the quota sectors because a decrease in emissions from the Danish quota-covered sectors will, to a large extent, be counterbalanced by an increase in greenhouse gas emissions in the rest of the EU in the future. This is due to the design of the EU quota system.

The leakage rates are generally lower for the sectors not covered by the EU quota system. One reason for this is that many EU countries are committed to reducing their emissions from the non-quota sectors by 2030. These countries are, therefore, not able to increase their emissions in the non-quota sectors in response to a tighter climate policy in Denmark.

The leakage rate is higher for Danish agriculture than for the remaining non-quota sectors. This reflects, among other things, that consumption of food is less affected by changes in income and prices than other products. Consequently, the production and associated emissions in agriculture increase relatively more in other countries when production in agriculture decreases in Denmark as a result of regulation. The leakage rate for agriculture is, however, limited by the fact that many EU countries have binding targets for reducing their emissions in the non-quota sector that they must meet by 2030.

The leakage rate for agriculture is also very dependent on climate policy *outside* the EU. A sensitivity analysis shows that the leakage rate for agriculture is more than halved if some countries outside the EU are assumed to have binding targets as well, while the leakage rates in other sectors are almost unaffected.[2] The sensitivity analysis illustrates that there is considerable uncertainty associated with estimating the leakage rate for agriculture.

LEAKAGE AND DANISH CLIMATE POLICY

The design of cost-effective regulation that reduces greenhouse gas emissions depends on the political objectives of the regulation. If the objective of Danish climate policy is to meet the goals of reducing CO_2e emissions from the Danish territory, this is achieved most cost-effectively by a uniform (increasing) CO_2e tariff on all emission sources. Thus, differences in leakage rates between different sectors should not be taken into account.

If, however, the objective of Danish climate policy is to reduce global emissions over and above the targets set by the existing international obligations and national reduction targets, the regulation should take CO_2e leakage into account. If such a supplementary objective is to be pursued cost-effectively, the climate effort must, to some extent, be shifted from sectors with high leakage rates to sectors with low leakage rates. Such a shift can be achieved by introducing leakage-

2) The sensitivity analysis assumes that all countries, except large economies such as China, Russia, India and the United States, have binding targets and, therefore, that they cannot increase their emissions. It should be emphasized that there is considerable uncertainty as to whether various countries have binding climate goals according to "business-as-usual". As an example, it is assumed in the analysis that the USA does not have binding climate targets. The USA's affiliation with the Paris Agreement is assessed by some as binding, however, the USA has indicated its intention to withdraw from the Paris Agreement.

adjusted CO_2e tariffs that are lower for sectors where the leakage rate is high.

Leakage-adjusted tariffs increase the socio-economic costs of reaching the purely national obligations and objectives, but a larger global reduction in CO_2e could be achieved for this additional price. The additional socio-economic costs associated with leakage-adjusted tariffs compared to a uniform tariff are estimated in the chapter to be DKK 220-660 per extra global tonne reduction of CO_2e. This is about the same magnitude as estimates in the literature for the global marginal damage cost of a tonne of CO_2e emissions – the so-called social cost of carbon.[3]

The analysis in the chapter illustrates the effects of adjusting for leakage while reaching the 2030-obligations for the non-quota sector.[4] However, the analysis should not be viewed as a proposal for an optimal Danish climate policy to reduce global emissions. This is because other measures, e.g., climate-differentiated consumption taxes or a reduction of North Sea oil and gas extraction, could potentially be included in an optimal leakage-corrected Danish climate policy.

The analysis is based on estimated socio-economic reduction costs in 2030 for various parts of the non-quota sector. These were presented in the 2018 Economy and Environment report by the Danish Economic Councils. Here it was found that the marginal socio-economic reduction costs were significantly higher for passenger cars than for agriculture and the remaining non-quota sector.

The calculations indicate that the contributions of the different sectors to the overall reduction requirement for the non-quota sector do not change significantly when imposing leakage-adjusted tariffs instead of a uniform tariff.

Despite its relatively high leakage rate, agriculture should still contribute significantly to the overall reduction when leakage is adjusted for. The high leakage rate does, however, contribute to a slightly smaller reduc-

3) In previous reports by the Danish Economic Councils, DKK 563 per tonne CO_2e (2017 prices) is stated as a good estimate of the social cost of carbon based on an overview study by Tol (2013). It should, however, be emphasized that there is a great deal of uncertainty related to the size of the social cost of carbon.

4) The calculations illustrate the additional effort needed to achieve the reduction requirements in the non-quota sector by 2030. There is uncertainty about the exact size of the reduction requirement, so the calculations are undertaken for reductions of 2.5 million tonnes as well as 4.0 million tonnes of CO_2e by 2030.

tion in agriculture when adjusting for leakage.[5] The relatively modest effect on agriculture's share of the overall reductions reflects the fact that there are socio-economic benefits associated with reducing greenhouse gas emissions for this sector, specifically in the form of a better aquatic environment and less air pollution.

Even though the leakage rate is very small for consumption of transport fuel, increased tariffs on CO_2 from passenger cars are not a part of the leakage-adjusted tariff policy. This is because the marginal socio-economic costs of further reductions are relatively high, since passenger cars are already heavily regulated in Denmark.

According to an agreement with the EU, Denmark may use cancellations of quota allowances corresponding to at most 0.8 million tonnes of CO_2e per year to meet the reduction requirement. There is a *negative* leakage rate associated with this type of quota cancellation of approximately -53 per cent in the long run, which reflects mechanisms linked to the reform of the quota system from early 2018. The calculations in the chapter show that the quota cancellations should be fully utilized if the reduction requirement by 2030 is 4.0 million tonnes of CO_2e, regardless of whether a uniform or leakage-adjusted tariff policy is used. If the reduction requirement is only 2.5 million tonnes of CO_2e, quota cancellations should only be used when adjusting for leakage.

The analysis shows that there would be a relatively limited impact on global emissions from introducing leakage-adjusted tariffs instead of a uniform tariff. With a national reduction requirement of 4.0 million tonnes by 2030, global emissions are reduced by 3.2 million tonnes with a uniform tariff. With leakage-adjusted tariffs, global emissions are reduced by 3.4 million tonnes. The relatively limited effect of introducing leakage-adjusted regulations is in line with studies for other countries. This is not in itself an argument for not using a leakage-adjusted climate policy, but it is important not to have unrealistic expectations for the effect on global emissions.

5) Agriculture's share of overall reductions decreases from 43 to 33 per cent with a reduction requirement of 2.5 million tonnes, and from 37 to 29 per cent with a reduction requirement of 4.0 million tonnes.

Economy and Environment, 2019