TNO Report

Description of current temporal emission patterns and sensitivity of predicted AQ for temporal emission patterns

EU FP7 MACC deliverable report D_D-EMIS_1.3

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Contents

Abstract For modeling purposes a set of temporal factors was constructed to breakdown annual total emissions into hourly emissions. The profiles are for aggregated source sectors according to the SNAP (Selected Nomenclature for Sources of Air Pollution) level 1. Most profiles show a sinusoidal curve and distinguish monthly, daily and hourly factors. For example the road transport sector temporal emission profile were based on long time series (1985-1998) of Dutch data registering the traffic intensity and include rush hour peaks as well as the weekend effect. For several combustion sources the temporal patterns were based on the work done in the GENEMIS project (Friedrich and Reis, 2004). The impact of applying the temporal emission profiles is visualized for various substances.

To test the sensitivity of predicted air quality for temporal profiles two model runs with the TNO Regional air quality model LOTOS-EUROS were done. The default or base run was done with the current temporal emission profiles. The second run had a flat temporal emission profile with no monthly, daily or hourly variation. This implies that every hour of the year has the same emission rate. The results show that the impact on annual average concentrations is visible but not extremely strong. At hot spots of anthropogenic emissions (e.g. major cities) the impact is strongest. It is also expected that the impact will be more important when looking at episodes within the year.

As a first exploration of the possibility of generating new updated time profiles, we have constructed new emission profiles for the power generation sector (SNAP 1) for the year 2008 using electricity load data from each country, assuming that electricity consumption and production are balanced (no storage) and neglecting the influence of electricity trade between countries. The impact of improved more accurate temporal profiles for this sector were limited mostly because power plants operate on a rather continuous basis.

The analysis shown in this report suggests that it is recommendable to first make educated guesses of what variation in temporal emission profiles by source sector for different countries could be expected. The range in indicative temporal variation could be used to do a sensitivity analysis with a regional air quality model to verify if the impact is significant enough to justify allocation of resources. First test cases to be explored, based on the insights of the present study, would be residential combustion, agriculture and road traffic rush hours.

Guidance to the reader

The emissions used in air quality models such as the TNO-MACC emission data for Europe (Kuenen et al., 2011) are based on yearly emission totals for every sector in each country. In air quality modelling these emissions are divided over the year using monthly, weekly and hourly time profiles to reflect real world variations in activities that cause emissions. However, the temporal profiles are a generalization, not regularly updated and not country specific. The aim of this MACC deliverable report is to present a representative set of currently used temporal profiles in European air quality modelling and illustrate its impact on emission timing (Chapter 1). Furthermore, the impact of applying such temporal profiles is explored in chapter 2 and a first example of updating and improving such temporal profiles is presented (chapter 3). The analysis and update of temporal profiles described here is a starting point for further work.

1. Currently used temporal emission profiles for predicting air quality

For modeling purposes a set of temporal factors was constructed for the LOTOS EUROS model to breakdown annual total emissions into hourly emissions (Schaap et al., 2005). The profiles are for aggregated source sectors according to the SNAP (Selected Nomenclature for Sources of Air Pollution) level 1. Most profiles show a sinusoidal curve and distinguish monthly, daily and hourly factors (Figure 1). For example the road transport sector temporal emission profile were based on long time series (1985-1998) of Dutch data registering the traffic intensity and include rush hour peaks as well as the weekend effect. For several combustion sources the temporal patterns were based on the work done in the GENEMIS project (Friedrich and Reis, 2004). The time factors are presented in detail in Appendix 1. Especially residential combustion (SNAP 2) and Agriculture (SNAP 10) show large monthly temporal variations. For residential combustion higher emissions are occurring in winter when more energy is used to heat houses and offices, while in agriculture winter emissions are generally smaller than summer emissions, but the peak in the emissions is occurring in the early spring. When the timing of emissions across the day is considered, the picture is different. Now the largest variations are observed for the road transport sector (rush hours) and again residential combustion (morning and evening), while the agricultural sector has a flat profile during the day. Note that in Figure 1 hour within the day is local time, since it represents features such as the rush hour. Information over the deviation from GMT is therefore collected for each country and stored in the model. Currently it is assumed that all countries have the shift from summer to wintertime and vice versa at the same days, i.e. the last Sunday of October and March, respectively.

The emission data that are used as input for the LOTOS-EUROS model are taken from the TNO-MACC emission inventory (Kuenen et al, 2011) which provides gridded annual anthropogenic emissions by source sector. The annual totals are divided over the year using the time factors shown in Figure 1 and Appendix 1. Application of the temporal profiles strongly influences anthropogenic emission releases during the year. This is illustrated by calculating as an example for three pollutants (NH_3, NO_x and PM2.5) the monthly, daily and hourly emission source strengths by source sector as shown in Figure 2, Figure 3, Figure 4, respectively.

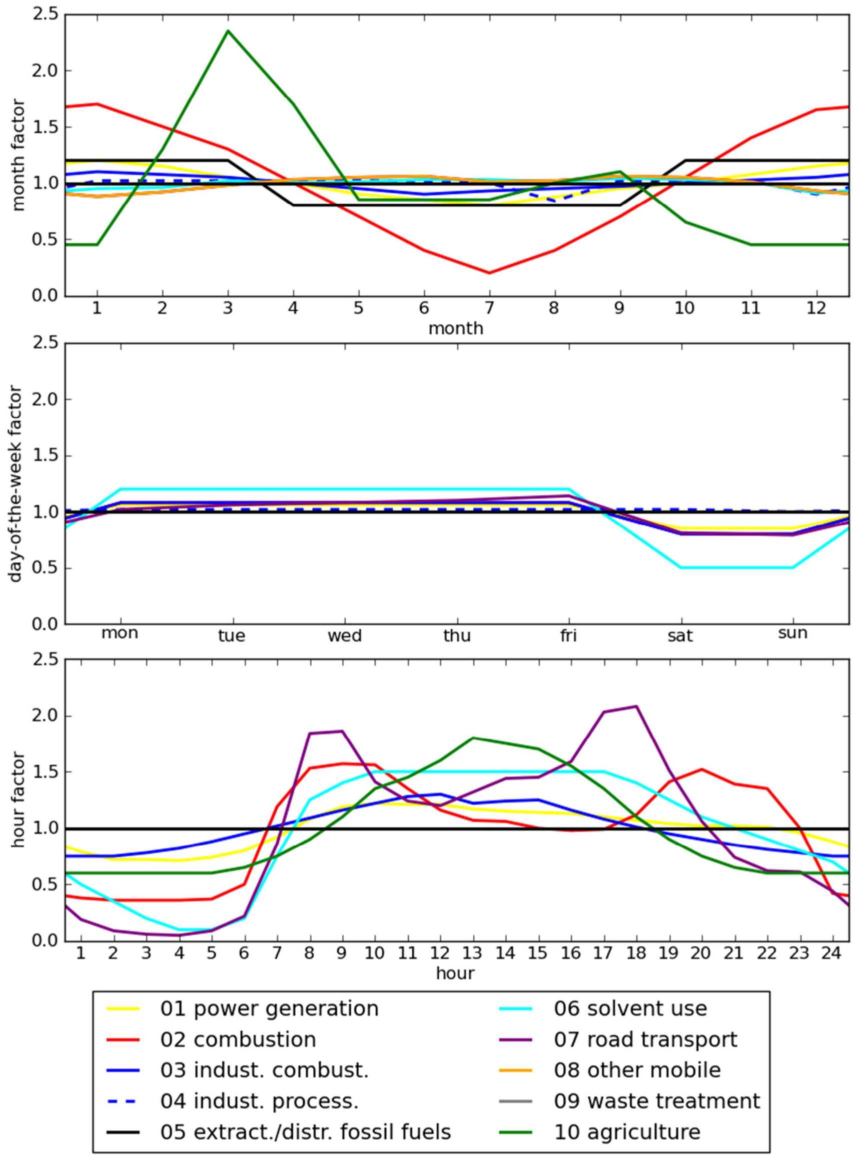


Figure 1 Time profiles applied to anthropogenic emissions

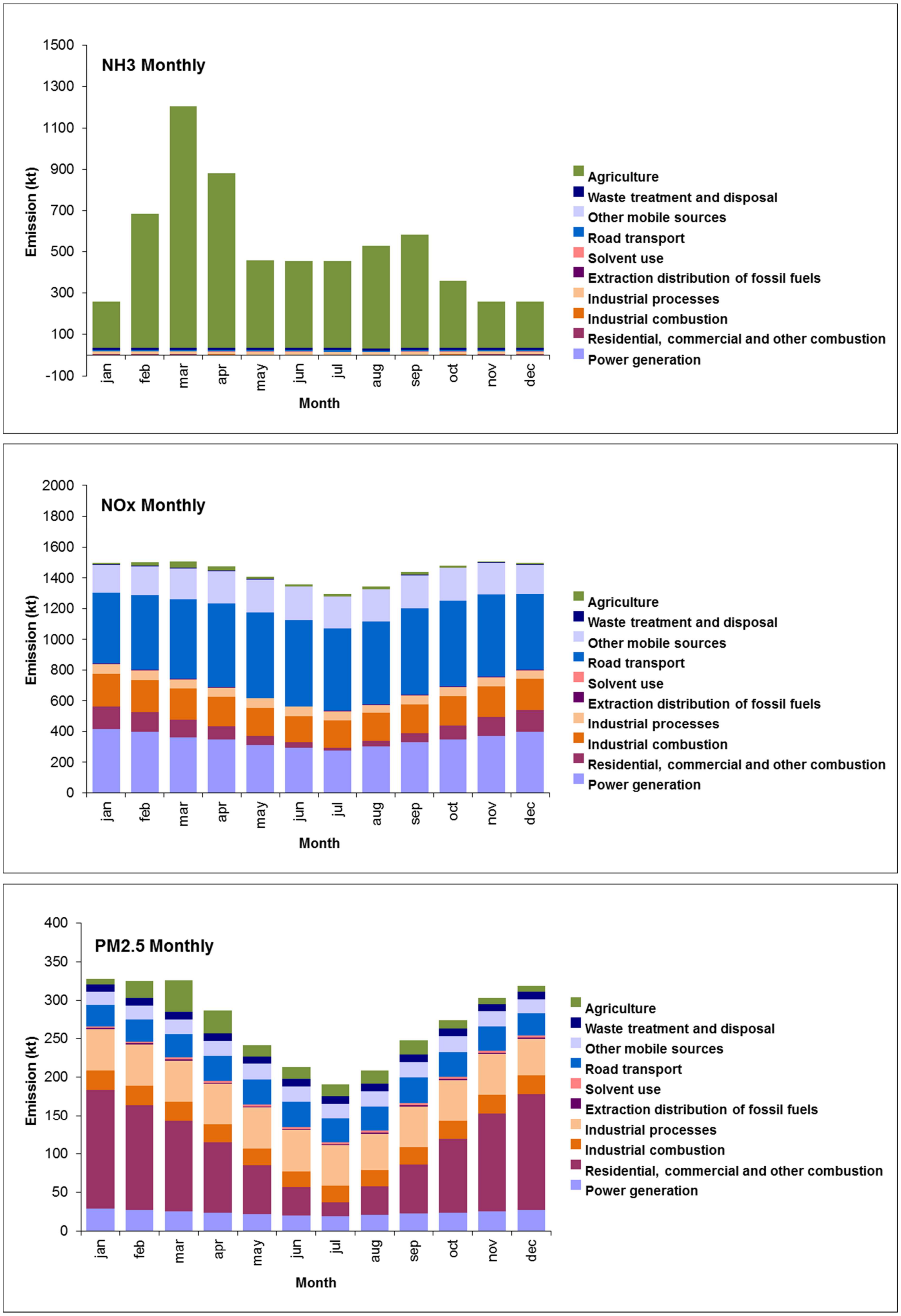


Figure 2 Example of monthly European emission source strengths for NH_3, NO_x and PM2.5

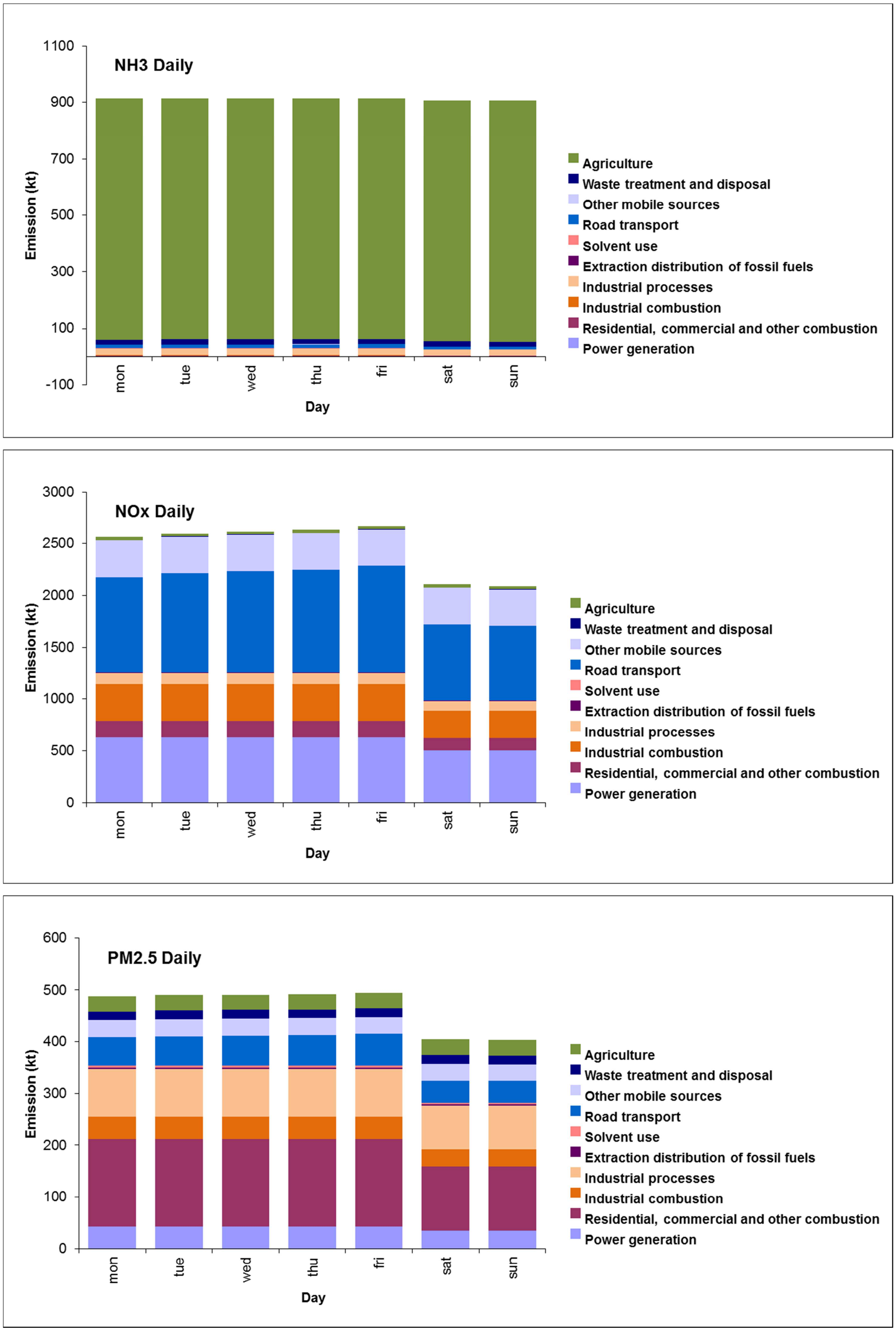


Figure 3 Example of daily European emission source strengths for NH_3, NO_x and PM2.5

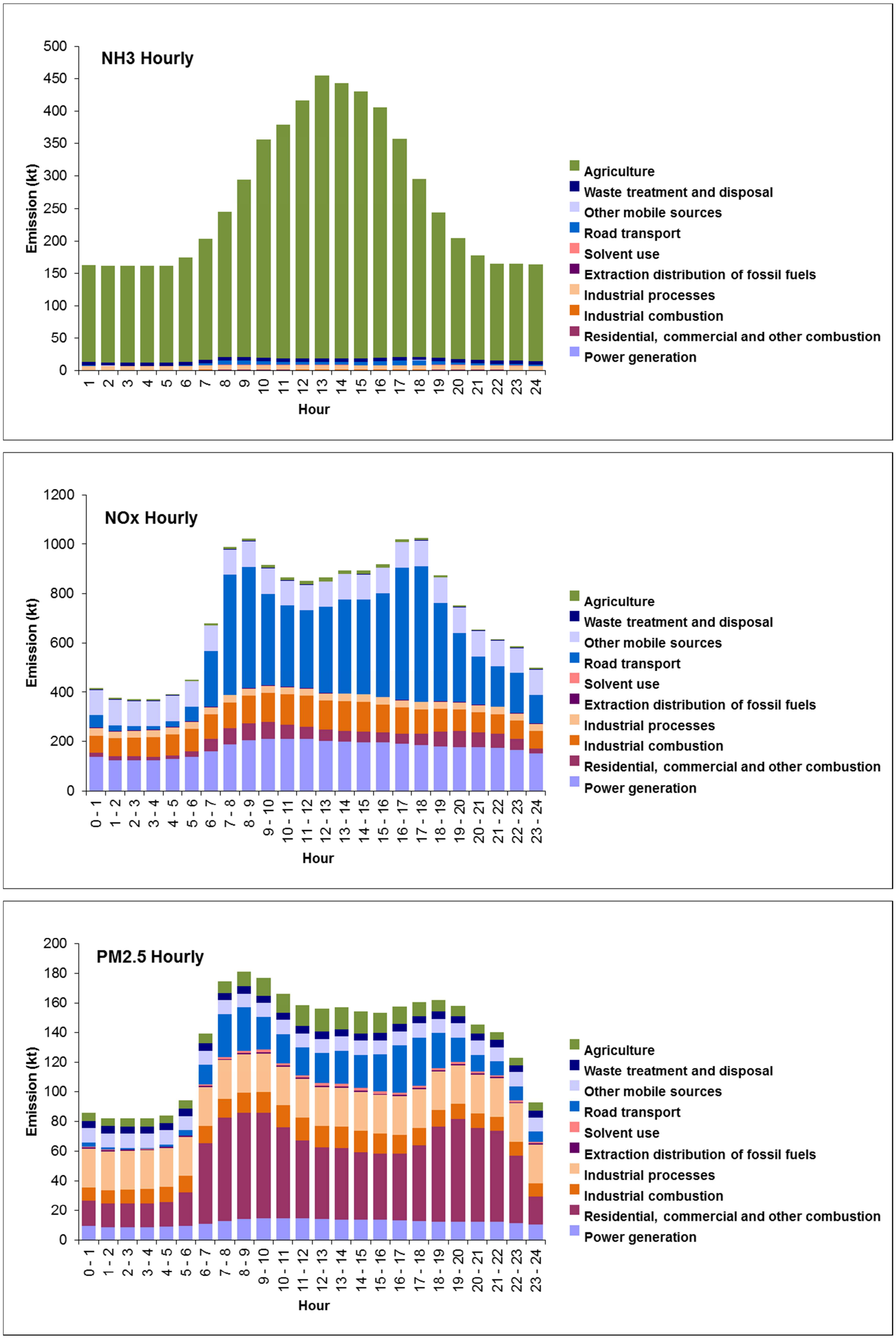


Figure 4 Example of hourly European emission source strengths for NH_3, NO_x and PM2.5

2. The sensitivity of model-predicted air quality for temporal emission profiles.

The emission data that are used as input for the LOTOS-EUROS are taken from the gridded yearly averaged anthropogenic emission database (Figure 1). For NH3 the standard time profiles as described in chapter 1 were ignored and replaced by the monthly and hour profiles shown in Figure 5. The shape of the profiles is rather similar to those used by default for 'agriculture' category, but better reflects the time dependencies for NH3.

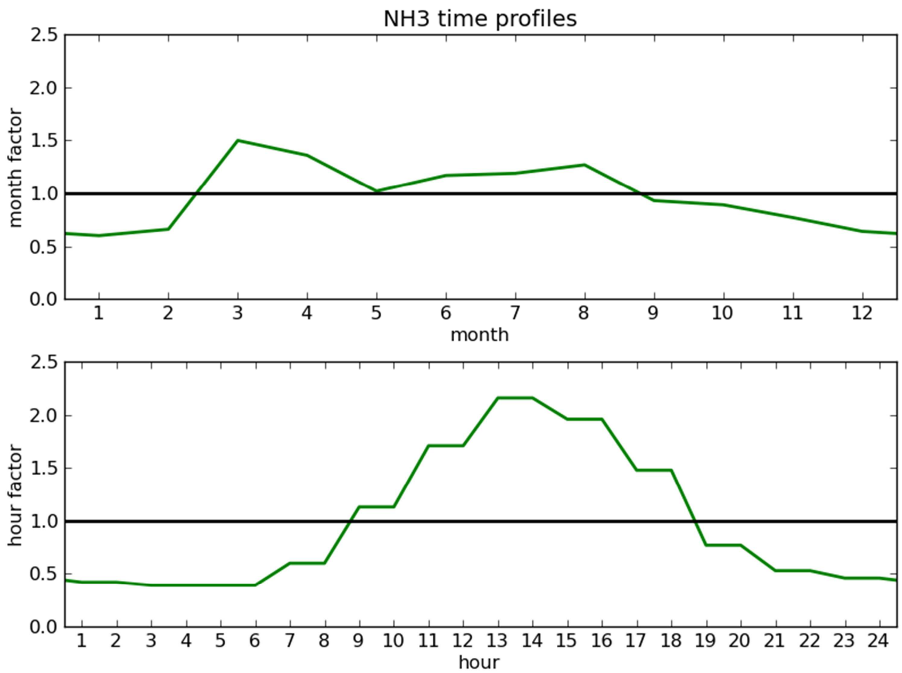


Figure 5 Time profiles applied to NH_3 emissions

To test the impact of these time profiles, a set of simulations was performed for the year 2006: one simulation using the time profiles as described above and another in which no time profiles were used. In this second simulation, the yearly emission is divided equally over each hour in the year.

Impact on annual average predicted concentrations

The difference in annual average ozone and ammonia concentrations for the two simulations is displayed in Figure 6. For ozone, the omission of time profiles causes a decrease in annual average concentration of 0-0.5 µg/m3 for west and central Europe, with decreases of 2 µg/m3 (around 10%) over polluted areas like the Netherlands. Over hot spots like Madrid and Paris, the difference can be up to 4 µg/m3. For ammonia, a significant increase in concentrations is observed for locations with high ammonia emissions, most notably the Po Valley and the Benelux. For total PM_{10}, displayed in Figure 7, a small increase is seen for the whole domain except Northern Europe.

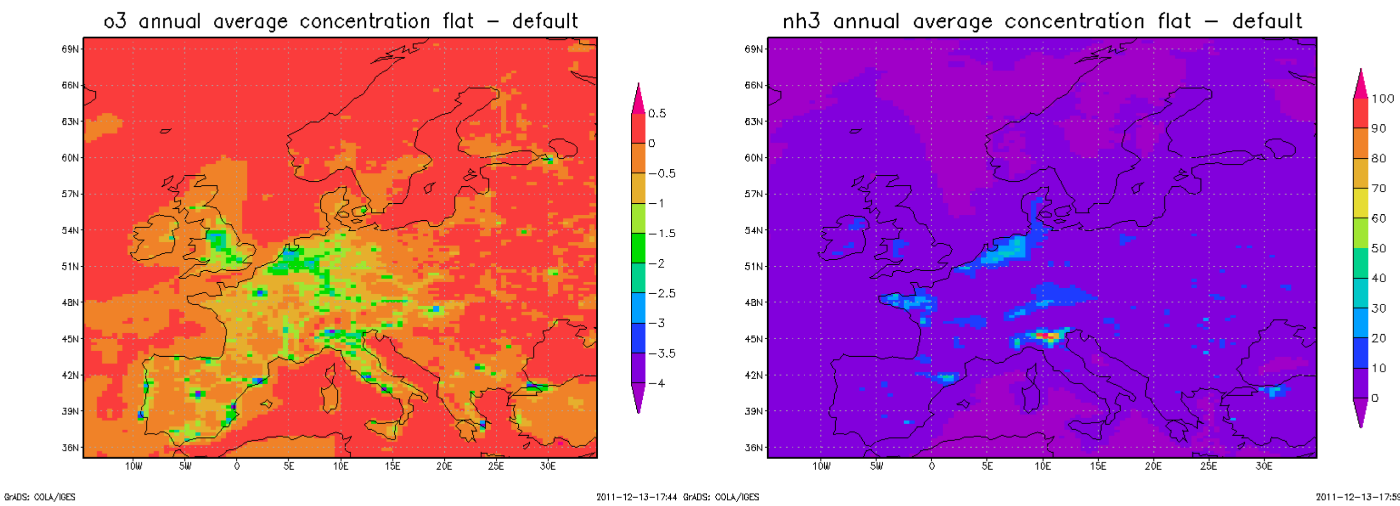


Figure 6 Average annual concentration difference for ozone (µg/m3; left) and ammonia (%; right)

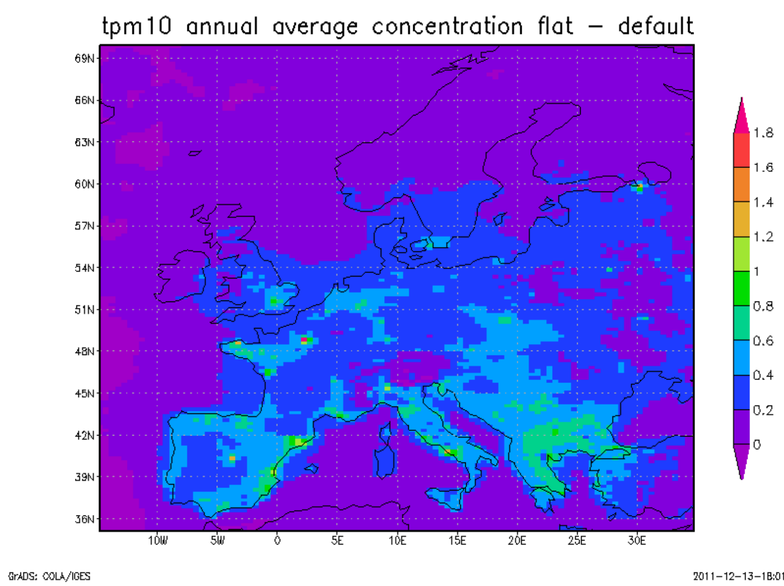
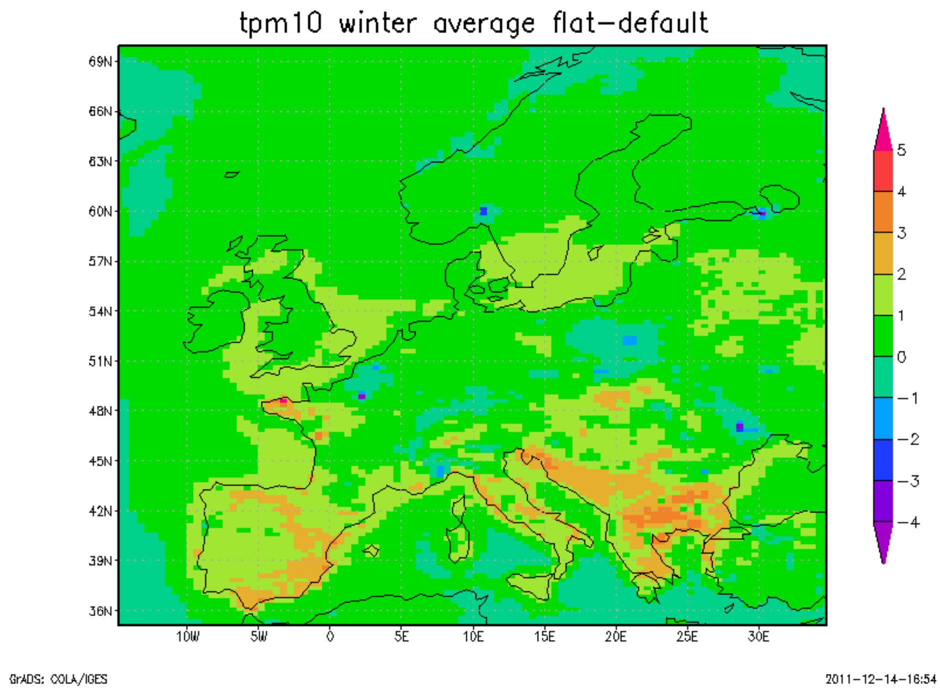


Figure 7 Average annual concentration difference for total PM10

Impact on seasonal average predicted concentrations

The impact of using a temporal time profile on predicted annual total PM10 appears rather small (Figure 7). However, this is partly because variations within the year are averaged out. If we look at discrepancies between particular seasons, the impact is larger (Figure 8). It can be seen that for example residential combustion is one of the key sources where the temporal profiles have an impact on predicted concentrations. For example, for the Paris region it can be seen that with a flat temporal profile predicted concentrations decrease with 3-5 µg/m3 and increase in summer with over 6 µg/m3.



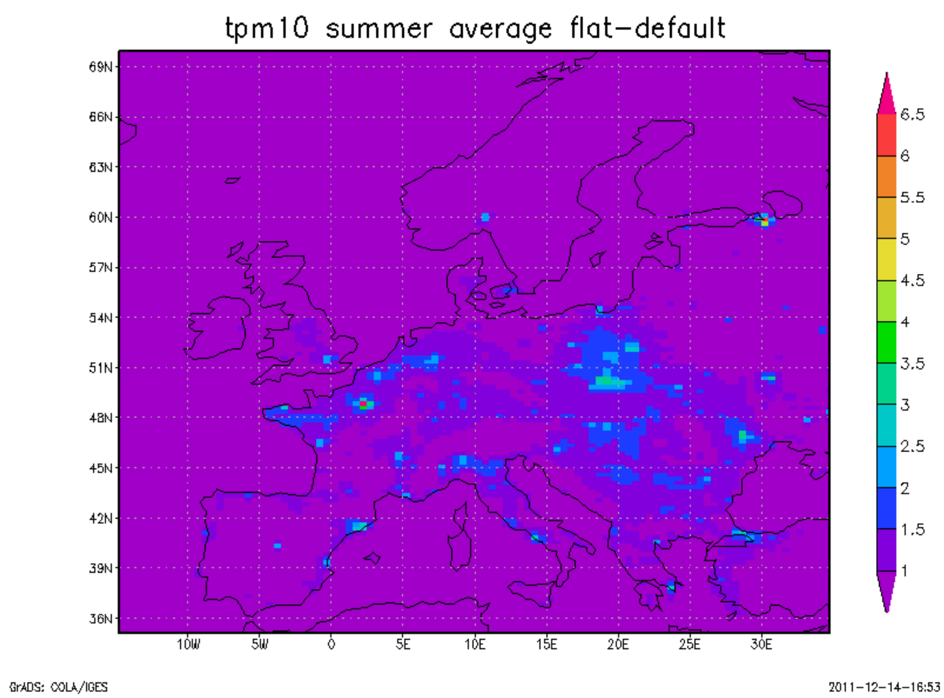


Figure 8 Average concentration difference for PM10 in winter (top) and summer (bottom)

Impact on daily average predicted concentrations

In the previous sections, the focus was on annual average or seasonal variations. The impact of the flat time profile versus the default temporal profile (Figure 5) was also preliminary investigated for time series of modeled ammonia concentrations for Ispra (Italy, 45.8N 8.63E) and Bilthoven (the Netherlands, 52.12N 5.2E) during the spring of 2006. These figures show that the temporal pattern is changed quite a lot when the time profile of the emissions is omitted. The peak values are lower if no time profiles are used. In the time profiles, ammonia emissions are relatively high in spring; this effect is of course not taken into account in the simulation without time profiles.

The impact on ozone concentrations is smaller than for the primary NH_3, but still some changes can be observed. In Ispra and especially Bilthoven, the modeled ozone concentrations during the night are lower for the flat time profile. For $TPM_{10,}$ no large differences are observed.

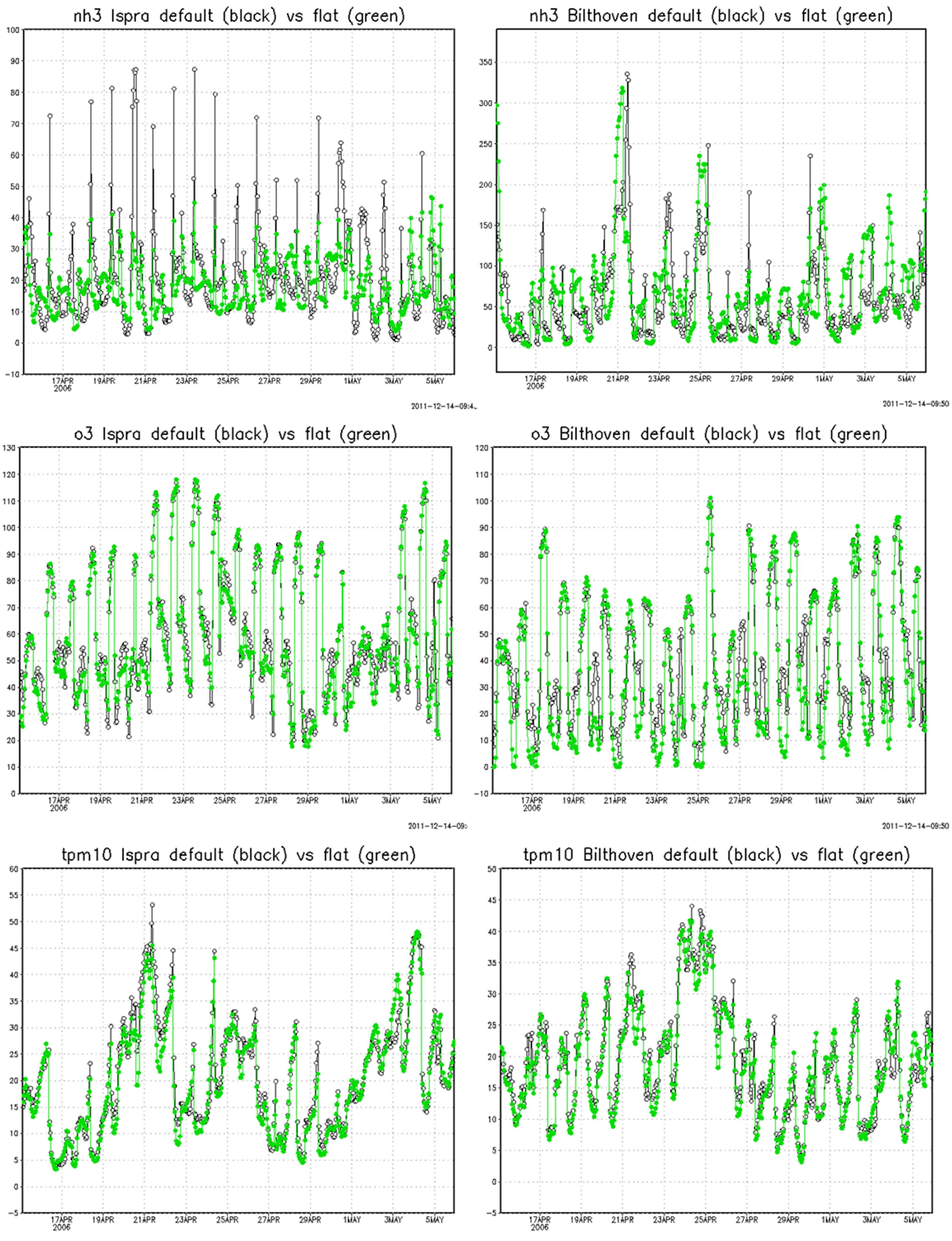


Figure 9 Hourly predicted concentrations for Ispra, Italy (left) and Bilthoven, Netherlands (right) during spring 2006 for NH3 (top), O3 (middle) and PM10 (bottom).

3. improvement of emission time profiles – a case study for power generation sector

Emission from power plants are driven by electricity consumption which may vary between seasons, weekday-weekend and day-night. The currently used time profiles (see chapter 1) are different for each SNAP level 1 source category but the same for all countries. This may not be the best representation of reality, since e.g.:

- climate conditions may cause differences in time profiles for countries across Europe;
- variations in the emissions due to changes in meteorology during the year are not represented (e.g. during cold periods more energy is used).

This chapter briefly describes a more in-depth analysis of improved time profiles for one category (electricity generation sector).

As a first exploration of the importance of time profiles, we have constructed new emission profiles for the power generation sector (SNAP 1) for the year 2008 using electricity load data from each country, assuming that electricity consumption and production are balanced (no storage) and neglecting the influence of electricity trade between countries. The most pronounced differences between the new and the old time profiles were found in the monthly (seasonal) variation, especially in southern Europe. It turns out that here the emissions from power generation are more evenly spread over the year than is reflected in the uniform time profiles currently used (Figure 1),which have a marked dip in emissions over the summer period. To illustrate this, the relative month-to-month variation of the electricity is shown in Figure 10. While for Scandinavian countries a clear summer minimum is found (difference between summer and winter up to a factor of 2), this is much less pronounced for Southern European countries where differences are smaller and a summer maximum is even found for Italy and Greece. The latter is probably due to the extensive use of air conditioners during this period, while due to the mild winter heating systems are often not necessary.

To test these new time profiles for the power generation sector (SNAP 1), model runs were performed using LOTOS-EUROS version 1.7.2. Various types of runs were done using the meteorology for the year 2008 and using MACC emissions for 2005 (as 2008 was not available), overlaid with different time profiles. Two model runs are further used here:

1. A base run, using the standard uniform time profiles (no difference between countries); this run is referred to as ‘run 1’;
2. A run with new time profiles for the power generation sector, keeping the time profiles for all other sectors the same, on an hourly basis (‘run 2’);

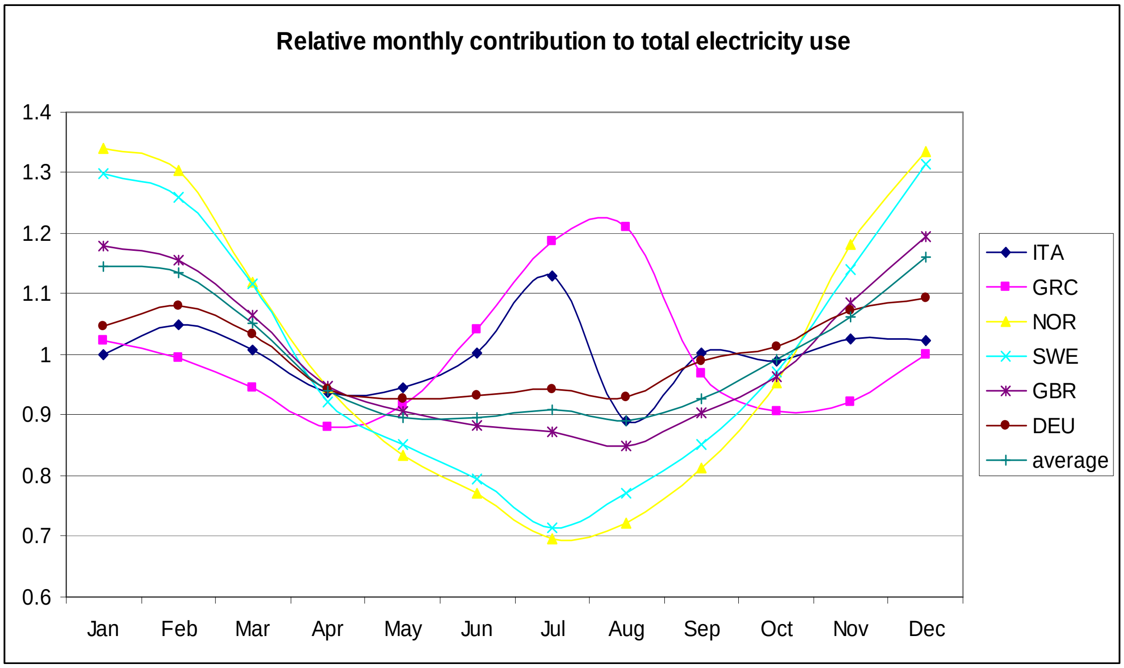


Figure 10 : Seasonal pattern for different countries compared to the European average

Figure 11 (left panel) displays the difference in NO_2 concentrations in the summer period (July and August) between runs 1 and 2. This shows that in summer, concentrations in Northern Spain and (less prominently) the Ruhr area are higher. Especially Northern Spain is an area with many power stations for which the emission time profile differs the most between runs 1 and 2, with higher emissions in summer (see figure 1). This is reflected in the modelled atmospheric concentrations. Figure 11 (right panel) shows this trend is much stronger in modelled SO_2 concentrations. Eastern Europe also shows markedly higher SO_2 concentrations using the updated emission time profiles, which is not reflected in the NO_2 concentrations. A reason for this might be that in Eastern Europe, many power stations still run on coal and lignite, fuels which could still have a high sulphur content. Therefore, the response of atmospheric SO_2 concentrations to a change in emission time profiles is stronger. Note the emission totals were for the year 2005, hence major changes in SO2 emissions from power plants in Spain as achieved in the period 2008-2010 are not accounted for.

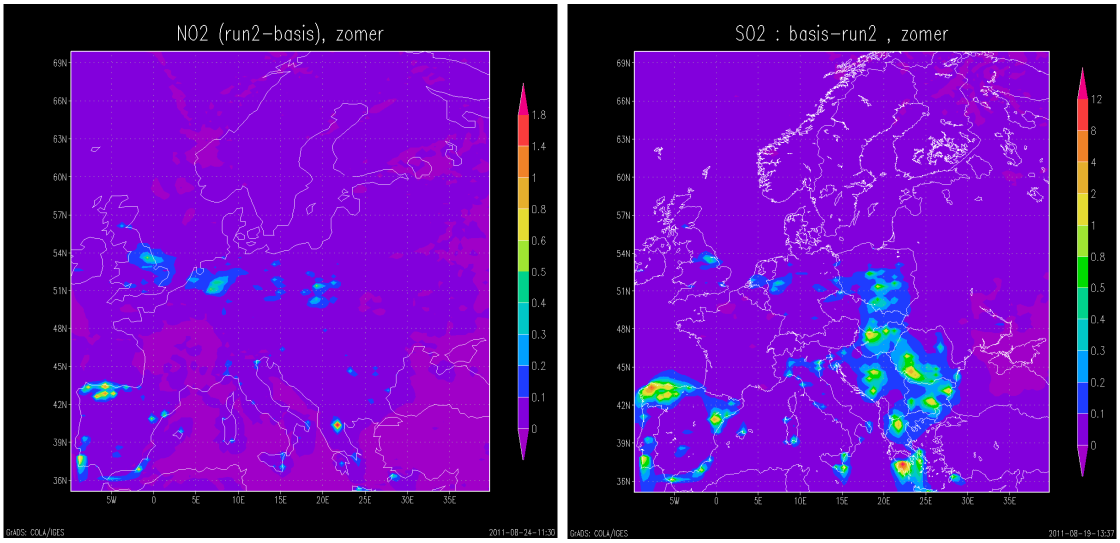


Figure 11 Difference in modelled NO_2 (left) and SO_2 (right) concentrations in summer between model runs using the updated emission time profiles and the original ones. Emission totals as for 2005.

While the updated time profiles do show a difference in modelled concentrations for some of the measurement stations considered, the overall performance of LOTOS-EUROS does not change significantly. No differences were observed between the hourly and monthly updated time profiles, or between the ‘base’ profiles and constant emissions throughout the year. This suggests that for most locations, power generation is not a very important time-dependent emission source. The contribution of power stations to the background concentrations of NO_2, SO_2 and O_3 is of course less time-dependent than the concentrations near power stations.
Although the statistics do not show an improvement of the modelled concentrations, the time series of some selected stations do show a clear effect of using the updated time profiles: in summer, SO_2 and NO_2 concentrations are higher, in winter they are slightly lower. This is not always reflected in a better correlation with observations, because at these locations, all runs deviate from the observations so much that a small change in modelled concentrations does not change the statistics. Especially in the summer period, correlation of NO_2 and SO_2 modelled concentrations with observations is low.
Even though the use of new time profiles for the power sector does not yield overall better correlation between model results and observations, it is an improvement to the previous situation in the sense that the new time profiles better reflect the real emissions.

4. Conclusions and outlook

Temporal emission profiles are important additional tools to properly distribute emissions over time for air quality modelling. The importance however differs much by source sector. Some source sectors operate on a more or less continuous basis – in such cases a more accurate temporal profile will only give minor improvements in the representation of emissions. This is illustrated by a case study for SNAP 1 (energy generation) which shows that the use of actual, more accurate time profiles of electricity generation does not have too much impact on the results. This is expected since the electricity generation sector is not so variable as some other sectors.

The impact of temporal emission profiles when we look at annual average concentrations over Europe is limited but especially near anthropogenic hot spots (major cities, urbanized regions) it may be substantial. Furthermore it is expected that when we zoom in on episodes the impact may be larger but this has not been fully explored yet. Another important notion is that by keeping all temporal profiles “flat”, one source sector may partly compensates another. The overall annual average is than not much influenced but source attribution becomes significantly less accurate.

In a follow-up of this study a more detailed comparison of the model runs with observational data is needed because the correlation over time between modeled and predicted might become substantially less as was suggested by the preliminary data for two sites in this study.

The analysis shown in this report suggests that it is recommendable to first make educated guesses of what variation in temporal emission profiles by source sector for different countries could be expected. The range in indicative temporal variation could be used to do a sensitivity analysis with a regional air quality model to verify if the impact is significant enough to justify allocation of resources. First test cases would be residential combustion, agriculture and road traffic rush hours.

Future improvements could come from replacing default profiles used in the models to meteorologically driven functions. Especially for e.g. residential combustion and agriculture large variations are observed between the different seasons which could depend strongly on the actual meteorology. For example if colder temperatures as a start of winter start relatively late or early in a year. This will be further investigated.

References

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Appendix 1 Temporal profiles used in LOTOS EUROS

The profiles presented here are partly based on published studies and further modified or gap-filled with TNO expert estimates in the past to support the LOTOS-EUROS model. It should be noted that no recent review has been performed and profiles may be outdated or not universally applicable.

Monthly variation

SNAP	Month (J, F, M, A, M, J, J, A, S, N, D)
01	1.2/1.15/1.05/1/0.9/0.85/0.8/0.875/0.95/1/1.075/1.15[1,5]
02	1.7/1.5/1.3/1/0.7/0.4/0.2/0.4/0.7/1.05/1.4/1.65[1,5]
03[2]	1.1/1.075/1.05/1/0.95/0.9/0.93/0.95/0.97/1/1.025/1.05[1,5]
04	1.02/1.02/1.02/1.02/1.02/1.02/1/0.9/1.02/1.02/1.02[3]
05	1.2/1.2/1.2/0.8/0.8/0.8/0.8/0.8/0.8/1.2/1.2/1.2 [5]
06	0.95/0.96/1.02/1/1.01/1.03/1.03/1.01/1.04/1.03/1.01/0.91 [5]
07	0.88/0.92/0.98/1.03/1.05/1.06/1.01/1.02/1.06/1.05/1.01/0.93[4]
08	0.88/0.92/0.98/1.03/1.05/1.06/1.01/1.02/1.06/1.05/1.01/0.93[4]
09	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

[1]) overall fuel use; the variation is mainly due to gaseous fuel use and not solid fuel use

[2]) mainly industrial combustion

[3]) depends on culture; differs per continent and group of countries; based on the iron and steel industry for the EU 0.98/1.04/1.05/1.04/1.06/1.05/0.97/0.88/1.01/1.04/1.01/0.87 can be used (within the EU large variations exist), for the former U.S.S.R. 0.95/0.98/0.99/1.01/1.03/1.01/ 1.01/0.99/0.99/1.00/1.01/1.02 and for other Europe 0.95/1.00/1.02/1.01/1.05/1.04/1.04/1.00/ 1.00/0.97/0.97/0.93 (large variations exist)

[4]) based on Dutch data (1985-1998); quarterly data for the UK and USA show a flatter profile, data for Schleswig-Holstein are comparable with the Dutch data (a bit more traffic in the third and less in the forth quarter)

[5]) profiles based Veldt 1991;1992, GENEMIS (Friedrich and Reis, 2004) and own interpretation of measured data http://genemis.ier.uni-stuttgart.de/

Weekly variation

SNAP	Mo/Tu/We/Th/Fr/Sa/Su
01	1.06/1.06/1.06/1.06/1.06/0.85/0.85
02	1.08/1.08/1.08/1.08/1.08/0.8/0.8
03	1.08/1.08/1.08/1.08/1.08/0.8/0.8
04	1.02/1.02/1.02/1.02/1.02/1.02/0.88[1,2]
05	1/1/1/1/1/1/1
06	1.2/1.2/1.2/1.2/1.2/0.5/0.5
07	1.02/1.06/1.08/1.10/1.14/0.81/0.79[2]
08	1/1/1/1/1/1/1[2]
09	1/1/1/1/1/1/1
10	1/1/1/1/1/1/1

[1]) depends on type of industry: the metallurgic and chemical industry operate continuously and the food and beverage industry operate only on weekdays; average is flat profile, 1/1/1/1/1/1/1

[2]) Expert estimate Emission Registration, the Netherlands (personal communication, 1995)

Hourly variation

Category	Hour
01	0.79/0.72/0.72/0.71/0.74/0.80/0.92/1.08/1.19/1.22/1.21/1.21/1.17/1.15/1.14/1.13/1.1/1.07/1.04/1.02/1.02/1.01/0.96/0.88[5]
02	0.38/0.36/0.36/0.36/0.37/0.5/1.19/1.53/1.57/1.56/1.35/1.16/1.07/1.06/1.0/0.98/0.99/1.12/1.41/1.52/1.39/1.35/1.0/0.42[1,5]
03	0.75/0.75/0.78/0.82/0.88/0.95/1.02/1.09/1.16/1.22/1.28/1.30/1.22/1.24/1.25/1.16/1.08/1.01/0.95/0.9/0.85/0.81/0.78/0.75[5]
04	1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1
05	1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1
06	0.5/0.35/0.2/0.1/0.1/0.2/0.75/1.25/1.4/1.5/1.5/1.5/1.5/1.5/1.5/1.5/1.5/1.4/1.25/1.1/1.0/0.9/0.8/0.7[2]
07	0.19/0.09/0.06/0.05/0.09/0.22/0.86/1.84/1.86/1.41/1.24/1.20/1.32/1.44/1.45/1.59/2.03/2.08/1.51/1.06/0.74/0.62/0.61/0.44[3]
08	1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1/1[3]
09	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	0.6/0.6/0.6/0.6/0.6/0.65/0.75/0.9/1.1/1.35/1.45/1.6/1.65/1.75/1.7/1.55/1.35/1.1/0.9/0.75/0.65/0.6/0.6/0.6[4]

[1]) biofuel consumption is predominantly used for cooking, so its hourly variation should follow the cultural eating practices of the countries (breakfast, lunch and dinner)

[2]) own estimation based on working practices

[3])Expert estimate Emission Registration, the Netherlands (personal communication, 1995) Schleswig-Holstein shows a busier evening rush hour and less traffic in the evening

[4]) Asman (1992)

[5]) based on GENEMIS (Friedrich and Reiss, 2004) and own interpretation of measured data