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TRENDS IN AIR POLLUTION IN IRELAND: A DECOMPOSITION ANALYSIS

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Abstract: Trends in the emissions to air of sulphur dioxide, nitrogen oxides, carbon monoxide, volatile organic compounds, and ammonia in Ireland are analysed with a logarithmic mean Divisia index decomposition for the period of 1990-2009. Emissions fell for four of the five pollutants, with ammonia being stationary, despite rapid economic change. A fall in emissions per unit output was the main driver of this trend, except for ammonia where structural economic change was the main driver. Extrapolating these trends continue, Ireland will keep emissions below its National Emission Ceilings, except in the case of nitrogen oxides where the target will likely be met by 2015.

Key words: decomposition analysis, air pollutants, Ireland
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1. Introduction

Ireland economic development has been a rollercoaster. Long one of the poorest countries of Western Europe, Ireland's economy grew and modernized rapidly, eventually overheating and collapsing into one of the longest and deepest recessions in modern history. This makes Ireland an interesting case study of the relationship between environmental pollution and economic growth and development. We here focus on emissions to air of sulphur dioxide, carbon monoxide, nitrogen oxides, volatile organic compounds, and ammonia. We use index decomposition analysis.

Index decomposition analysis is a method to split a trend, in this case emissions to air, into its constituent parts, here population growth, per capita income growth, structural economic change, and technological progress. This helps to explain observed changes, and thus assists future projections (which are beyond the scope of the current paper). We focus on the five substances above because they are priorities in air quality policy in Ireland and the EU.

(Ang and Zhang 2000) survey index decomposition analyses in the areas on energy and environment. In the surveyed literature, emissions are limited carbon dioxide, sulphur dioxide, and nitrogen oxides. No specific studies for Ireland are reported. A search of Scopus suggests that, since 2000, index decomposition papers have focussed on energy use and carbon dioxide emissions. Although often included in multi-country analyses, there are only two papers specifically on Ireland. (Cahill et al. 2010) use the same method as used here, but for energy use. (Llop and Tol 2011) use subsystem decomposition analysis for greenhouse gas emissions. (Wier 1998) uses structural decomposition analysis for trends of carbon dioxide, sulphur dioxide, and nitrogen oxides emissions in Denmark. (Anttila and Tuovinen 2009) use regression analysis to decompose trends in sulphur dioxide, carbon monoxide, and nitrogen oxides in Finland. (Shrestha and Timilsina 1998) use index decomposition analysis to study nitrogen oxide emissions from the power sector in Thailand. We are not aware of any decomposition analyses of volatile organic compounds or ammonia.

The paper proceeds as follows. Section 2 presents data and methods. Section 3 discusses the results. Section 4 extrapolates the observed trends and compares the results to the emission targets. Section 5 concludes.

2. Data and methods

2.1. Data on past trends

Emissions for sulphur dioxide (SO_2), nitrogen oxide (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC), and ammonia (NH_3) were taken from the

ESRI Environmental Accounts (Lyons et al. 2009). This is not a primary data source. Ammonia emissions per sector were taken from the CSO Environmental Accounts (CSO 2007). For the other substances, emissions per activity were taken from the annual reports to the UN Framework Convention on Climate Change (McGettigan et al. 2010) and attributed to the sectors in the ESRI Environmental Accounts (see Table 1). Total emissions were reconciled with the official estimates (EPA 2008), by re-scaling the sectoral emissions so that the totals match.

2.2. Decomposition

The ESRI Environmental Accounts shows emissions per sector, as well as total emissions. In order to help interpret changes in total emissions, we use logarithmic mean Divisia index decomposition (Ang 2005).

Emissions M_t at time t follow from the identity

(1) $$M_t = \sum_{i=1}^{I} M_{i,t} = \sum_{i=1}^{I} x_{i,t}^1 x_{i,t}^2 \dots x_{i,t}^n$$

where i denotes sector, and n is the number of components x.

The proportional change D in emission M is decomposed as follows:

(2) $$D_t = \frac{M_t}{M_0} = D_t^1 D_t^2 \dots D_t^n$$

where

(3) $$D_t^j = \exp\left[\sum_{i=1}^{I} \frac{\left(M_{i,t} - M_{i,0}\right) / \left(\ln M_{i,t} - \ln M_{i,0}\right)}{\left(M_t - M_0\right) / \left(\ln M_t - \ln M_0\right)} \ln\left(\frac{x_{i,t}^j}{x_{i,0}^j} \right) \right]$$

We here use

(4) $$M_t = \sum_{i=1}^{I} M_{i,t} = \sum_{i=1}^{I} \frac{M_{i,t}}{Y_{i,t}} \frac{Y_{i,t}}{Y_t} \frac{Y_t}{P_t} P_t$$

where Y_i is the gross output per sector i, Y is total production, and P is population size. That is, we decompose the change in emissions into the change in emission intensity (M_i/Y_i), the change in the structure of the economy (Y_i/Y), economic output growth per capita (Y/P), and population growth (P). We refer to this as technological change, structural change, economic growth, and population growth, respectively. Note that the technology term in fact is a residual: it captures true technological change (emissions per activity level) as well as changes in production (activities per value added) and changes in the structure of the sector. Note also that (2-3) is a first-order approximation. There is a typically small, unexplained change in emissions.

2.3. Residential emissions

Households directly emit each of the five pollutants. Households are responsible for up to one-fifth of sulphur dioxide emissions, and for almost one-quarter of carbon monoxide emissions. The decomposition analysis outlined above is defined for economic production. Households are not a sector in the economic accounts, but they are in the environmental accounts. We extended the economic accounts to include a household production sector as follows. Energy use is the main source of household pollutants. Households do not use energy for its own sake, but rather convert it into energy services (e.g., light, heat).That is, we reinterpret household energy use as household production of energy services. Assuming rationality and ignoring wear and tear, the marginal value (and implicit price) of these energy services would the cost of the fuels used. Thus, household production equals household fuel use times consumer price.

Consumer prices per fuel were taken from the International Energy Agency. Domestic fuel use were taken from the ESRI Environmental Accounts, which in turn take data from the SEAI Energy Balances.

3. Results

Figure 1 shows the trends between 1990 and 2009 in total emissions of the five air pollutants. Table 2 has the numbers. The population of Ireland grew by 27%. Output grew by 238%; output per capita by 4.7% per year. Despite that, emissions of nitrogen oxides and rose only slightly in the first decade, but fell later and were somewhat lower in 2009 than in 1990; the average annual growth rate was 1.6%. Ammonia rose first and fell later; 2009 emissions were almost the same as in 1990. Emissions of volatile organic compounds (-4.1% per year) and carbon monoxide (-4.8% per year) fell steadily over the entire period. Sulphur dioxide emissions show the greatest variability and the steepest fall (-8.0% per year). With emissions steady or falling while the economy was growing rapidly, technological and structural change must have been massive.

Figure A1 in the appendix shows the sectoral structure of economic output. Figure A2 shows sulphur dioxide emissions by sector. Power generation is the largest source of emissions. Emissions fell for almost all sectors. Figure 2 decomposes the changes in emissions into technological change, structural change, economic growth, and population growth. Figure 2 shows the annual changes, as well as the overall trend for 1990-2009. Table 2 also shows the overall trend. Population has grown steadily, 1.1% per year on average. Economic output per capita has also grown in every year except 2008 and 2009; average growth was 4.7% per year. Emissions fell because of changes in the structure of the economy, 2.1% per year on average, and technological change, 10% per year. In most years, emission intensive sectors (i.e., power generation) grew more slowly than the overall economy; but this is not true for every year. Technology improved in all but two years. In three years (2002, 2003, 2009), emissions per unit output fell by more than one-fifth.

Figure A3 shows nitrogen oxide emissions by sector. Transport and power generation are the main emitters. Emissions from power generation have fallen, but emissions from most other sectors are roughly stationary. Figure 3 and Table 2 decompose the trends. Population growth and economic growth are as for sulphur dioxide. Changes in the structure of the economy pushed down emissions by 1.7% per year on average. Annual changes are much larger than that, but positive and negative changes largely cancel out. Technological change is again the main reason that emissions fell. On average, emissions per unit output fell by 5.4% per year. The years 2004, 2006, 2007 and 2009 stands out with a drop in emissions per unit output in excess of 10%.

Figure A4 shows carbon monoxide emissions by sector. Transport is the dominant source but shows a steady decline. Households are the second largest source but show a smaller decline. Figure 4 and Table 2 decompose the trends. Population and economic growth are as above. Structural change slightly reduced emissions: 0.3% per year on average. The year 1999 stands out. The economy grew rapidly (10%) but transport fell slightly. In other years, however, transport grew faster than the rest of the economy. Again, technological change has driven emissions down: 8.1% on average. Technological change was positive in all years except 1999. The years 2000 and 2007 stand out with an improvement of emissions per output of over 15%.

Figure A5 shows emissions of volatile organic compounds by sector. Transport is the largest source of emissions but steadily declining from 1998 onwards. Construction is the second largest source and growing over time. Figure 5 and Table 2 decompose the trends. Population and economic growth are as above. Structural change slightly reduced emissions: 0.9% per year on average. The year 1999 again stands out, for the same reason as above. Technological change is once again the dominant force in emission reduction: 8.2% per year on average. Technological change was positive in all years except 2009. The years 2000, 2004 and 2007 stand out with a fall of more than 15% in emissions per output.

Figure A6 shows emissions of ammonia by sector. Agriculture is the predominant source of emissions, with a small contribution from transport. Figure 6 and Table 2 decompose the trends. Population and economic growth are as above. Structural change reduced emissions by 6.6% per year on average. This is because agricultural output lost over one-fifth of its output between 1990 and 2009 while the total economy more than tripled in size. The years 1997, 1999 and 2009 stand out, with drops over 20%.Technological change pushed emissions up by 1.3% per year. There are wild swings around this trend though, with technological regress of 18% in 1997 and technological progress of 20% in 2007.

4. Future projections and emission targets

Above, we explore past trends. We here extrapolate those trends for 2010-2015, about one-quarter of the historic record (1990-2009). We compare the projected emissions to the applicable National Emission Ceiling (European Parliament and Council of the European Union 2001).

(IFAC 2011) collects five economic projections. We use the mean and standard deviation of the annual growth rate of GDP. See Table A2. The result is shown in Figure 7. The surveyed projections are unanimous that Ireland will return to economic growth in 2011, and that the economy will continue to grow until 2015. This may be overconfident, but there are no alternative projections by official forecasters.

We use the mean and standard deviation of the observed annual structural and technological change for the period 1990-2009 for the five air pollutants. See Table A2. Table A2 also gives the correlation between the growth rate of total output, structural change, and technological change. We use this to project emissions. Algebraically,

(5) $$M_t = (1+g_t)M_{t-1}; g_t = g_t^{output} + g_t^{technology} + g_t^{structure}$$

(6) $$\sigma_g^2 = \sigma_{output}^2 + \sigma_{technology}^2 + \sigma_{structure}^2 + 2\sigma_{output,technology} + 2\sigma_{output,structure} + 2\sigma_{structure,technology}$$

(7) $$\sigma_{M_t}^2 = (1+g_t)^2 \sigma_{M_{t-1}}^2 + M_{t-1}^2 \sigma_{g_t}^2$$

Figure 7 shows the results. There is no emissions target for carbon monoxide. Emissions fell steadily in the past, and with slow economic growth, there is no reason to believe that emissions would start rising in the future. Emissions were 156 KtCO in 2009 and are projected to fall to 101 KtCO in 2015 with a standard deviation of 12 KtCO.

Similarly, emissions of sulphur dioxide, volatile organic compounds, and ammonia are projected to fall too, from 32 KtSO_2 in 2009 to 16 (4) KtSO_2 in 2015, from 48 to 30 (4) KtVOC, and from 76 to 55 (6) KtNH_3, respectively. Volatile organic compounds are closest to the target: There is a change of two in million that actual emissions will exceed the National Emission Ceiling.

Emissions of nitrogen oxides are projected to fall too, from 93 to 66 (6) KtNO_x, but it is only in 2015 that emissions get close to the National Emission Ceiling of 65 KtNO_x. As emissions from power generation have fallen sharply (cf. Figure A3), policy should target the transport sector.

5. Discussion and conclusions

In this paper, we decompose trends in the emissions to air of sulphur dioxide, nitrogen oxides, carbon monoxide, volatile organic compounds, and ammonia in Ireland for the economically tumultuous period of 1990-2009. Despite very rapid economic growth, emissions fell for four of the five pollutants, with ammonia being stationary. Technological progress – a fall in emissions per unit output – was the main driver of this trend, again excepting ammonia for which structural change in the economy as the main driver. Assuming that these trends continue, Ireland will keep its emissions below the National Emission Ceilings, except in the case of nitrogen oxides where the target will likely be exceeded until the middle of the decade.

These results come with a number of caveats. It would be good to extend the period of analysis, but this would require elaborate historic reconstructions of emissions. Alternative decomposition techniques may be used, be it other variants of index decomposition analysis or structural decomposition methods. Perhaps most importantly, the current analysis omits activity levels. The economic data are for output, rather than passenger-kilometres (for transport), number of animals (for agriculture) and so on. Unfortunately, comprehensive time series of activity data are not available for Ireland.

With those caveats and future research directions in mind, the results shown here illustrate that it is feasible to combine rapid economic growth with rapid environmental improvement.

Acknowledgements

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Table 1. A decomposition of trends (per cent per year) in emissions, Republic of Ireland, 1990-2009.

	SO_2	NO_x	CO	NMVOC	NH_3
Emissions growth	-7.95	-1.60	-4.76	-4.11	0.02
Technological change	-10.08	-5.36	-8.09	-8.15	1.15
Structural change	-2.05	-1.68	-0.27	-0.89	-6.64
Economic growth	4.74				
Population growth	1.12				
Residual	-1.83	-0.58	-2.62	-1.19	-1.10

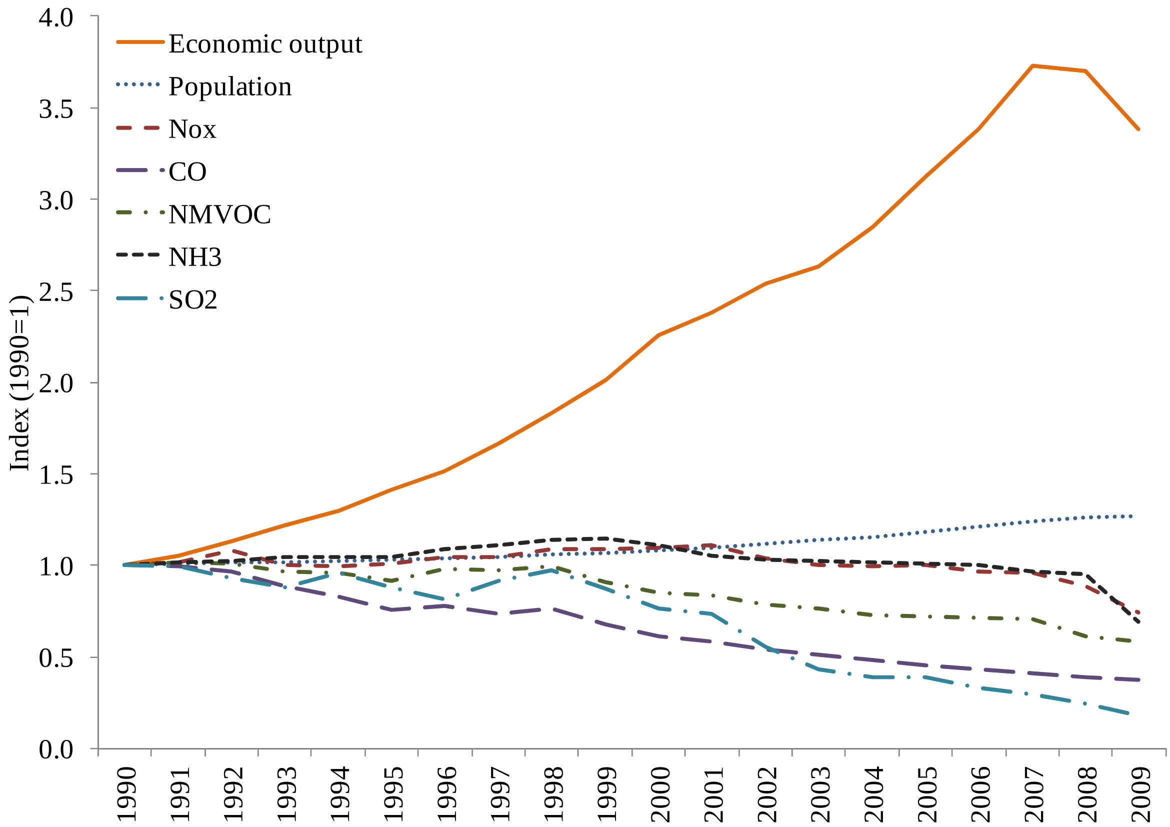

Figure 1. Emissions of sulphur dioxide, nitrogen oxides, carbon monoxide, non-methane volatile organic compounds, and ammonia, economic output, and population in Ireland between 1990 and 2009; numbers are indexed so that 1990 = 1.

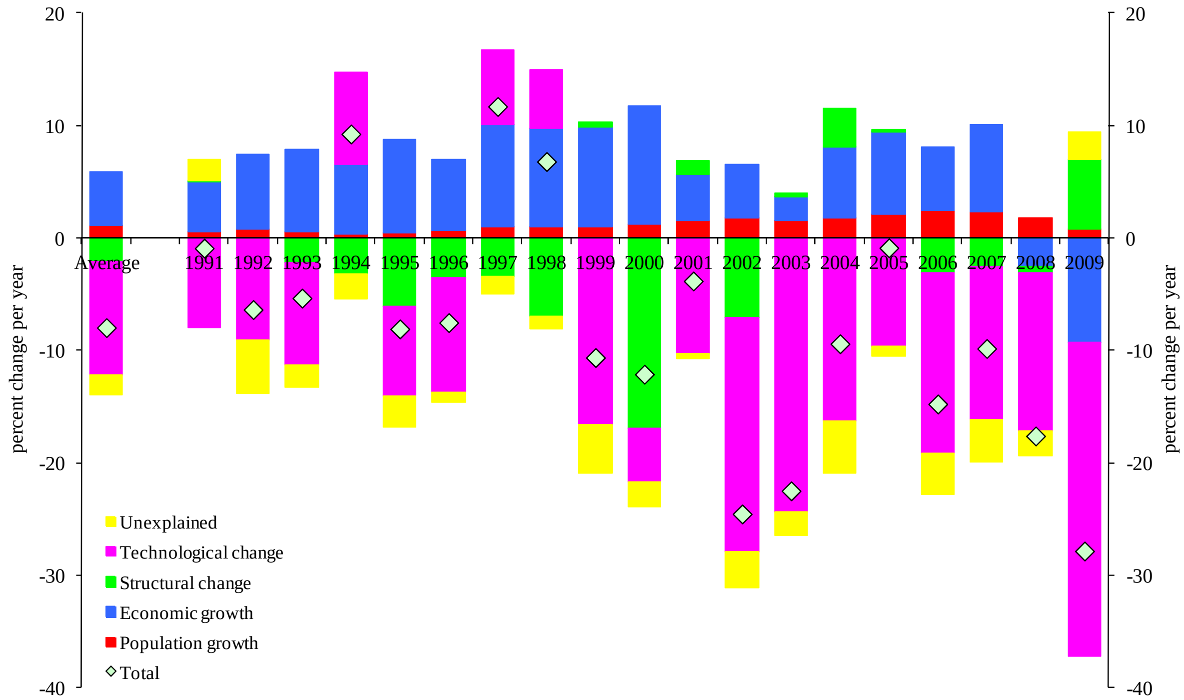

Figure 2. A decomposition of trends in sulphur dioxide emissions in Ireland between 1990 and 2009 into population growth, economic growth (per capita income), structural change (sectoral composition of the economy), and technological (and behavioural) change.

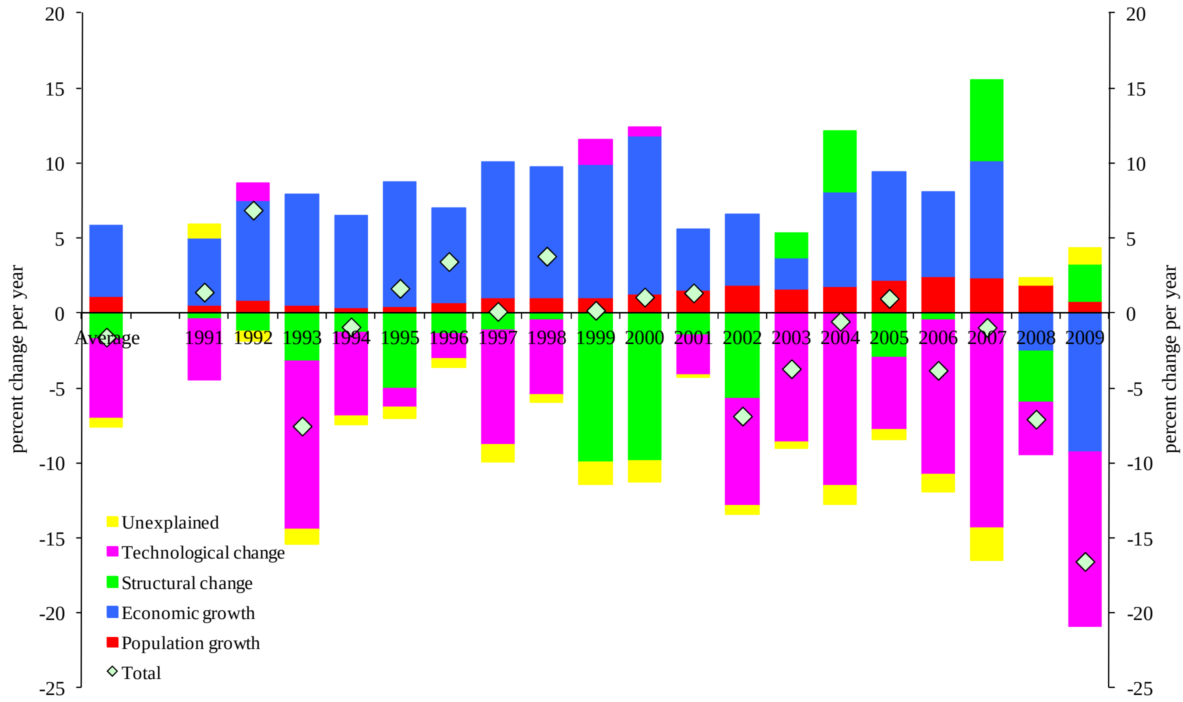

Figure 3. A decomposition of trends in nitrogen oxide emissions in Ireland between 1990 and 2009 into population growth, economic growth (per capita income), structural change (sectoral composition of the economy), and technological (and behavioural) change.

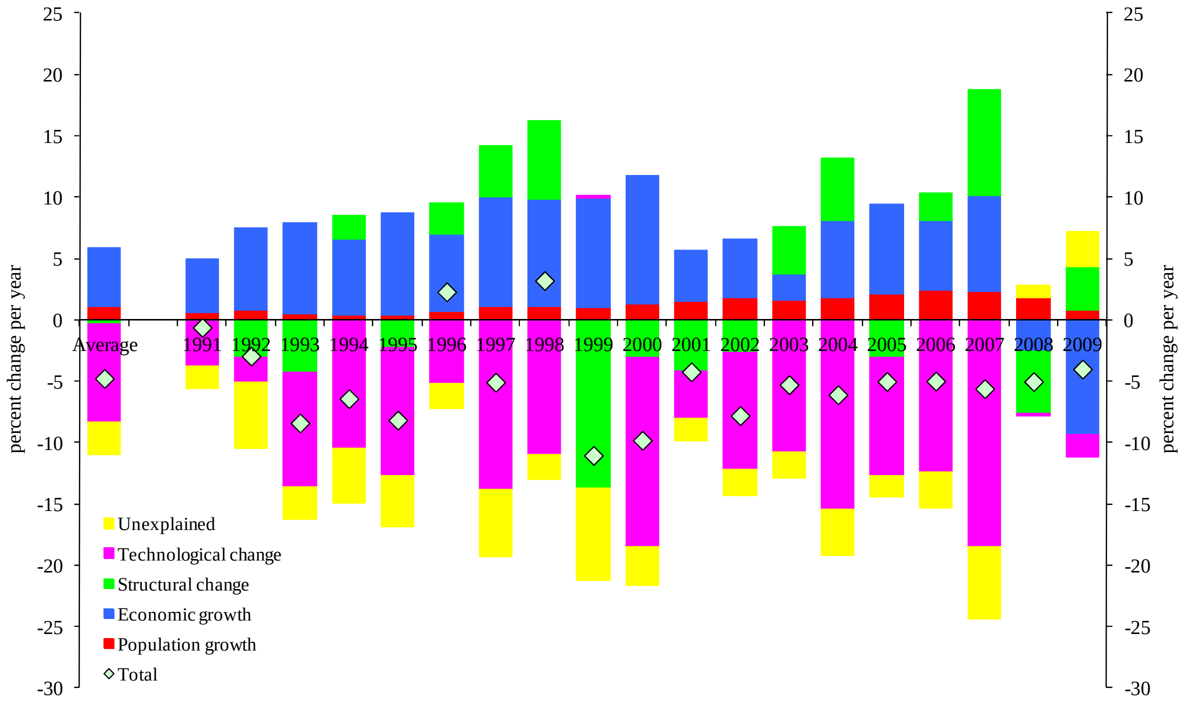

Figure 4. A decomposition of trends in carbon monoxide emissions in Ireland between 1990 and 2008 into population growth, economic growth (per capita income), structural change (sectoral composition of the economy), and technological (and behavioural) change.

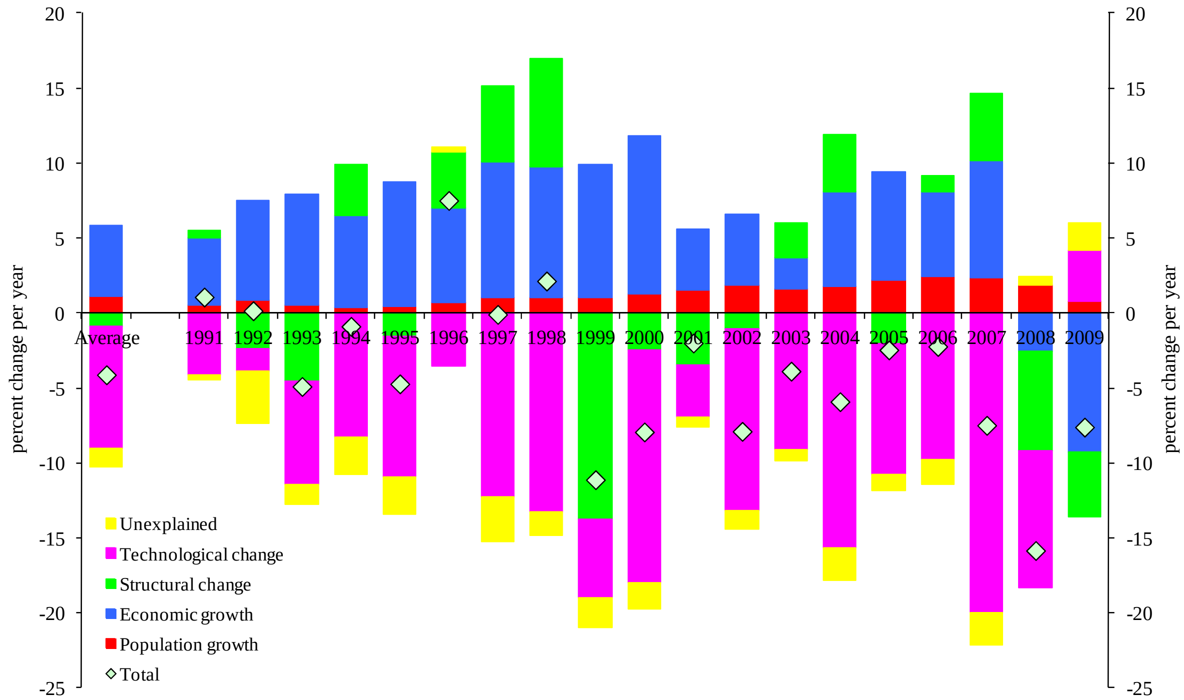

Figure 5. A decomposition of trends in non-methane volatile organic compounds emissions in Ireland between 1990 and 2008 into population growth, economic growth (per capita income), structural change (sectoral composition of the economy), and technological (and behavioural) change.

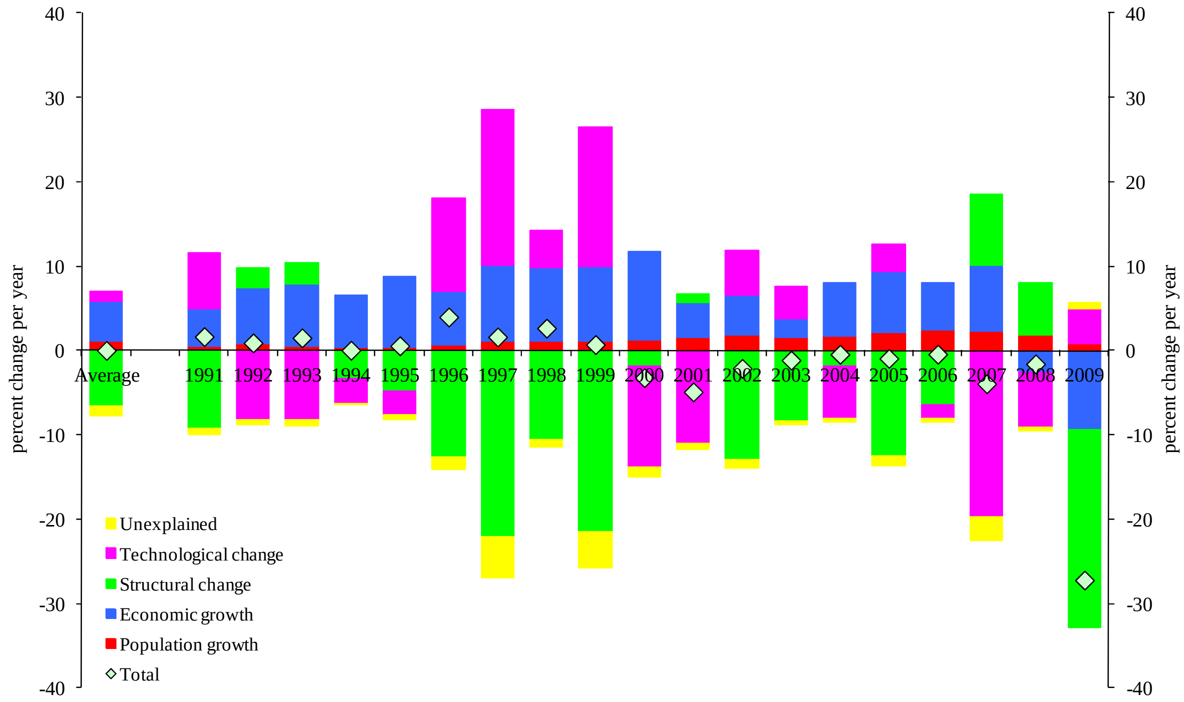

Figure 6. A decomposition of trends in ammonia emissions in Ireland between 1990 and 2008 into population growth, economic growth (per capita income), structural change (sectoral composition of the economy), and technological (and behavioural) change.

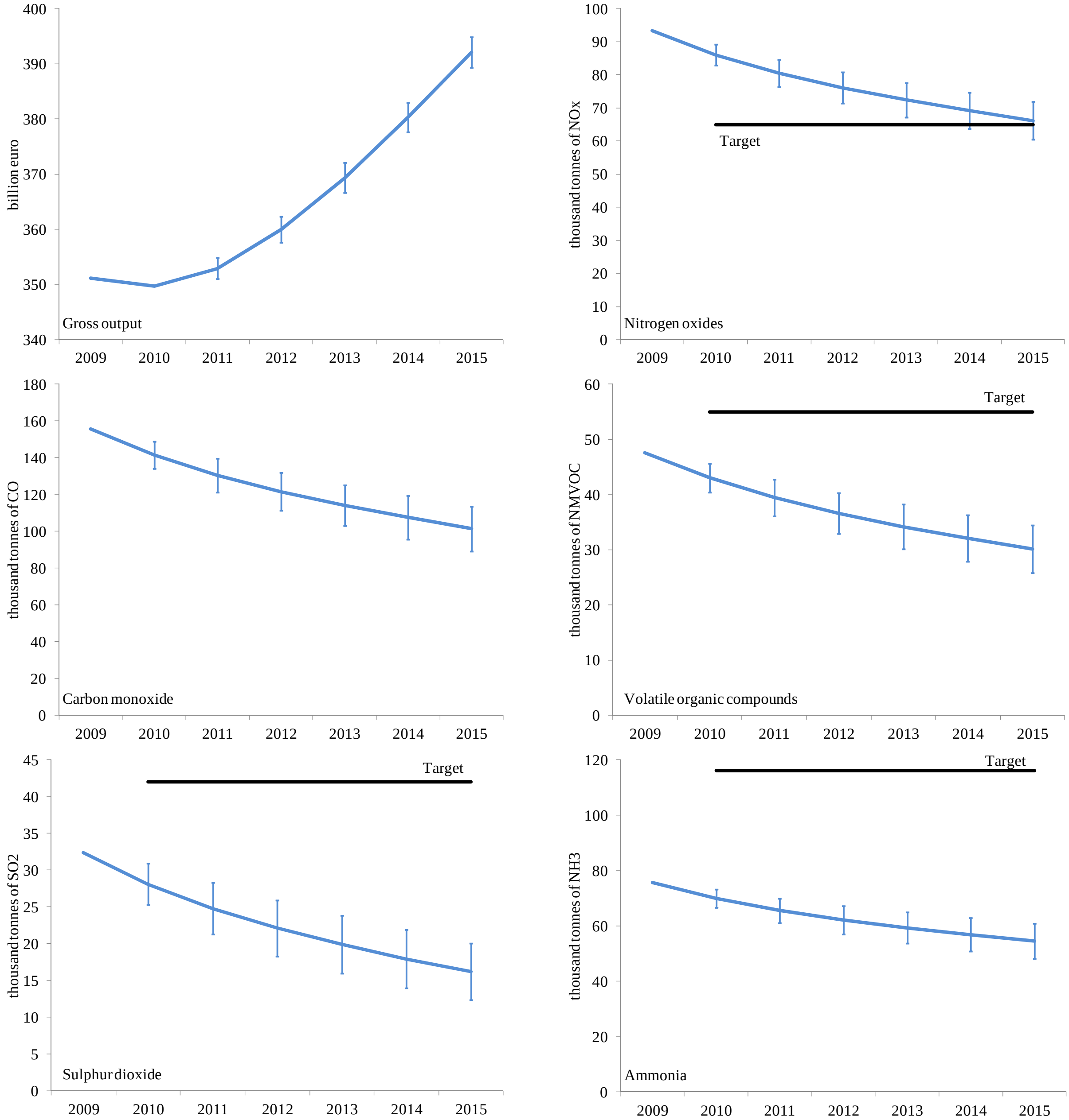

Figure 7. Projected output, projected emissions of air pollutants, and National Emissions Ceilings where applicable.

Table A1. Economic sectors in the ESRI Environmental Accounts for the Republic of Ireland and their concordance to NACE sectors and CRF activities.

Code	Sector	NACE	CRF
1	Agriculture, fishing, forestry	1-5	A4c
2	Coal, peat, petroleum, metal ores, quarrying	10-14	B2a, B2d
3	Food beverage and tobacco	15-16	A2d, A2e
4	Textiles, clothing, leather and footwear	17-19	
5	Wood and wood products	20	
6	Pulp, paper and print production	21-22	A2c
7	Chemical production	24	A2b
8	Rubber and plastic production	25	
9	Non-metallic mineral production	26	
10	Metal prod. Excl. machinery and transport equipment	27-28	A2a
11	Agriculture and industrial machinery	29	
12	Office and data process machines	30	
13	Electrical goods	31-33	
14	Transport equipment	34-35	
15	Other manufacturing	23,36-37	A1b, A1c
16	Fuel, power, water	40,41	A1a
17	Construction	45	
18	Services, excl. transport	50-55,64-95	A4a
19	Transport	60-63	A3
20	Households	-	A4b

Table A2. Economic growth rate.

2010	-0.4	
2011	0.9	(0.5)
2012	2.0	(0.4)
2013	2.6	(0.3)
2015	3.0	(0.1)
2014	3.1	(0.2)

Table A3. Technological and structural change.

	Growth rate		Correlation	
Sulphur dioxide			Output	Technology
Technology	-10.5	(9.6)	0.53	
Structure	-2.3	(4.9)	-0.58	-0.44
Nitrogen oxides			Output	Technology
Technology	-5.6	(4.7)	0.24	
Structure	-1.8	(4.0)	-0.31	-0.72
Carbon monoxide			Output	Technology
Technology	-8.6	(5.5)	-0.55	
Structure	-0.2	(5.2)	-0.07	-0.61
Volatile organic compounds			Output	Technology
Technology	-8.7	(5.6)	-0.61	
Structure	-0.6	(5.0)	0.24	-0.45
Ammonia			Output	Technology
Technology	-0.3	(9.9)	-0.06	
Structure	-6.9	(9.3)	0.18	-0.90

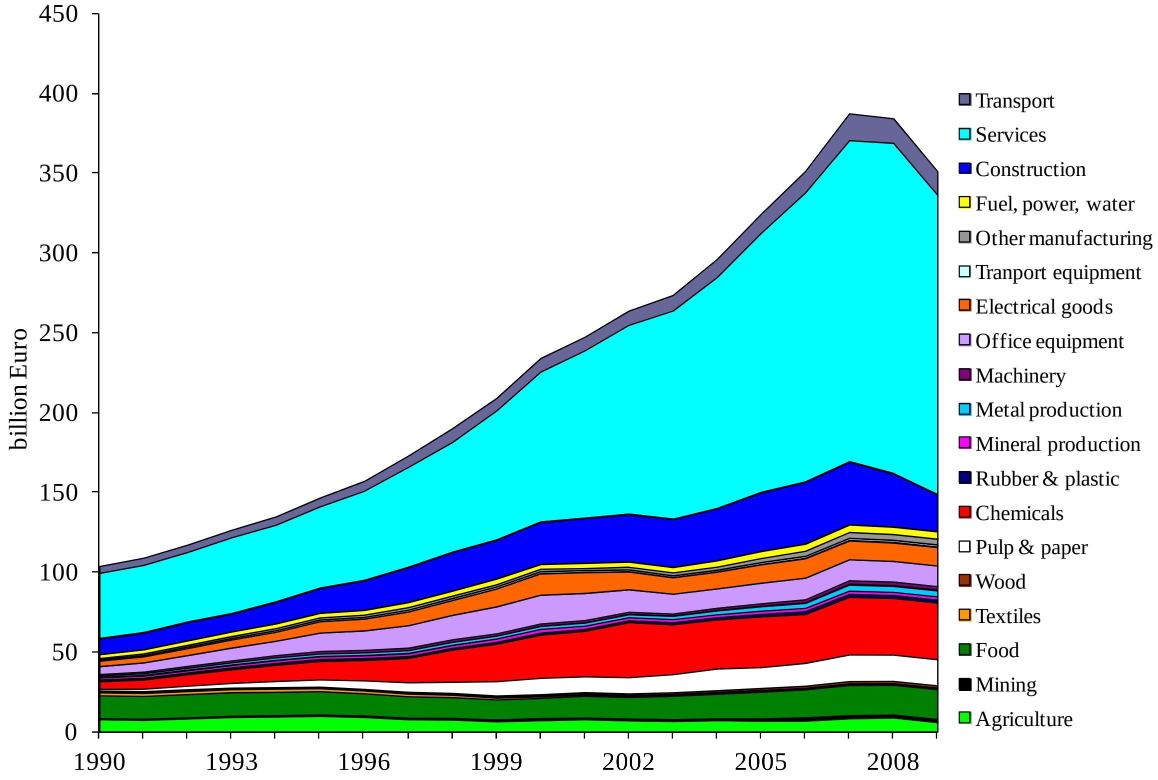

Figure A1. Economic output by sector.

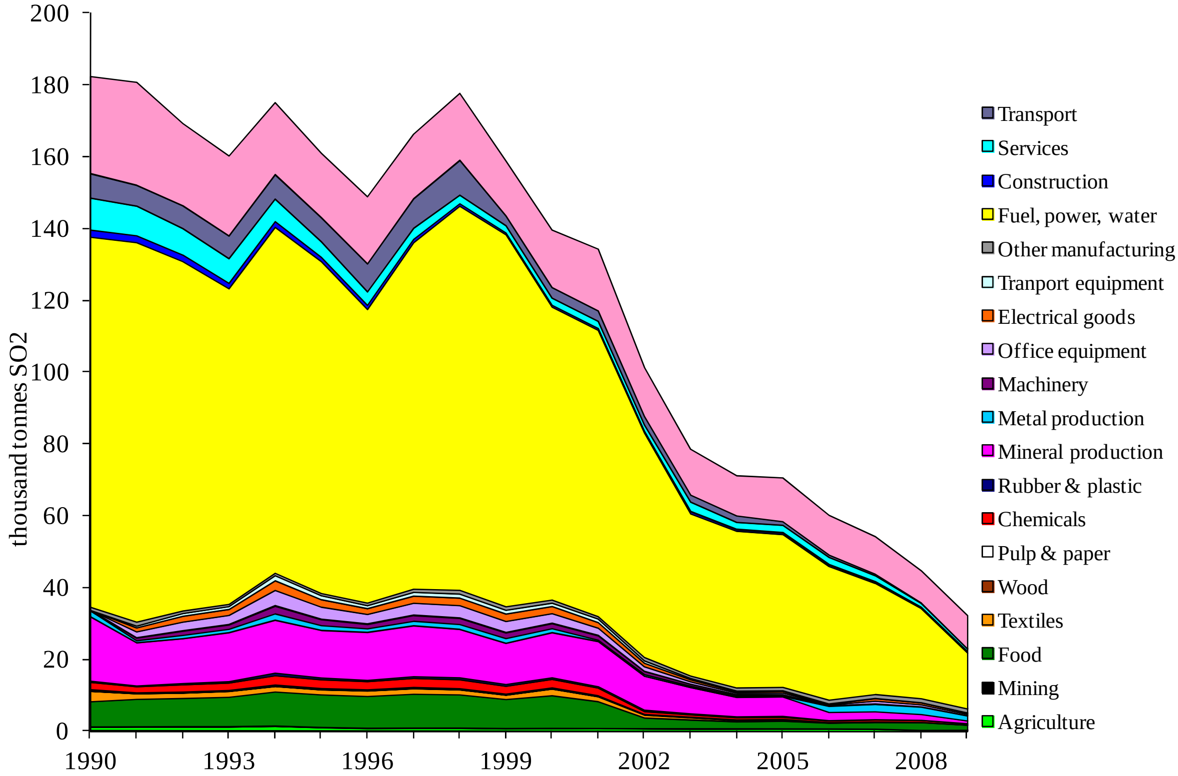

Figure A2. Sulphur dioxide emissions per sector in Ireland between 1990 and 2008.

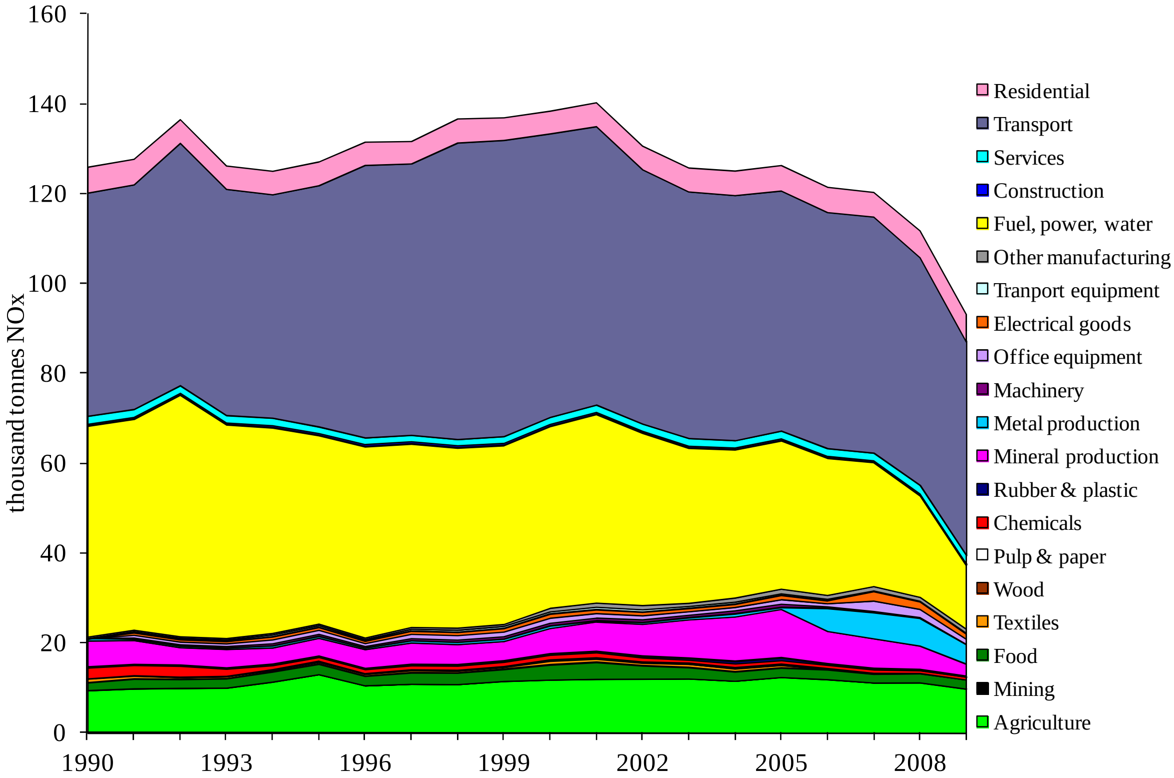

Figure A3. Nitrogen oxides emissions per sector in Ireland between 1990 and 2009.

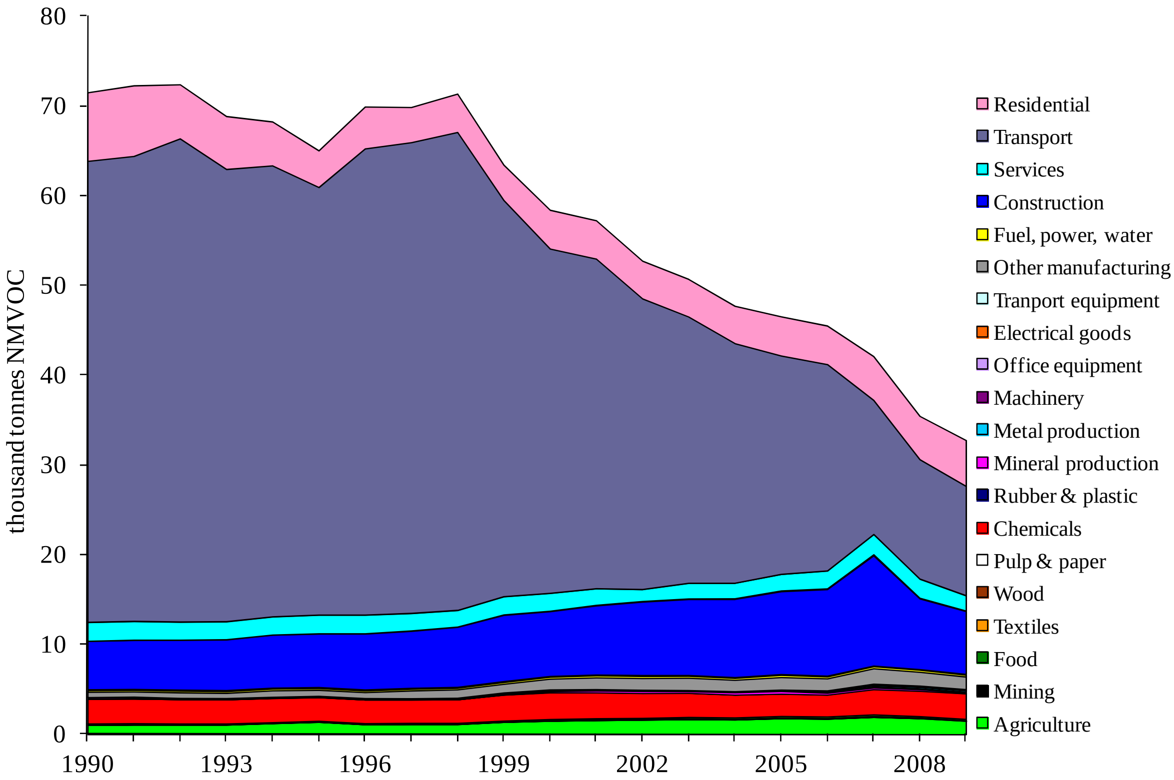

Figure A4. Carbon monoxide emissions per sector in Ireland between 1990 and 2009.

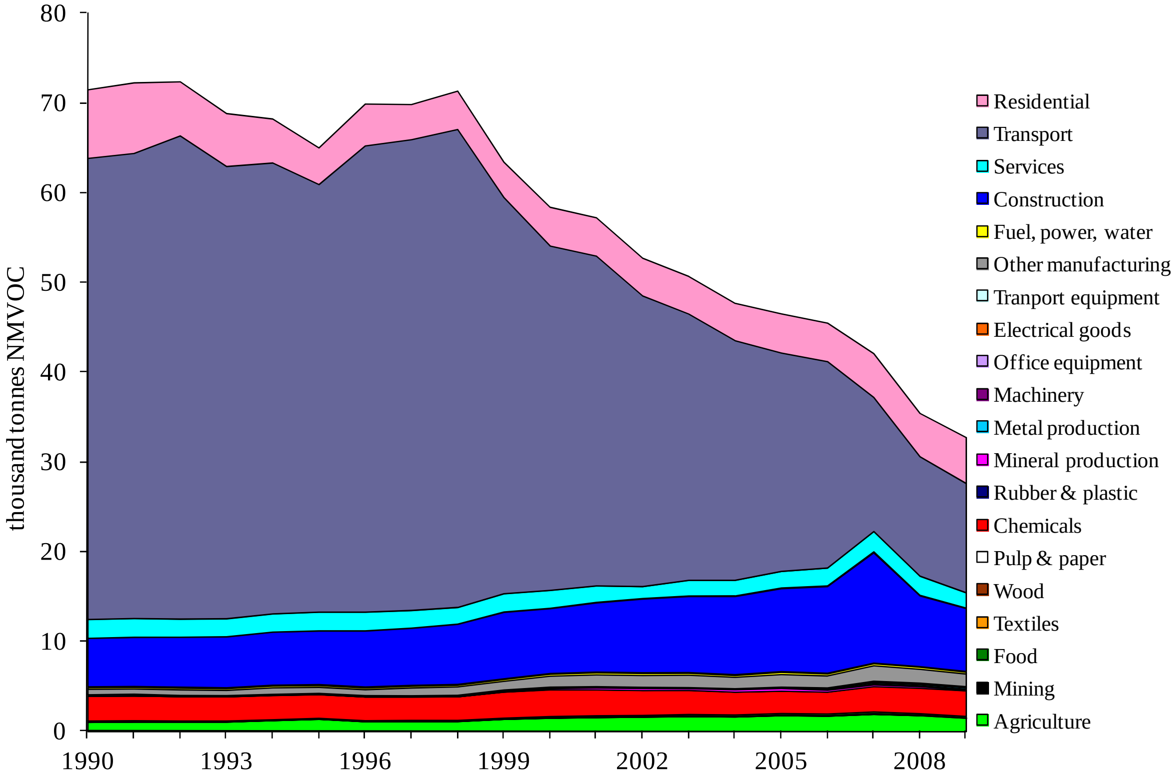

Figure A5. Non-methane volatile organic compound emissions per sector in Ireland between 1990 and 2009.

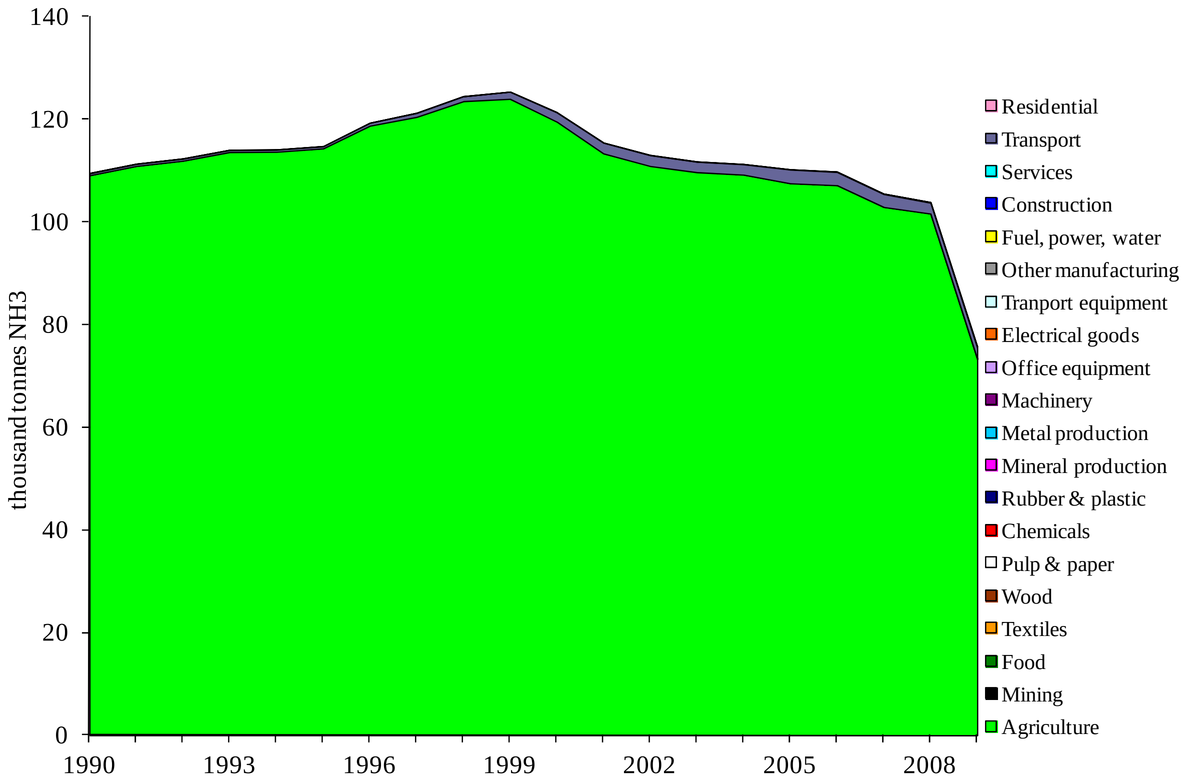

Figure A6. Ammonia emissions per sector in Ireland between 1990 and 2008.

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