ANNEX to Deliverable 6.1:
Overview of initial dynamic biogenic and anthropogenic emission data available to ECLAIRE

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This is the former deliverable on dynamic biogenic emissions data. It now includes information on anthropogenic emissions inventories, since during project discussions it was deemed useful to have all information on emissions from both sources included in a single document.

A) Background

Emissions of air pollutants and their precursors are vital input data for atmospheric chemistry transport models (ACTMs). Accurate emissions originating from both biogenic and natural sources, and anthropogenic activities need to be available for current years and future scenarios in ECLAIRE to determine the effect of changes in emissions on modelled atmospheric concentrations and deposition values.

The challenges for selecting the most appropriate set of emission data for the ECLAIRE modelling tasks are:
Consistency:

- across spatial scales: Emissions used for modelling at global/hemispheric, regional/European, national and local/ landscape scale need to be consistent to allow for comparison and interpretation of model results across scales;
- over time: To model the effect of climate change and future scenarios, emission data used in models need to be consistent with the assumptions underlying climate change scenarios, e.g. on power generation systems, fossil fuel use and agricultural production, as well as land-use and land-cover change;

Completeness:

- Gaps, e.g. in officially reported emission datasets, often limit their usefulness for modelling;
- National or regional inventories which are not available for other regions result in differences that impact on the comparability between model results on different spatial scales.

Structure & contents:

- Most emission inventories are generated based on reporting requirements for political/regulatory purposes, with structures that are not immediately accessible for current models;
- Definitions of substances and units (e.g. NH_3 or NH_3-N, NMVOCs, PM) need to match those used in models to avoid errors and inconsistent results.

The core objective of deliverable D6.1 was to collect information on currently existing emission data, available from ECLAIRE partners, that could be used for setting up test runs of ACTMs to establish protocols for file transfer, file format etc. The following text briefly describes some of the main features of these emission products. An overview of these data sources, including contact details for the data providers, is also available to ECLAIRE partners in table format via the website.

B) Biogenic emissions

Biogenic and natural emissions for use within ACTMs can be calculated on-line or off-line, or can be provided to the ACTM from an existing inventory. Most of the inventories of anthropogenic emissions described later also contain emissions data for biogenic and natural emissions.

It is preferable for biogenic and natural emissions to be calculated on-line within ACTMs. This ensures internal consistency: the emissions are, for example, driven with the same meteorological data as the subsequent atmospheric chemistry. However, parameterisation of the land surface and vegetation is often crude within ACTMs and biogenic emissions are strongly dependent on vegetation distribution and characteristics, and how these respond to changing environment.

Hence, biogenic emissions are now also increasingly provided from off-line calculations in dynamic global vegetation models (DGVMs) that have process descriptions for bVOC emissions and coupled C-N cycles. They have the potential advantage that emissions are not only a direct function of climate, but also of atmospheric CO_2 concentration, interactions with vegetation, N-deposition and/or O_3 toxic effects which cannot be represented within ACTMs. Model representations of such effects are under development within ECLAIRE and future projections can be expected to be quite different from a climate-only driven approach. Such offline simulations require meteorological driving data and atmospheric concentrations of relevant gases (CO_2 and O_3 in particular), as well as deposition rates (for N and O_3) that are consistent with the atmospheric models.

Alternatively, off-line biogenic emissions can be generated from stand-alone algorithms (see below), using the same meteorological input data driving the ACTM itself. This is, however, only feasible if the meteorology is generated off-line prior to the ACTM chemistry calculations, as is the case for the EMEP and EMEP4UK models. This method has the disadvantage that it is not fully consistent with either the ACTM or the land surface, and also lacks the capability of capturing the dynamic interactions between the land surface and the atmosphere.

1. bVOC emissions

(a) Emissions models: There are currently two approaches to modelling trace gas emissions from the terrestrial biosphere: empirical and process-based. The former is more widely used, as the algorithms can be easily applied off-line or incorporated into ACTMs; the latter requires the use of a DGVM as the model is intrinsically linked to photosynthesis and physiology.

MEGAN (Model of Emissions of Gases and Aerosols from Nature [1]) is essentially an empirical model for estimating emissions of VOCs (mainly the terpenoids: isoprene, monoterpenes and sesquiterpenes) from vegetation, although it has its foundations in the link between terpenoid synthesis and electron transport during photosynthesis and terpenoid synthase. The original model [2] included simple algorithms for calculating emissions of isoprene and a single generic monoterpene; the latter could also be applied to other VOCs as it takes the form of a simple temperature dependency. These algorithms were refined to account for the influence of other environmental factors that had been observed to affect emission rates [1]; and have now been developed into a model that is capable of providing estimates of the emissions of over 140 different trace gases [3]. It should be noted that most of these estimates are poorly constrained, and ACTMs generally only include the chemical mechanisms for the atmospheric reactions of a handful of these compounds (most commonly isoprene, and the monoterpenes α-pinene, β-pinene and 'other', and possibly a generic sesquiterpene).

The MEGAN algorithms [1] have been developed into the BVOCEM model which is run off-line to provide emissions estimates for the LMDZ or other ACTMs. The original algorithms[2] on which the MEGAN model was based are used to generate on-line emissions in the ORCHIDEE DGVM [4,5] which can be coupled with the LMDZ ACTM (Partner CNRS; see below). CLM4 (Partner JRC; see below) also implements the MEGAN [1,2] algorithms to estimate emissions of isoprene, monoterpenes and "other VOCs".

While a number of process-based models have been developed (see Arneth et al. (2008) [6] for an overview), only one has been incorporated into a global model. The Niinemets model [7] explicitly links isoprene synthesis and emissions with photosynthetic activity and electron transport. It forms the basis of the bVOC emissions module within the LPJ-GUESS DGVM (partner ULUND, now moved to KIT-1) [6]. LPJ-GUESS also incorporates a process-based model of monoterpene synthesis, storage and emission[8].

The three main models (MEGAN, BVOCEM and LPJ-GUESS) have participated in an intercomparison study [9] and estimates from each have been evaluated against observations. The uncertainties involved in estimating emissions of bVOCs have been shown to be substantial.

(b) Drivers of emissions: The synthesis of terpenoid compounds within plant structures and organs is linked to photosynthesis, and the competition for electrons and nutrients for synthase compounds. Emissions of isoprene and other terpenes are thus strongly dependent on the key drivers of photosynthesis: light and temperature, although storage of some terpenoids effectively de-couples the synthesis and emission of these compounds. Emission rate, and indeed the mix of compounds emitted, are species-dependent, although in a non-predictable way. Vegetation distribution is therefore a key driver of bVOC emissions. In addition, leaf age and canopy structure are well known to affect emission rates.

Both biotic and abiotic stresses alter emissions. Some compounds (e.g. methyl jasmonate and methyl salicylate) are in fact only emitted as the result of environmental stresses, while others may be emitted in greater or lesser quantities from plants subject to, for example, water stress, insect attack or mechanical wounding. While a very basic parameterisation of the effect of drought on isoprene emissions is included in most models, other stresses are not.

Finally, the atmospheric concentrations of key trace gases (CO_2 and O_3) have been shown to affect the emission rate of certain bVOCs. High mixing ratios of CO_2 inhibit isoprene production and emission to such an extent that model simulations project decreases in isoprene emissions over the course of the 21st Century, in spite of increasing temperatures and primary productivity. All three models described above (LPPJ-GUESS, ORCHIDEE and CLM4) include this effect. Odd oxygen (O and O_3) are powerful oxidants that damage plant cells. Increasing atmospheric levels of O_3 can therefore be expected to reduce the productivity of the biosphere. However, the impact is highly dependent on the uptake of O_3 into plant tissue through the stomata, and could be offset by the (speculative) role of isoprene in plant protection. The determination and parameterisation of the toxic effects of O_3 are a key part of the ECLAIRE project. It is not currently included in any of the emissions models.

(c) Availability of emissions data: Under the auspices of the ECLAIRE project, bVOC emissions modules within DGVMs and ACTMs will be developed and used to provide emissions inventories at the spatial and temporal scale required for regional modelling. Currently, bVOC emissions data are only available from the LPJ-GUESS, CLM4 and ORCHIDEE models. The table overview gives details of how ACTM users can access these data.

2. Fire emissions

(a) Emissions models: There are currently two approaches to modelling wild fires and biomass burning: inverse modelling from satellite retrievals and empirical parameterisations. The former is more widely used, as the drivers of fires are poorly understood and highly complex; they are often heavily dependent on human influences.

Parameterisations of fire count and intensity have been developed for inclusion in DGVMs. In most cases, only burnt area and carbon fluxes are explicitly calculated. Emission rates of compounds other than carbon are calculated based on average ratios [10]. For one of the ECLAIRE DGVMs, fire emissions from two modelling strategies are currently available: applying an empirical but fully prognostic wildfire model (GlobFirM [11]), or prescribing area burned from satellite products, but calculating fire emissions based on vegetation growth and litter production (adopted from Lehsten et al. [12]). Combustion and emission factors can be treated either as fixed values, or variables, depending on assumptions taken from literature. This approach has recently been used to assess the effects of climate change, and changes in atmospheric CO_2 concentration, on vegetation productivity and the amount of combustible litter. See the table overview for details of how to access these initial data.

(b) Drivers of emissions:

Within the fire emissions modules, fire count and intensity are simulated based on soil moisture and availability of fuel. Observations show that fire events are also highly dependent on population density, although this is not yet fully included in current models. In LPJ-GUESS, a parameterisation of burned area from population density, as well as vegetation productivity and canopy composition is currently under development, and emissions for past, present-day and future are expected to be available to ECLAIRE from late 2012.

(c) Availability of emissions data: During the ECLAIRE project, fire emissions modules within DGVMs will be developed and used to provide emissions inventories at the spatial and temporal scale required for regional modelling. Currently, fire emissions data are only available from the LPJ-GUESS (Partner KIT-1) and CLM4 (Partner JRC) models. The table overview gives details of how ACTM users can access these data.

3. Ammonia emissions from seabirds

Seabird colonies are major hot spots for ammonia emissions, with emissions equivalent to large poultry farms, and are often the main source of atmospheric N deposition in remote areas, away from anthropogenic or agricultural activities [13,14]. A global spatial model of ammonia emissions from seabird colonies was developed [13].

The model incorporates detailed seabird population figures from a large number of contributors across the globe, information on nesting substrates (bare rock, sand, vegetation, underground burrows, etc), avaian ecology parameters (e.g., breeding season duration, time spent at colony, metabolic rates, N excretion rates, number of chicks) and relationships with climate variables. In the dataset, the climate dependence of NH_3 emissions is limited to a temperature relationship, which has been shown to be the key influence on volatilisation rates. These data are available at a 0.1 degree spatial resolution, and are considered to be representative for the period 2000-2010. The table overview gives details of how ACTM users can access these data.

A more detailed process-based version of the model, which was developed in conjunction with field-based measurement campaigns, incorporates additional climate parameters, such as relative humidity, precipitation and wind speed. The process-based emissions data will become available to project partners during the ECLAIRE project.

4. Agricultural emissions

Agricultural emissions are considered as ‘biogenic’ within ECLAIRE, due to their similarity in temporal variation arising from processes that are driven or influenced by meteorology (e.g. temperature, humidity, wind speed). Emissions from agriculture are also driven by human activities (e.g. timing and location of manure spreading and fertiliser application, animal grazing). The development of a conceptual framework to address this duality and improve the modelling of agricultural emissions will be addressed in ECLAIRE.

Annual data for NH_3, NO and CH_4 agricultural emissions for the whole of Europe are available to project partners from the Integrator (Partner ALTERRA) model. Agricultural emissions of NH_3, CH_4 and N_2O for the UK are available from the AENEID model (Partner CEH), which incorporates detailed national crop and livestock statistics, landcover data, agricultural practice and management information and emission factors. The annual maps are made available via the UK National Atmospheric Emission Inventory (NAEI) and Greenhouse Gas Inventory (GHGI), which collates emissions from all source sectors into a single system (www.naei.org.uk). Emission data for a large number of pollutants and source sectors are provided at the best possible resolution. NH_3 emissions data at high spatial and temporal resolution are also currently available for Northern Europe (Partner AU).

The table overview gives details of how ACTM users can access these data. Further data will become available over the course of the ECLAIRE project.

C) Anthropogenic emissions

Anthropogenic emissions and their temporal and spatial distribution are generally more influenced by human activities and less by meteorological parameters. This is the case for road transport, power generation, household combustion, industrial production, solvent use and other mobile sources.

The selection of suitable emission data for anthropogenic emissions in ECLAIRE needs to be based on both the requirements of the atmospheric models used and the scenarios to be modelled. Global coverage would be beneficial, to allow modelling at different spatial scales within a common framework of emission input data, which is consistent across scales and climate scenario assumptions. Since most inventories do not provide temporal profiles by sector and pollutant, annual emissions will need to be distributed using profiles from literature or based on activity data, derived from ground-based monitoring or Earth Observation products. This can range from seasonal (or monthly) variations, which is likely to be sufficient for global/hemispheric scale modelling, to daily or hourly variations which will be needed to model atmospheric concentrations and depositions at landscape and regional scales. The latter is particularly relevant for comparison with measurement data from the intensive field campaigns.

In the following section, currently available data for anthropogenic emissions are briefly described and their advantages and disadvantages (with regard to their use for modelling within ECLAIRE) summarised. The table overview gives details of how ACTM users can access these data.

1. Anthropogenic emissions inventories:

The EDGAR[15] inventory is freely accessible after individual user registration and provides emission data both in a relatively high sectoral resolution, and mapped to 0.1 degree spatial resolution. EDGAR is hosted by JRC, but has been a collaborative effort over several years. The latest release (version 4.2) comprises emission data for GHGs ,ozone precursors and other pollutants (http://edgar.jrc.ec.europa.eu/overview.php?v=42). EDGAR does not provide temporal resolution information as such, but in the past has referred to data from the EUROTRAC sub-project GENEMIS[16], which had derived European temporal profiles for the year 1994, or more recent work conducted under the CARBOEUROPE project[17].

The EMEP Centre for Emission Inventories and Projections (CEIP[18]) first and foremost collects official country submissions of pollutants covered by the various protocols under the Convention on Long-Range Transboundary Air Pollution. The sectoral profiles have changed over time, due to efforts to harmonise inventory structures to a system comparable with (and reducing reporting burdens for) GHG reporting. In addition, activity data and mapped emission data (currently at a 0.5 degree resolution) are now reported (but are not available for all years). Independent estimates were also used to gap-fill incomplete or missing submissions for a specific year or country to create a complete set of emission data (also held by CEIP) for modelling. A recent decision within the CLRTAP to move to a higher spatial resolution will affect the future EMEP emission datasets, but it is still unclear if data on, e.g., a 0.1 degree resolution will be available within the time frame of the ECLAIRE project.

The RCP v2.0 data (held by IIASA[19]) provides global emissions data based on inventories and simulations for future scenarios from the IMAGE, MINICAM, AIM, MESSAGE models. Data download requires registration and a specific data section for date from the Coupled Model Intercomparison Project Phase 5 (CMIP5) is provided.

GEIA[20] does not generate emission inventories, but rather links to existing activities (e.g. EDGAR) and has recently launched a portal, Emissions of Atmospheric Compounds & Compilation of Ancillary Data (ECCAD), for emission data and supporting information (e.g. population, land use) through which data are freely available, although registration is again required.

D) Other possible data sources

In addition to the emission inventories detailed on the attached spreadsheet, individual projects such as the MACC project (http://www.gmes-atmosphere.eu), PEGASOS (http://www.pegasoproject.eu) and others generate datasets and supporting information that can be useful for ECLAIRE. The datasets discussed above do not cover all possible sources, but focuses on those which (a) are openly accessible and (b) are not one-off activities, but have a longer term perspective.

E) Key publications and data sources

1. Guenther, A. et al. **(2006)**. Estimates of global terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature). *ACP*, **6**(11), 3181-3210.
2. Guenther, A. et al. **(1995)**. A global model of natural volatile organic compound emissions. *JGR*, **100**(D5), 8873-8892. doi:10.1029/94JD02950.
3. Guenther, A. et al. **(2012)**. The Model of Emissions of Gases and Aerosols from Nature (MEGAN2.1): an extended and updated framework for modelling biogenic emissions. *GMDD*, **5**, 1503-1560.
4. Lathiére, J. et al. **(2006)**. Impact of climate variability and land use changes on global biogenic volatile organic compound emissions. *ACP*, **6**, 2129-2146.
5. Lathiére, J. et al. **(2010)**. Sensitivity of isoprene emissions from the terrestrial biosphere to 20th century changes in atmospheric CO_2 concentration, climate, and land use. *GBC*, **24**(GB1004). doi: 10.1029/209GB003548.
6. Arneth, A. et al. **(2007)**. Process-based estimates of terrestrial ecosystem isoprene emissions: incorporating the effects of a direct CO_2-isoprene interaction. *ACP*, **7**(1), 31-53.

7. Niinemets, U. et al. **(1999)**. A model of isoprene emission based on energetic requirements for isoprene synthesis and leaf photosynthetic properties for Liquidambar and Quercus. *PCE*, **22**(11), 1319-1335. doi: 10.1046/j.1365-3040.1999.00505.x.
8. Schurgers, G. et al. **(2009)**. Process-based modelling of biogenic monoterpene emissions combining production and release from storage. *ACP*, **9**(10), 3409-3423.
9. Arneth, A. et al. **(2011)**. Global terrestrial isoprene emission models: sensitivity to variability in climate and vegetation. *ACP*, **11**, 8037-8052.
10. Andreae, M. and Merlet, P. **(2001)**. Emission of trace gases and aerosols from biomass burning. *GBC*, **15**(4), 955-966.
11. Thonicke, et al. **(2001)**. The role of fire disturbance for global vegetation dynamics. Coupling fire into a Dynamic Global Vegetation Model, *Glob. Ecol. & Biogeog.*, **10**, 661-678.
12. Lehsten, V. et al. **(2009)**, Estimating carbon emissions from African wildfires. *BGS*, **6**, 349-360.
13. Riddick S., Dragosits U., Blackall T., Daunt F., Wanless S. and Sutton M.A. (2012) Global ammonia emissions from seabirds. Atmospheric Environment 55, 319-327. doi:10.1016/j.atmosenv.2012.02.052
14. Wilson L.J., Bacon P.J., Bull J., Dragosits U., Blackall T.D., Dunn T.E., Hamer K.C., Sutton M.A. and Wanless S. (2004) Modelling the spatial distribution of ammonia emissions from seabirds in the UK. Environmental Pollution 131, p.173-185.
15. European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), release version 4.2. http://edgar.jrc.ec.europa.eu, 2011
16. Friedrich R, Reis S (eds.) (2004) Emissions of Air Pollutants – Measurements, Calculation, Uncertainties - Results from the EUROTRAC Subproject GENEMIS. Springer Publishers, 335 pp, ISBN 978-3540008408
17.Reis S, Pfeiffer H, Scholz Y and Theloke J (2008) Temporal and Spatial Distribution of Carbon Emissions. In: Dolman, H (ed) The Continental-Scale Greenhouse Gas Balance of Europe. Springer Publishers, 73-90 (18 pp), ISBN 978-0-387-76568-6
18. Centre for Emission Inventories and Projections (CEIP), UNECE Convention on Long-range Transboundary Air Pollution, http://www.ceip.at/
19. RCP Database (v. 2.0), http://www.iiasa.ac.at/web-apps/tnt/RcpDb/dsd?Action=htmlpage&page=welcome
20. Global Emissions Initiative (GEIA), http://geiacenter.org/