Response to the reviewers' comments

We are pleased that both reviewers indicate that our study is interesting and worth publishing in Atmospheric Chemistry and Physics. We have tried to address all of the reviewers' comments in the revised manuscript. The most important issues that were asked for were extra info on the emission input and sensitivity of the model, a justification of the climate impact analysis and some textual additions and corrections. We have substantially expanded the description of the emission input and provided the referee with a detailed overview in our response. An extra figure and accompanying text is added to the manuscript to assess the climate impact issue. Furthermore, all requested corrections and additions are made to the text, including two extra references. We believe the applied changes significantly improve the scientific value of the manuscript and hope they make it acceptable for the remainder of the publication process in Atmospheric Chemistry and Physics.

Anonymous Referee #1

The paper reports about simulations with one-way coupled regional air quality model with a climate model addressing two emission cases for Belgium during a 10yr mean period around 2030 and using the RCP4.5 climate scenario. The reference is a 10yr period 2000-2009 and emission changes have been only considered for Europe at 25 and 3 km resolution, but still 34 layers only in the vertical direction.

Even though 3km resolution is detailed (a similar resolution was used by e.g. An et al. ACP (2007) for simulations over Beijing), it can not really include urban details, but it is sensitive to point source emissions. No breakdown of the emissions at sector-specific level, no info on proxy data for geospatial and temporal distribution was given, which is crucial especially when going to higher resolution. Therefore an extra section describing the emission input is needed.

We agree with the reviewer that info about the emission data are crucial when using this high resolution. Therefore, we have added an extra paragraph to the text providing more details about the emission input. However, describing all the details and data sources used for the emission input would require more than a few extra pages of text, tables and figures. In our opinion, this would make the paper lose focus and make it unnecessary long, since all the details about the geospatial proxy data can be found in Maes et al. (2009) and the temporal distribution parameters in Builtjes et al. (2003), as is indicated in the revised manuscript (3th paragraph of Section 2.1).

To provide clarity to the reviewer, we give a concise overview of the applied method below:

To obtain the emission data for this study, we made use of the European Monitoring and Evaluation Programme (EMEP) dataset. Based on the official reports by member states, EMEP provides corrected and gap filled expert emissions on a country basis as national totals. In this emission inventory, sources are broken down over 11 SNAP (Selected Nomenclature for sources of Air Pollution) categories:

sector_name	sector_description
SNAP 1	Combustion in energy production and transformation
SNAP 2	Non-industrial combustion plants
SNAP 3	Combustion in manufacturing industry
SNAP 4	Production processes
SNAP 5	Extraction and distribution of fossil fuels and geothermal energy
SNAP 6	Solvent use and other product use
SNAP 7	Road transport
SNAP 8	Other mobile sources and machinery
SNAP 9	Waste treatment and disposal
SNAP 10	Agriculture
SNAP 11	Other sources and sinks

For each SNAP source category, point source emissions are allocated on the air quality model domain, using the European Pollutant Emissions Register (EPER). This database contains point source emission data for about 12000 facilities occurring in the EU-25 for the years 2001 and 2004. Next, remaining non-point emissions are spatially distributed using quantitative spatial surrogate data (Table 1).

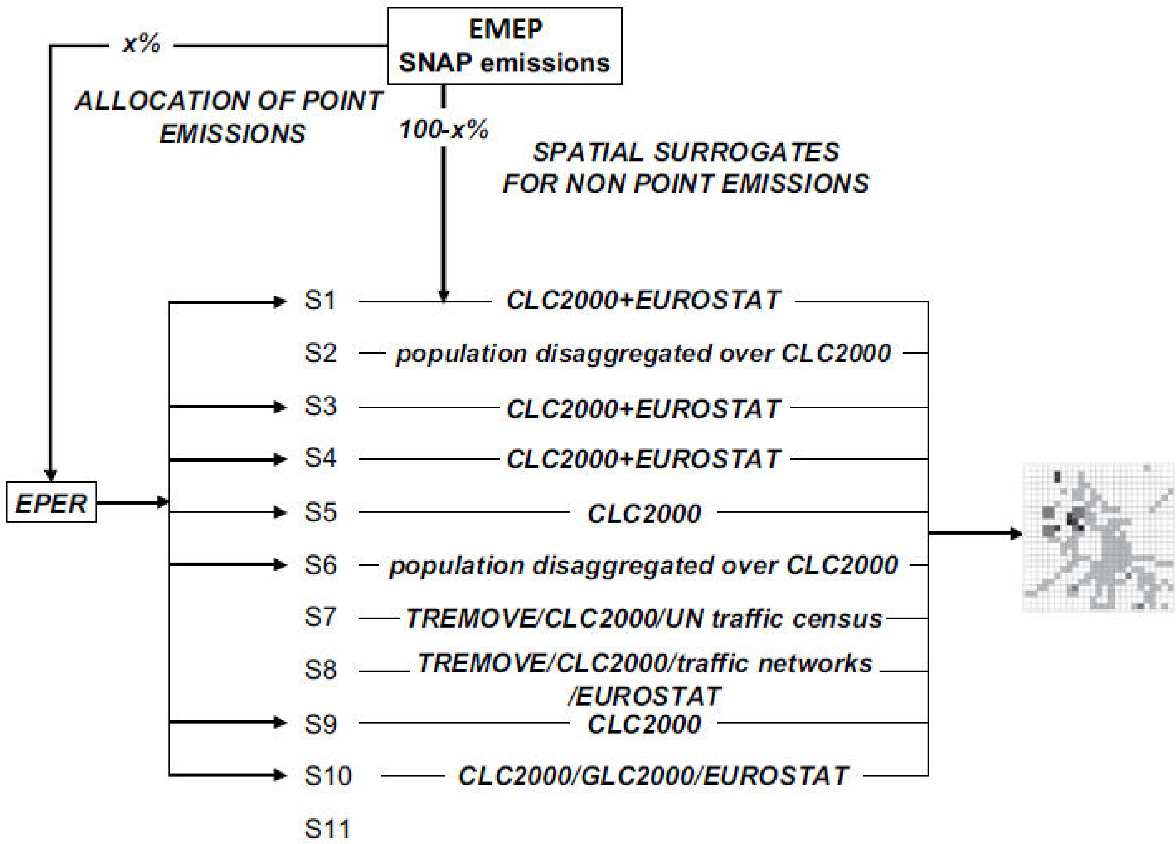


Figure 1: Conceptual model of the disaggregation procedure. In a first step point source emissions are allocated on the air quality model domain. Next, remaining (100- x%) non-point emissions were spatially distributed using quantitative spatial surrogate data (from Maes et al., 2009)

Table 1: Description of the auxiliary data sets used for the spatial disaggregation of the emission inventory (from Maes et al., 2009).

Data source	Description
EUROSTAT	EUROSTAT publishes economic, monetary, trade statistics, business, social, regional, agricultural, environmental and energy statistics. The web site offers free access to download all data. In this paper three data sets were used. Employment in persons at NUTS 3 level (2001), animal populations at NUTS 2 level (data for 2005, gapfilling using data for previous years); air traffic data by airport (data for 2006, gapfilling using data for previous years). URL: http://epp.eurostat.ec.europa.eu/.
EPER	EPER is the European Pollutant Emission Register. EPER contains data on the main pollutant emissions to air and water reported by about 12,000 large and medium-sized industrial facilities in the EU-25 Member States. Data are available for 2001 and 2004. URL: http://eper.ec.europa.eu/.
CLC2000	The CORINE Land Cover 2000 data (CLC2000) is a map of the European environmental landscape based on interpretation of satellite images with land cover types in 44 standard classes. The map was created in GIS ARC/INFO format at an original scale of 1:100,000. The resolution of the raster data is 250 × 250 m. The European Environmental Agency owns CLC2000 and grants free access to the data. Derived from this data set is the population density disaggregated with CLC2000 (Gallego and Peedell, 2001). The owner of this data set is the Joint Research Centre of the European Commission. URL: http://www.eea.europa.eu.
GPWv3	Gridded Population of the World, Version 3 (GPWv3) consists of estimates of human population for the years 1990, 1995, and 2000 by 2.5′ grid cells and associated data sets dated circa 2000. Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT). 2005. Gridded population of the World Version 3 (GPWv3): population density grids. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. URL: http://sedac.ciesin.columbia.edu/gpw.
TREMOVE	TREMOVE is a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector. The model covers passenger and freight transport in the EU 25 and covers the period 1995–2030. National emissions are estimated using the COPERT methodology. TREMOVE is owned by the European Commission. The database is available in MS Excel and MS Access. URL: http://www.tremove.org.
UN Traffic Census	The 2000 Census of Motor Traffic on Main International Traffic Arteries is a compilation of road traffic data on main international roads in Europe. The census shows the average annual daily traffic on the E-Roads of 37 European countries. The data can be purchased at UNECE Transport Division. URL: http://www.unece.org/trans/.
GLC2000	The Global Land Cover 2000 database categorizes land cover using 22 different classes at a spatial resolution of 1 km. The data are made available by the Joint Research Centre of the European Commission. URL: http://www-gem.jrc.it/glc2000.
ESRI data and maps	ESRI data and maps is a set of map data that is included with ArcGIS software. It was used to have spatial information of inland waterways and railroads of Europe. The data are not publicly available. URL: http://www.esri.com/data.
RRG GIS database	The RRG GIS database (Raumforschung, Raumplanung und Geoinformation) is a geodatabase covering all trans-European Transport Networks. The database was used to map sea shipping routes in Europe. The data are not publicly available. URL: http://www.brrg.de.

The resulting annual emissions are distributed temporally according to monthly (January-December), daily (Monday-Sunday) and hourly (0-23h) factors, following Builtjes et al. (2003). These factors are specific to each pollutant and emission sector and reflect the different activity patterns as a function of time.

Monthly factors:

Sector	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
1	1.2	1.15	1.05	1	0.9	0.85	0.8	0.87	0.95	1	1.08	1.15
2	1.7	1.5	1.3	1	0.7	0.4	0.2	0.4	0.7	1.05	1.4	1.65
3	1.1	1.08	1.05	1	0.95	0.9	0.93	0.95	0.97	1	1.02	1.05
4	1.02	1.02	1.02	1.02	1.02	1.02	1	0.84	1.02	1.02	1.02	0.9
5	1.2	1.2	1.2	0.8	0.8	0.8	0.8	0.8	0.8	1.2	1.2	1.2
6	0.95	0.96	1.02	1	1.01	1.03	1.03	1.01	1.04	1.03	1.01	0.91
7	0.87	0.94	1.01	1.05	1.03	1.05	1	1.08	1.04	1.03	0.95	0.95
8	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1
10	0.45	1.3	2.35	1.7	0.85	0.85	0.85	1	1.1	0.65	0.45	0.45
11	1	1	1	1	1	1	1	1	1	1	1	1

Daily factors:

Sector	sun	mon	tue	wed	thu	fri	sat
1	0.85	1.06	1.06	1.06	1.06	1.06	0.85
2	0.8	1.08	1.08	1.08	1.08	1.08	0.8
3	0.8	1.08	1.08	1.08	1.08	1.08	0.8
4	0.88	1.02	1.02	1.02	1.02	1.02	1.02
5	1	1	1	1	1	1	1
6	0.5	1.2	1.2	1.2	1.2	1.2	0.5
7	0.8	1.03	1.05	1.07	1.06	1.12	0.87
8	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1
10	0.7	1.05	1.05	1.05	1.05	1.05	1.05
11	1	1	1	1	1	1	1

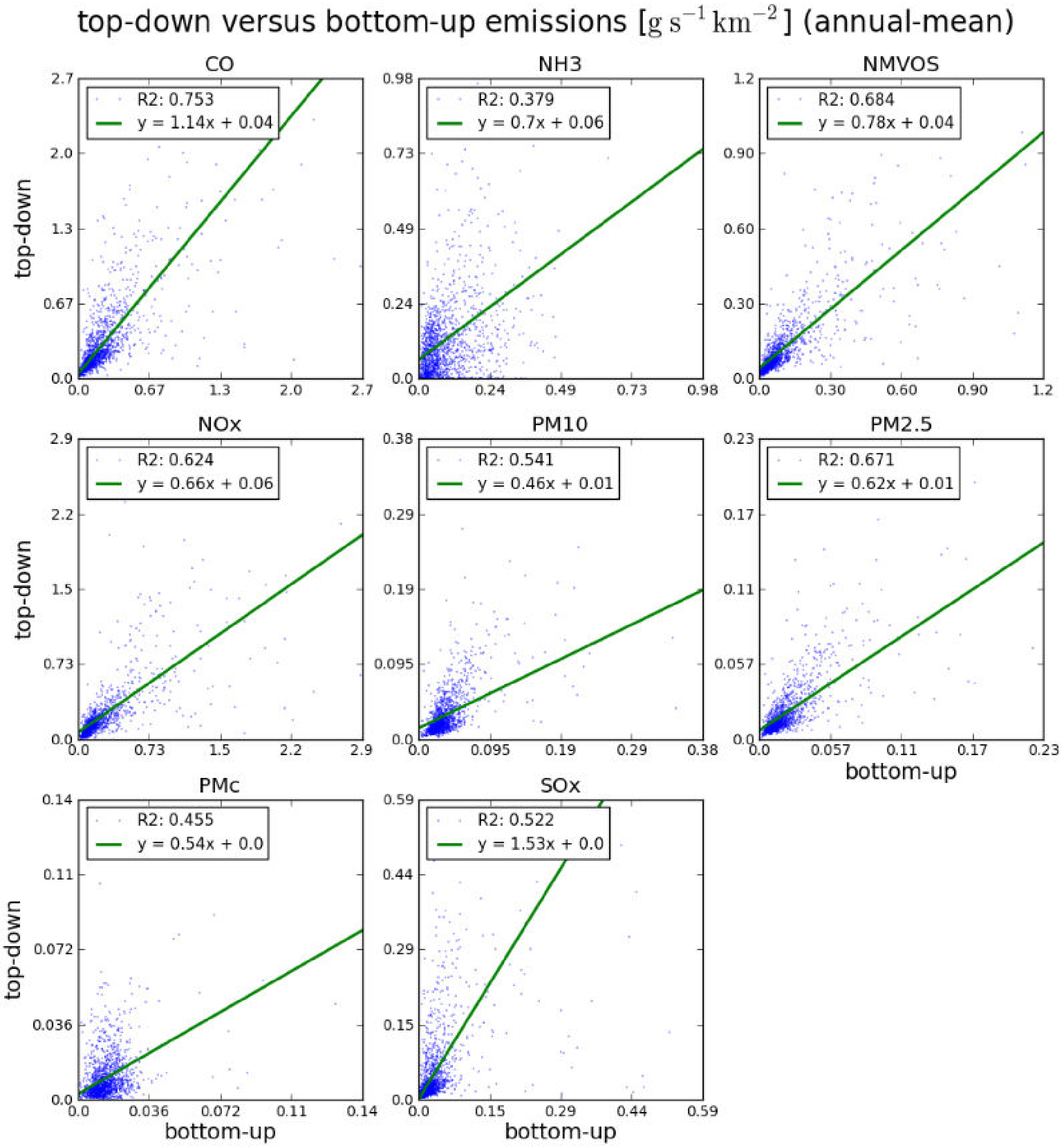
Hourly factors:

Sector	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
1	0,79	0,72	0,72	0,71	0,74	0,8	0,92	1,08	1,19	1,22	1,21	1,21	1,17	1,15	1,14	1,13	1,1	1,07	1,04	1,02	1,02	1,01	0,96	0,88
2	0,38	0,36	0,36	0,36	0,37	0,5	1,19	1,53	1,57	1,56	1,35	1,16	1,07	1,06	1	0,98	0,99	1,12	1,41	1,52	1,39	1,35	1	0,42
3	0,75	0,75	0,78	0,82	0,88	0,95	1,02	1,09	1,16	1,22	1,28	1,3	1,22	1,24	1,25	1,16	1,08	1,01	0,95	0,9	0,85	0,81	0,78	0,75
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	0,5	0,35	0,2	0,1	0,1	0,2	0,75	1,25	1,4	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,4	1,25	1,1	1	0,9	0,8	0,7
7	0,2	0,12	0,08	0,09	0,14	0,33	0,89	1,61	1,72	1,54	1,36	1,26	1,25	1,4	1,42	1,56	1,95	1,95	1,7	1,22	0,75	0,59	0,52	0,35
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	0,5	0,5	0,5	0,5	0,5	0,5	0,7	0,9	1,2	1,4	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,4	1,1	0,9	0,7	0,5	0,5	0,5
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

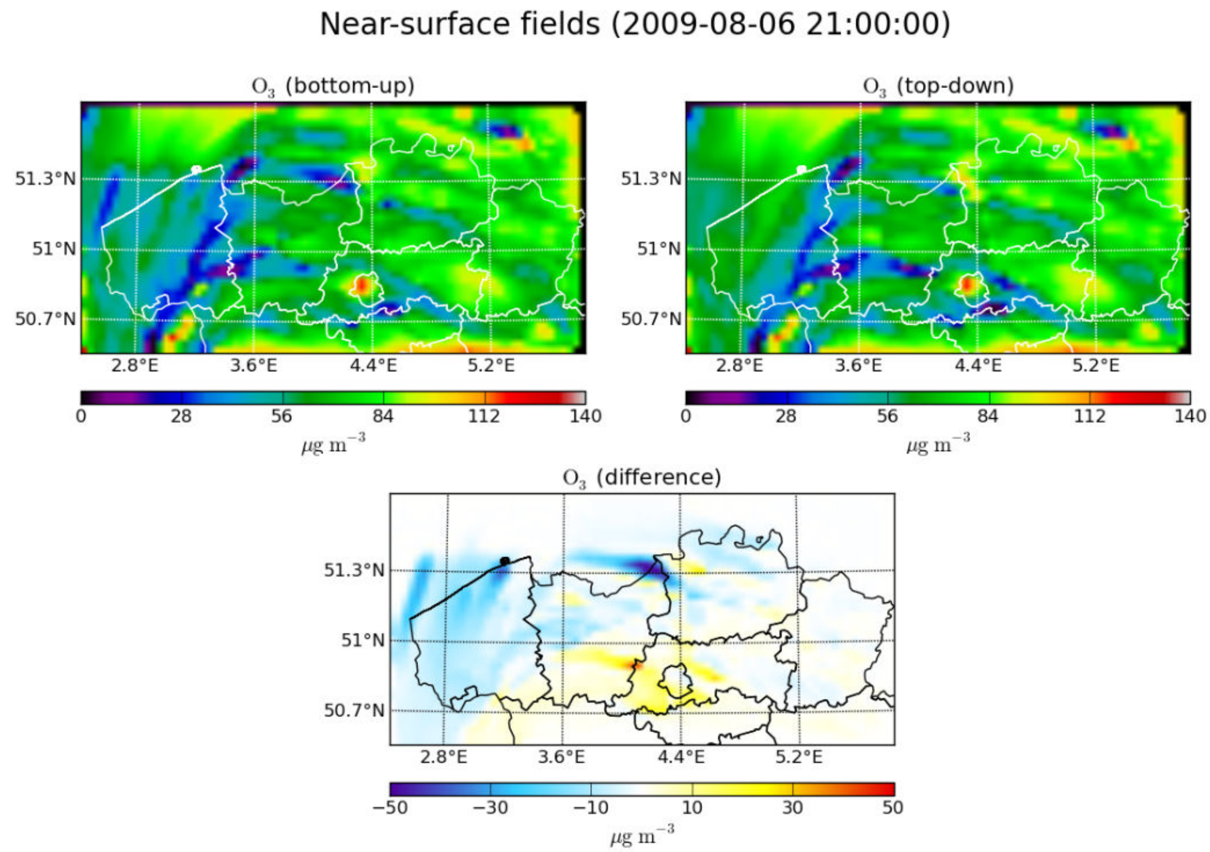
Sensitivity of the simulations on variation in emissions would be interesting, but would need to be assessed with more than just two runs of emission cases.

We agree with the reviewer that studying the sensitivity of the simulations on variation in emissions is an interesting research topic. However, executing (a lot of) extra sensitivity experiments for 10-year periods at this high resolution is beyond the means and scope of our project.

In our institute, we do however work on this topic in a related research project, coordinated by Dr. Hendrik Wouters. Some preliminary results of his work (of which a publication is in preparation) can give some insight in the sensitivity of our model. He compared our standard top-down approach (described above) with a bottom-up emission inventory that exists for the region of Flanders (Belgium). The Figure below shows the comparison of both data sets for a model grid of 1 km resolution. Clearly, there are large differences between both data sets, also in the location of the sources.



Afterwards, he performed short-term modelling experiments with the AURORA model to assess the sensitivity of modelled near-surface O_3 concentrations to these different emissions. The Figure below shows the resulting concentrations and their differences at the moment when these are largest (during the late evening). Even at this time, the area-mean amounts and overall pattern are not very sensitive to the applied changes. Locally, the effects can be large of course (e.g. when a large point source is missing or located differently). During the day, the differences are found to be much smaller.



With these results in mind, we are strengthened in our confidence that the overall outcome and storyline of our study is solid, and little sensitive to reasonable variation in emissions.

The 10 yr period around 2030 is not reported to be coupled back with the reference period via a transient run, but the climate change signal from the ERA-Interim analysis over 2000-2009 was claimed similar to the RCP4.5 climate signal (including cfr to Table 2). A stronger justification would be welcomed.

In order to strengthen our case that the ERA-Interim and RCP4.5 climate signal are of comparable magnitude, we have added an extra figure to the manuscript (Figure 7), showing the histograms of the hourly area-mean 2 m temperatures and rainfall amounts for all scenarios. Together with the 10-year mean values that are compared in Table 2, it is clear that ERAINT and RCP4.5 have a similar shift towards higher temperatures and less small rainfall events compared to the reference scenario. Clearly, the climate change signal is not identical (e.g. there are slightly less heavy rainfall events in ERAINT), but both scenarios seem comparable enough to obtain our objective to get an estimate of the relative importance of the climate change effect alone. This point is also made more clear in the text (paragraph 1 of Section 3.4).

Finally, it is not clear how the land-use change assumed in RCP4.5 fits with the use of GLC2000 and the land-use/vegetation input of SPOT and CORINE (1994) to the regional climate model AURORA. It is highly desirable that this is also addressed in the paper.

The referee is correct that we did not take the assumed land-use changes in RCP4.5 into account in our study. We have indicated this in the text now (paragraph 1 of Section 2.3). Taking them into account would be a very difficult task, given the differences in resolution and land use data between both data sets. We opted to make the scenario runs consistent with the reference simulation by keeping the same emission patterns, using only the country totals from the RCP4.5 emissions and spreading them following the same approach (as is explained in Section 2.3). This makes the interpretation and comparison of all scenarios easier and more straightforward.

Anonymous Referee #2

The paper titled, "The effect of climate change and emission scenarios on ozone concentrations over Belgium: a high resolution model study for policy support" provides results from a series of numerical experiments at high resolution over the country of Belgium. The goal of the numerical experiments is to provide policy support on the impact of climate change on future year air quality, specifically ozone. Each experiment was a 10 year simulation in which the goal was to capture average conditions and not actual day to day changes. The scientific value of this paper is noteworthy because of the value of high resolution (3km) compared to 25km is explored. The results are consistent with our understanding of Ozone formation chemistry.

There are a number of minor points that the authors should consider which are noted below:

(1) Abstract, page 1762, lines 3-5: The second sentence could be worded better: "A high resolution (3km) modeling experiment is employed to provide guidance to policy makers about expected air quality changes in the near future (2026-2035)"

The sentence is adapted as suggested by the reviewer.

(2) Abstract, page 1762, Lines 19-21: The sentence is unclear and needs to be reworded

The sentence has been rewritten and is hopefully more clear now.

(3) Page 1762, line 23: "Belgium ranks among the areas in Europe with the highest levels of air pollution, failing . . ."

The sentence is adapted as suggested by the reviewer.

(4) Page 1762, Line 26: "As the effects of global climate change are increasingly being felt in Belgium, policy makers . . ."

The sentence is adapted as suggested by the reviewer.

(5) Page 1763, Line 8: recommend changing to "The study focuses on impacts in the near future (around 2030) since Belgian policy makers, stakeholders in this project, have indicated that this is more relevant than projections to more distance future (e.g. 2100) as is common practice in scientific literature."

The sentence is adapted as suggested by the reviewer.

(6) Page 1763, Line 18: Change "learn" to "teach"

The sentence is adapted as suggested by the reviewer.

(7) Page 1763, Line 24: Delete "possible"

The sentence is adapted as suggested by the reviewer.

(8) Page 1765, Line 7: Change "going towards" to "uses"

The sentence is adapted as suggested by the reviewer.

(9) Page 1766: Line 5. Please indicate the resolution of the SPOT VEGETATION and the CORINE datasets.

The SPOT VEGETATION images have a horizontal resolution of 1 km whereas the CORINE dataset has a resolution of 250 m. This is indicated in the text now.

(10) Page 1766, Line 26: Delete "that is applied"

The sentence is adapted as suggested by the reviewer.

(11) Page 1767, Line 10: Describe in more detail the implementation of the emission heights for the different sources since it was different than that given in the reference

The referee is correct that this information was missing in the manuscript. We would like to refer to a recent paper by van Noije et al. (2014), which tackles this issue: http://www.geosci-model-dev-discuss.net/7/1933/2014/gmdd-7-1933-2014.html. The reference is added to the manuscript (paragraph 4 of Section 2.1).

(12) Page 1768, Line 20: Indicate that the bilinear interpolation adds additional uncertainty to the experiments.

This is correct and is indicated in the text now.

References

Builtjes, P.J.H., van Loon, M., Schaap, M., Teeuwisse, S., Visschedijk, A.J.H. and Bloos, J.P. 2003. Project on the modelling and verification of ozone reduction strategies: contribution of TNO-MEP, TNO-report, MEP-R2003/166, Apeldoorn, The Netherlands.

Maes, J., Vliegen, J., Van de Vel, K., Janssen, S., Deutsch, F., De Ridder, K., and Mensink, C. 2009. Spatial surrogates for the disaggregation of CORINAIR emission inventories. Atmospheric Environment, 43, 1246–1254.

van Noije, T. P. C., Le Sager, P., Segers, A. J., van Velthoven, P. F. J., Krol, M. C., and Hazeleger, W.: Simulation of tropospheric chemistry and aerosols with the climate model EC-Earth, Geosci. Model Dev. Discuss., 7, 1933-2006, doi:10.5194/gmdd-7-1933-2014, 2014.