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Projections of greenhouse gas emissions

Data preparation, model assumptions

DISSERTATION THESIS

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Study programme: Environmental modelling

I hereby declare that I wrote this dissertation thesis independently, under the supervision of Marek Vach. I have listed all literature and publications from which I have acquired information. Further, I used my own research in the thesis.

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ABSTRACT

European Union member states are obliged every second year to report projections of greenhouse gas emissions. The obligation is given by the Regulation No 525/2013 EP. Global estimates of greenhouse gas emission levels are also part of the Synthesis and Assessment report of IPCC. Specific sectors require specific environment of used models. In the Czech Republic couple of models were developed, however none on them is working with the detailed data from the official reporting of greenhouse gases. The research provides preparation of computational model for Energy sector and Industrial Processes and Product Use data from the most detail from the official reporting. The projection estimates are built on top of the developed computational models for the inventory. Also, relevant scenarios are described as well as expected development and assumptions for specific subsectors for the future. Further, structure of the projection report was prepared.

Key words: greenhouse gas emissions, data, model, IPCC, energy, industrial processes, emission factor

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1) Introduction

The Czech Republic is one of the Parties of United Nations Framework Convention on Climate Change (UNFCCC). In terms of this framework it is also required to report annually emissions and sinks of greenhouse gases, which were produced during the year in the region of the Czech Republic and which are controlled within the scope of The Kyoto and Montreal protocol. As a member of European Union the Czech Republic has also obligations given in Regulation (EU) No 525/2013 of the European Parliament and of the Council of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC. The reporting of greenhouse gases is related to the obligation of reporting of projections of greenhouse gases. The projection reporting requirement is based on the article 14, Regulation (EU) No 525/2013 reported every two years. The data for this reporting are determined based on two basic scenarios. Scenario with existing measures (WEM) includes different policies and measures (legislative, national programmes, economical initiatives etc.), which have come into force before the time of reporting preparation. The scenario with additional measures (WAM) includes also prepared and expected regulations, for which is assumed that will come into force after the projections reporting.

The structure of the division of emission is the same as is used for the greenhouse gas emission inventories, meaning the same as in Common Reporting Format (CRF). The main sectors are: Energy, Industrial Processes and Other Product Use, Agriculture and Land Use, Land Use Change and Forestry Activities (LULUCF). The emissions are estimated for CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3 on CO_2 equivalent.

The main purpose of the thesis is to develop basic data, scenarios, and assumptions, which are used for the computation of expected emission levels. For that it is necessary at first to provide a research of the main models used in other European countries, better in the neighbouring countries of the Czech Republic. In the second step these models will be evaluated with regard of possible use for the Czech

Republic territory. From the knowledge obtained by this research evaluation of the data and also comparison of currently available models and their outputs is provided. The input for calculation has to be provided in transparent and user friendly outline. All of the activity data are provided in spreadsheet forms, as well as the final requested document for reporting. Automatic computational tool in spreadsheets is then used for the model.

The goal was to develop user friendly, but enough sophisticated model for the purpose of the reporting of greenhouse gas emissions and projections.

2) Main goals and methodology

As noted in introduction the main goal is to develop country specific model, which would be capable to estimate emission projections for Energy and Industrial Processes. In the Czech Republic few models for different sectors were developed, however none of them is working with the detailed data from the reporting of greenhouse gas emissions.

All member state of European Union has obligation given by the Regulation No 525/2013 EP to report biennially it's projections of greenhouse gas emissions. The base year for the projection assessment is always the closest year for which was submitted official inventory of greenhouse gas emissions to the UNFCCC, which is ending by 5 or 0. Even though for the Czech Republic this obligation arises from the European legislation, projections of greenhouse gas emissions levels are done also globally. The assessment of future emission levels is part of Synthesis and Assessment Report published by the IPCC. Fifth synthesis and assessment report was published in 2014 (IPCC, 2014).

Reporting obligations for EU member states include all sectors and gases, which are part of the inventory of greenhouse gas emissions. The main focus is on projections of CO_2, however projections of other greenhouse gases are also obligatory.

Currently in the Czech Republic is used combined approach for compiling of this reporting. Each sector for reporting needs specific approach and has specific requirements for the model. However models which are aimed to be used for the projections in Energy sector are usually capable to project also emissions from Industrial processes. For the Energy and Industrial Processes sector was in history in the Czech Republic used model EFOM –ENV, which is access based model. Detailed methodological approaches are explained further in respective chapters.

Further, no structure of the projections reporting was developed yet. The structure is developed in this thesis as well and will be used in the official reporting to the European Commission for the reporting in 2019. Calculation model developed in this thesis will be used for Energy sector for verification purposes of projections, calculation model for Industrial Processes is already used for emission estimation as well as for projections. Calculation model for Energy sector was already applied in the emission inventory submission in 2018.

3) Examples of models used for emission modelling

3.1. General types of model used for emission modelling

Forecast models

Numerical weather prediction models don’t consider in their structure chemical transformation of different substances. The use only physical state of air and water, their movement and also energy transfer in the atmosphere. These models include transfer of mass, heat or moisture in atmosphere. The physical processes in the atmosphere are represented by sophisticated sets of equations. Specific approach is used for coastal areas, where the exchange of masses above ocean and above land has to be considered. Even though these models in principle don’t include the chemistry of the processes, currently there are efforts to include this issue as well (McElroy and Fogal, 2007). Basically the forecast models are not often used for emission projection modelling. Simply because projection models have to consider different scenarios of energy stocks and fuels production and use as well as industrial production development. These features are not usually part of forecast models (Michaelsen, 2010).

Chemical box models

Chemical box models are simulating chemical development in the equilibrium state. They consider isolated mass of chemical substances. These models are used for the stadium of specific chemical reactions, their speed and research of new additional possible chemical reactions. These models are also used for the research of very fast reactions, which are not apparent in the large scale models (McElroy and Fogal, 2007). Hence these models also don’t consider different scenarios of energy and industrial production (Sportisse, 2001).

2D chemical models

These models include in their 2D network also longitude and latitude. They are representing average conditions as function of longitude and latitude. Hence these models are useful for areas like higher stratosphere, where the conditions are more homogenous. These models are basically used for modelling of interactions of radiation and chemical reaction (McElroy and Fogal, 2007). However no evidence was found about interactions between energy and industrial production as part of different scenarios for modelling and future emissions modelling (Rex et al., 2004).

General circulation models

As already the name of the models predicts, these are used for general climate circulation modelling. Even though part of the input parameter will be for instance production and use of fuels, the model are specified to be used for the large scale, i.e. global emission modelling. Using of this kind of model for the area of the Czech Republic would bring in the result high uncertainty of the results (McElroy and Fogal, 2007, Phillips, 1956).

3.2. Models used for emissions projection modelling

The model system EURAD is recently able to model for instance the ozone fluxes across tropopause or ozone input from free troposphere into atmospheric boundary layer or the VOC/NOx reduction effects. EURAD model was originally aimed for modelling of episodic events like smog situation (winter or summer). EURAD model system is composed from other input models, as MM4 (meteorological model), CTM2 (chemistry transport model) or EEM, EURAD emission model (Memmesheimer et al., 1991). For the projection modelling is needed emission model which is able to simulate emission development using specific scenarios. From the option EURAD system is offering, the EEM, EURAD emission model can be used. For the training and developing of EURAD emission model was used data from annual EMEP emission inventories. The EEM model was used for this purpose. Additionally emission scenarios were incorporated as well (Ebel et al., 1997). However EURAD was used was modelling emissions of NO, NO_2, SO_2, H_2SO_4, CO, NH_3 and VOC (Ebel et al. 1997, Lübkert and Schöpp, 1989), not for greenhouse gases. EURAD model can be for the modelling purposes of smaller scale air pollutant transport combined with additional models, for instance DRAINS model (Nester, Fiedle, Patz in Ebel et al., 1997).

3.3. Different approaches used by EU countries

In Austria are the emission projections from Energy sector based on the National Energy Balance of Statistic Austria and on macroeconomic model DEIO of the Australian Institute of Economic Research (Wifo, 2013). As supportive model are used TIMES model (electricity demand, public electrical power and district heating supply) (AEA, 2015), INVERT/EE-Lab (domestic heating and hot water supply) (TU Wien, 2015) and NEMO&GEORG (energy demand and emissions of transport) (TU, Graz, 2015). Forecast of emissions from industrial processes and solvent use emission are based on expert judgement of the Umweltbundesamt.

The emission projections are computed applying the same methodology as those used for national GHG inventory. There are also modelled two scenarios – WEM and WAM. For the Energy sector were applied two different scenarios with different assumptions in economic growth and energy prices. For each was considered different economic growth (Umweltbundesamt, 2015).

The main inputs for the calculations in the models mentioned above are: Availability of resources, market penetration of different technologies, maximum replacement and refurbishment periods, minimum and maximum lifetime of technical installations. The results obtained with different models were exchanged and balanced within a few cycles (Umweltbundesamt, 2015).

For the mobile combustion was used GLOBEMI model (Hausberger, 1998, Hausberger and Schwingshacl, 2012); for the off-road emissions was used GEORG model TU (Graz, 2015).

As in the other countries also Germany used two scenarios emissions projections development – WEM and WAM. For the modelling of stationary combustion emissions was used FORECAST model (Fraunhofer, 2014). For the construction category was used INVERT/EE-Lab model (Kranzl et al., 2013, Fraunhofer, 2014) and model ELIAS was used for electricity investment analysis (Harthan, 2014).

In Belgium are the projections compiled as a regional bottom-up projections. Those are compared with the national projections calculated by the Federal Planning Bureau (FPB) based on the macro-sectoral top-down econometric model (HERMES) (Bossier et al., 2004) which uses data from a recent study commissioned by the

Belgian federal authority based notably on the PRIMES energy model. For the Energy sector projections was used EPM model (Energy/Emissions Projections Model). The model has been developed progressively by ECONOTEC since 1993 using number of studies carried out for public authorities, as well as regional as at national level. The Brussels Institute for Environmental Management has developed its own projection model for energy demand and atmospheric emissions from stationary sources – Environment Brussels Emission Projections Model (Report for the assessment of projected progress – Belgium, 2015).

PRIMES model is also used by EEA (European Environment Agency) projections (EEA, 2013).

Like in other countries in Finland were modelled two emission scenarios WEM and WAM. For the WAM scenario was used REMA calculation model developed in VTT Technical Research Centre on Finland (Reporting of policies and measures under article 3(2) of Decision 280/2004/EC – Finland, 2013).

Denmark uses for its projection estimates different models for specific sectors and subsectors. The models are in most cases developed for the specific purpose for the emission projection modelling in Denmark. For instance for projection of the production of electricity and district heating is used the Danish Energy Authority's Ramses-model. It is designed to include the Nordic area, however it is mostly used for the specific purposes of Denmark (Danish Energy Agency, 2015). For the final energy consumption of businesses and the domestic sector is used economic macro model EMMA. EMMA describes final energy consumption split in number of sectors and seven types of energy (Andersen and Trier, 1995).

MESSAGE model with elements of PRIMES model is used for Energy projections (except of Transport) in Slovakia. Software for industrial processes projections is based on MS Excel platform (SHMU & Ministry of Environment of the Slovak Republic, 2015).

In Netherlands so called National Energy Outlook Modelling System (NEOMS) was developed for the Energy projections and policy evaluations. It incorporates 12 energy models (ECN, 2015).

3.4. Models used for emission projections

3.4.1. PRIMES model

PRIMES is partial equilibrium model simulation the entire energy system, both in demand and supply. There are mixed representations of computational approaches – bottom-up and top-down. Bottom-up approach includes engineering and explicit technology choices, although the Top-down approach includes microeconomic foundation of economic decisions by agent. The model obtains different modules for each demand and supply sector and separate decision making. The energy balancing of demand and supply per energy commodity is driven by market equilibrium prices. There are also simulations of electricity and gas trade within EU Internal Market performed. The set of policies is represented – taxes, subsidies, tradable permits or certificates, technology supporting policies and Energy/Environmental policy instruments including standards (Capros, 2013).
PRIMES model cover each EU – 27 member state taken individually and also candidate member states and neighbours. The results are modelled for the time frame starting 2000, ending 2050 with five year time step. The model includes market linked sub-models for specific sectors – industry, households, power/steam generation, fuel supply. The model is run in the mode country-by-country and also for multiple countries with endogenous electricity trade (Gusbin, 2012).
From the external inputs are covered economic activities, world energy process, technology parameters and policies and measures. Form the non-linear relations are taken into account economies of scale, consumer choices and saturation effects, supply cost-curves for potential of resources, new technologies and the used of new sites for energy plants and perceived costs of technology and risk premium (Gusbin, 2012).

Inputs

Inputs to the model are GDP and economic growth per sector, world energy supply outlook (world prices of fossil fuels), taxes and subsidies, environmental policies and constraints, technical and economic characteristics of future energy technologies, energy consumption habits, parameters about comfort, rational use of energy and savings, energy efficiency potential and parameters of supply curves for primary energy, potential of sites for new plants especially regarding power generation sites, renewables potential per source type, etc. (Capros et al., 1999; Capros, 2013).

Outputs

As the outputs from the model are considered detailed energy balance in Eurostat format, detailed balance for electricity and steam or heat, production of new fuels, transport activity and means of transport, investment, technologies and vintages in supply and demand sectors, energy supply per subsystem and primary energy, energy system costs, prices and investment expenditure, emission from energy and industrial processes, greenhouse gas emissions and policy assessment indicators, e.g. import dependence ratio. The outputs are provided per country and time period (Capros, 2013).

Data input sources

From Eurostat are available energy balance data (use of fuels for combustion in different subsectors), energy prices, macroeconomic and sectoral activity data and population data and projections (Capros, 2013). Technology databases are mostly developed under European Commission programs, i.e. MURE, ICARUS, ODYSEE for demand sectors, VGB, SAPIENTA, TECHPOL for supply sector technologies (Criqui et al., 2015). There are used activity data from different industry associations and specifically processed studies for special issues, e.g. TNO study on CO_2 storage potential (Capros et al., 1999, Capros, 2013).

Link with other models

The energy demand-supply-prices, emissions and investment model PRIMES is linked with macroeconomic and sectoral activity model GEM-E3, transport activity and flows are provided by SCENES or TRANSTOLLS models. POLES and Prometheus model provides inputs about world energy oil, gas and coal prices. Furthermore is used GAINS model for the contribution in air quality and non CO_2 greenhouse gases emissions and other supportive model for EU power plants (TECHPOL, VGB), EU refineries (IFP), Renewables potential (DLR, ECN, Observer) and energy efficiency (ODYSEE, MURE) (Gusbin, 2012).

Energy commodities and demand sectors

Fuels considered in the model for the energy sector emissions are coal, lignite, coke, briquettes, other solid fuels, crude oil, refinery gas, gasoline, biogasoline, diesel oil, biodiesel, kerosene, biokerosene, LPG, residual fuel oil, naphtha, other oil products, natural gas, coke oven gas, blast furnace gas, gas works gas, nuclear energy. From the biomass and waste used as fuels are considered biodiesel, bioethanol, biokerosene, biohydrogen, small scale solid biomass, large scale solid biomass, biogas, solid waste and waste gas. There are also considered industrial steam and distributed heat, electricity and hydrogen and renewable sources of energy, e.g. solar or wind power plants (Gusbin, 2012).

Households are subdivided in 5 dwelling types, services are subdivided in market services sector, non-market services and trade sector. The Agriculture is considered as separate sector. The industry is divided into specific categories based on final products – iron and steel, nonferrous metals, chemicals, paper and pulp, food, drink and tobacco, engineering goods, textiles and other industrial sectors. In Energy sector are considered extraction, refineries, nuclear fuel and waste, electricity self-use, gas supply and bio-energy production. Under each industrial category are number of subcategories covered distinguished by specific processes carried on for production of the specific product; e.g. under iron and steel are included electric arc furnaces, under nonferrous metals primary and secondary aluminium production, copper production, under building materials production cement dry and ceramics and bricks, etc. (Capros, 2013).

PRIMES cannot deliver short-term forecasts, so projections are not statistically based on past observations, which in PRIMES are only used for parameter calibration. It also cannot perform detailed short-term engineering analysis of electricity system or gas system operation. Finally, there is also lack of spatial information and representation at the level of countries and so lack of details about distribution and transport infrastructure and flows that depend in detailed spatial information (Capros, 2013).

PRIMES is fundamentally different from optimisation models, such as Markal, TIMES or MESSAGE. It is also different from Excel-type calculation models and other similar models that simulate technology penetration. For the energy sector PRIMES is partial market equilibrium model, in this means it differs from general equilibrium models (Gusbin, 2012).

3.4.2. IIASA GAINS model

The Greenhouse Gas and Air Pollution Interactions and Synergies model is developed by International Institute of Applied Systems Analysis model (IIASA GAINS). It is an online-based model with modules for Europe and Asia, there is also a North American version that will be finalized soon (IIASA, 2014).

GAINS is an extension of previous Regional Air Pollution Information and Simulation model (RAINS) that has been developed by IIASA in the 1990s (Cofala et al., 1999, Castells and Funtowicz, 1997). The RAINS model is also an optimization model that describes behaviour of air pollutants on their way from their sources to environmental impacts. RAINS model, unlike GAINS, uses nonlinear cost curves for each of the pollutants in order to assess costs and impacts of air pollution. This does not allow for any co-benefit and trade-off analysis. The scope of the model is limited to particulate matter, sulphur dioxide, nitrogen oxides, VOC and ammonia (Klaassen et al. (2004).

The European module of GAINS describes the EU27 and surrounding countries, divided into 42 land-based regions in Europe as well as five sea regions. The outcomes of analyses are aimed on middle-term development. All the main pollutants, 6 greenhouse gases and 6 air pollutants, are considered in the model: NH_3, CO_2, CH_4, NO_X, N_2O, particulate matter (TSP, PM_{10} and $PM_{2.5}$), SO_2, VOC, CO and the F-Gasses. The data on historical emissions, economic development drivers and other data used in analysis are taken from national inventories or existing registers (Wagner et al., 2007).

Inputs of the model are often outputs from other models: data on energy consumption and production and the future development of the energy sector are taken from the PRIMES energy system model of the EC, transport sector emission inputs are obtained from the TREMOVE model of the EC, data related to agriculture are outputs of the CAPRI model of the EC (Klaassen et al., 2005).

There are a few possible sources of uncertainty that could decrease the relevance of the model for the case of the Czech Republic. Firstly, the results of modelled situations are subject to various errors in measurement of input data arising from aggregation, inaccurate measurements, vague quantification of events in time and other sources. The results of analysis are heavily dependent on the inputs, and while the inputs are either aggregated data from national and international databases or results of other models, results of the analysis performed by GAINS might be biased. Secondly, GAINS is a macro model that performs best under certain assumptions and circumstances (Höglund – Isaksson & Mechler, 2005). It is reasonable to expect that the results of the analysis for the Czech Republic might be subject to certain errors simply because of the fact that the Czech Republic is too small in comparison to the whole EU, which is the main aim of the model. Unlikely to other macro-models such as E3ME model of the Cambridge Econometrics, the GAINS does not use recent data to predict the development of the factors in future. Instead, data on future development of economy, energy sector and other driving forces are imported from other models, the GAINS then only optimizes the mixture of measures needed to attain certain environmental goals under selected assumptions (Winiwarter, 2005).

Structure

There is a number of driving forces such as growth of the European economy and energy price. These have a direct impact on the main emission generating activities, above all energy production and consumption, agriculture, transportation and manufacturing industry. Each of the possible future developments of these industries is integrated into GAINS as so called “economic activity pathway”. Besides the economic activity, the emissions stemming from the industries are dependent also on control and regulation of GHGs and air pollution. Again, all the possible future states of relevant environmental legislation from business as usual to maximal technically feasible reduction are integrated into the model, forming the “emission control options”. Economic activity pathways and Emission control options are two variables defining the resulting level of emissions of both greenhouse gases and air pollutants and costs of reaching this emission level over a selected time horizon. Both are optimized values with respect to specific characteristics of various regions and pollutants (Tohka, 2005).

There are two modes of the GAINS model, scenario analysis and optimisation. The scenario analysis mode combines economic pathways and emission control options to describe the results of the interaction, in the way described above. The optimisation mode in fact reverts the chain, in this mode, GAINS counts the costs for selected emission levels under various scenarios. It assesses measures needed to achieve any desired emission levels under selected economic pathway. There is a huge number of measures that are considered by the model. Among the 162 mitigation options for CO_2 are measures such as shift to gas and renewables, cogeneration of heat and energy or carbon capture and storage in power plants, alternative fuels and rise in effectiveness of means of transport, fuel shifts in industry or end-use savings of domestic energy consumption. The 28 options for CH_4 mitigations involve above all reduced leakage during transmission and distribution of natural gas, better waste management by composting and recycling, better gas recovery from coal mines or dietary changes for cattle and livestock reductions. The 18 options for N_2O incorporate reduced fertilizer application in agriculture, optimized waste water treatment or tighter emission controls in chemical industry. There are also 22 options for the F-gasses such as alternative refrigerants in mobile and stationary cooling or measures in aluminium production and semiconductor industry (Bízek, 2009).

Both modes of the GAINS model, scenario analysis and optimisation, use as a starting point combination of economic activity pathways and emission control options. Both activity pathway and emission control options are recorded in the model as a scenario. Outcomes of analysis or optimization are based solely on selected scenario. The economic activity pathways of each scenario contain a number of variables describing economic driving forces, energy consumption, agriculture, CO_2 emissions forecast and historical emissions as well as future emission projections of non-EU countries. Population, per capita GDP and GDP growth are all important economic driving forces contained in the model. These indicators are output of PRIMES 2007 baseline projection for all the EU-27 countries, with base year of 2000 and forecast in 2020 (Bízek, 2009).

The PRIMES model is used to quantify the implications of economic driving forces on national energy systems. Macroeconomic development and international energy prices are the basis for energy consumption, another driving force in each scenario. Forecast of these factors for 2020 is based on year 2000 (Bízek, 2009).

3.4.3. E3ME Model

E3ME is an econometrically-estimated model that encompasses both long-term behaviour and dynamic year-to-year fluctuations. The endogenous variables are determined by a set of twenty two pairs of equations which are disaggregated into regions and then into sectors. The relationships among the time series are based on the concept of cointegration stemming from Granger (1983), Engle and Granger (1987) and Hendry et al. (1984). The basic idea behind the concept states that even two non-stationary time series can have stationary linear combinations characterizing long-run equilibrium between them.

Briefly, take two I(1) time series. The time series are cointegrated if residuals from their linear combination are I(0) meaning that they oscillate around some level and tend to move backwards towards it. It signals a long-term relationship between time series. Analyses of cointegration between time series can be conducted by an Engel-Granger two step procedure. In the first step, depending on the incorporation of trend, the long-term relationship of two I(1) time series is inspected by estimating the following equations, usually by simple OLS procedure.

$$\boldsymbol{y_t = \mu + \beta x_t + \varepsilon_t} \qquad \textbf{Equation 1}$$

The stationarity test, usually the ADF test (Kao, 1999, Gutierrez, 2003), on the residuals has to be performed in order to find out the existence of a long-term relationship between time series. If the null hypothesis is rejected, the time series ofresiduals is stationary implying that residuals tend to fluctuate and move towards the equilibrium point. Granger (1983) or Engle and Granger (1987) show that cointegrated time series can always be represented by an error correction model and vice versa. If the time series of residuals is stationary, the error correction model is estimated in the second stage. Such a dynamic equation then takes the following form:

$$\triangle y_t = \gamma_0 \triangle x_t + \gamma_1 \triangle \gamma_{t-1} + \delta(ECT_{t-1}) + u_t \qquad \textbf{Equation 2}$$

where ECT_{t-1} presents the residuals from the equation 1 lagged by 1 period. ECT is the error-correction term showing the speed of convergence to the equilibrium and is restricted to take a value between zero and minus one.

In the few cases where a cointegrating relationship cannot be found, the IDIOM software which underpins E3ME allows the econometric equation to be replaced with a simpler specification, for example based on country or European averages, or linked to a similar variable.

Each equation of the E3ME model is specified by the abovementioned process, i.e. the long-term relationship is estimated in the first step, then the dynamic relationship is estimated by plugging the error-correction term from the first step (Ščasný et al., 2009).

3.4.4. TIMES model

The TIMES (The Integrated MARKAL-EFOM System) combines two approaches to modelling energy – firstly technical engineering approach and secondly economic approach. TIMES is bottom-up model, which uses linear-programming in order to produce efficient energy system, for medium and long-term periods (Vaillancourt et al., 2008).

The structure of the model involves technologies, commodities and commodity flows and different scenarios. As primary data it uses fuel mining, primary and secondary production and import and export. One of the inputs is energy supply, which is represented by producers. On the output the energy is represented by consumers, who are split in between sectors of use, which are residential, commercial, agricultural, transport and industrial sectors. The relationship between producers and consumers is represented by mathematical, economic and engineering point of view (Loulou et al., 2005).

Technologies represent the devices used for transforming of commodities to other ones, e.g. mining process on one side, production of heat and electricity on the other side. Commodities including also fuels, materials and emissions. Important part is commodity flows, which represents links between processes and commodities. Technologies, commodities and commodity flows built in TIMES the energy system, which is the basic energy model before any changes (Loulou et al., 2005).

The energy systems are then adapted to specific scenarios. First step is scenarios without any policy limitations. Second scenario includes specific policy restrictions, for instance renewable energy policy; the model generates different energy system with specific fuel and technology choice (Loulou et al., 2005).

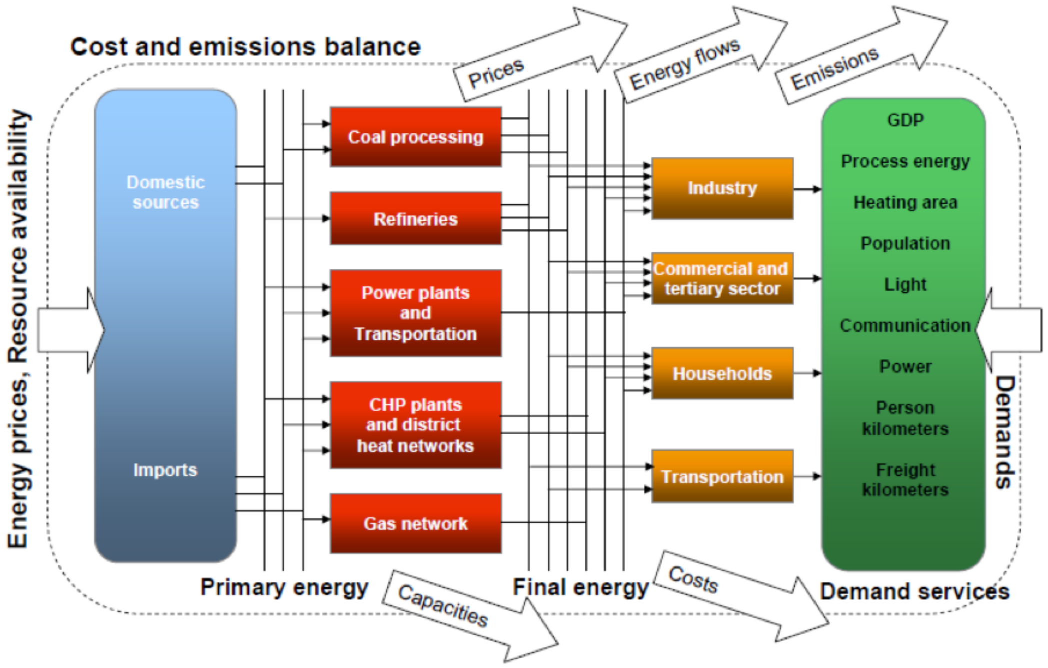

Figure 1 Structure of TIMES model

The main goal of the model is to find energy system, that meets all demands over the entire time period at least costs. The scenarios are used specifically for region needed based on the possibilities of energy supplies, energy trade and technology availability. The configuration of production and consumption of commodities and their prices is performed. The optimization is done across all sectors as well as across time periods. The result is optimal mix of technologies and fuels for the specific time period including emissions produced (Loulou et al., 2005).

As mentioned above the main output is specific energy system, which meets specific requirements, for instance specific percentage of emission reduction. The model analyses, if the target specified by the policy is feasible, and what would be the costs to reach this target. The outputs include energy flows, energy commodity process, greenhouse gas emissions, technology capacity, energy costs and emissions abatement costs (Loulou et al., 2005).

Specifically TIMES is comprehensive model used especially for modelling of greenhouse gas emissions arising from Energy sector and Industrial Processes sector.

4) Model for estimation of Energy and Industrial Processes emissions

The first step of developing of computational model is to define the purpose of the model, choose adequate algorithms, obtain relevant input data, verify the modelled data with the real situation and analyse the results (Jacobson, 2005).

Basically, emission projections mean to extrapolate baseline emission estimates to predict future emissions levels based on future emission activity levels and emissions controls. Projected emission levels are often used for planning, evaluation of potential control measures, analysis of new source impacts, modelling of future air quality and assessment of the effectiveness of air pollution control strategies. Since projections are quantifying unknown future, there will always be some uncertainty (Webster and Sokolov, 2000). Since the legislative of European Union is still developing, as well as requirement on the greenhouse gas emissions reporting from the position of United Nations Framework Convention in Climate Change, it is crucial to leave the model open for changes in categories and data requirement.

Building such comprehensive model requires a large amount of resources and extensive research of requirements and possibilities how to evaluate the best available and best working computational tool. While working on the research this thesis brings comprehensive explanation of necessary inputs including research of country specific emissions or other computational factors. The published articles of the author present variety of required basic research's tasks necessary for the whole computational model development.

The methodology employed for preparation of emission projections is in accordance with currently valid methodology for preparation of the National Communications. The methodology includes the following set of steps:

- inventory of greenhouse gases
- selection of base and final year and cross-cutting years for creating projections,

- selection of the actual methodology and model instruments for preparing the projection,
- collection and analysis of input data for the projection,
- establishment of initial assumptions,
- definition of scenarios,
- calculation of scenarios and presentation of their results,
- sensitivity analysis on selected assumptions.

Under the overall assumptions and important aspects to consider while preparing the projections estimates belong development of number of inhabitants – in the Czech Republic this data are available from the official census and statistics of Czech statistical office (CzSO, 2014). Further, it is economic development of the country – it means overall expected trend of GDP, price of emission allowances – recommended by the European Commission. European Commission is publishing such document every two years, so the member states are having actual data while preparing their own projections.

The emission calculation is done using three types (levels) of methods; each differs based on how sophisticated is the process of emission estimation. The level 'Tier 1' is the simplest approach, the emission computations are done by multiplying amount of fuel combusted by specific emission factors for the fuel and oxidation factor (Energy sector). In the Industrial Processes and Product Use sector is Tier 1 carried out by multiplying of amount of specific product (e.g. cement or lime) by emission factor. The Tier 2 is using more detailed data for emission estimation. In Energy sector it means using data for specific categories and country specific emission factors. For Industrial Processes and Product Use it means using data about type of product (i.e. cement clinker, type of cement, type of lime, kinds of glass). The most sophisticated Tier 3 method is using for estimation the data on the plant level (IPCC, 2006). Currently this approach in the Czech Republic is possible to apply using data reported to EU ETS scheme or by carrying out specific research about the processes. Tier 3 is currently applied for estimation of CO_2 emission from cement production, lime production, glass production and nitric acid production in the Czech Republic's inventory of greenhouse gas emissions. However further improvement is planned in the other sector as well also using data reported in the EU ETS scheme.

Other important feature which has to be added to the final computational figures is set of global warming potentials. Global warming potential (GWP) describes how much longer is the specific greenhouse gas staying in the atmosphere and thus having an impact on our climate (Lashof and Ahuja, 1990, Shine et al., 2005). GWPs are expressed in relation to GWP of CO_2, which has GWP=1. Since CH_4 has GWP=25 it means it will stay in atmosphere 25 times longer than CO_2. N_2O's GWP equals to 298.

The activity data for the emission calculation in the Energy sector are provided in official CzSO energy balance in the .xls format. Other separated files contain the specific emission and oxidation factors, as well as other necessary computation factors. The final emission figures have to be converted to the required .xls template. The calculated data is used for the reporting of greenhouse gas emissions as well as for the reporting of projections.

Extrapolation of the data is used in order to provide projections towards next 20 years under WEM scenario. The emission levels are projected for the future 20 years for the years which end up with 5 or 0, as required under the Dec. No 525/2013. For the WAM scenario the input data calculated by the computation model are be used as well as input, which is reflecting expected effects of the specific policy.

All the policies and measures planned to incorporate by the Czech Republic are listed in the Czech Republic's 7th National Communication as well as in 3nd Biennial report of the Czech Republic as well as in the official reporting of projections under the European Commission.

Furthermore the European Commission is providing specific reporting templates, by which the projections for the country should be reported. This template is built in the .xls. From this reason it is necessary to obtain also model results in the excel file.

In the first step the model read all necessary input files, i. e. files with activity data and factors needed for computation of the emissions. The structure for each sector (Energy and Industrial Processes and Product Use) is different, separated models are used. The categorisation of both Energy and Industrial Processes and Product Use sectors is presented in Annex 1.

The second step of the model is calculation of specific emissions in the specific subcategories. Important input for the projection model is to include the specific scenarios in the computation of projection for upcoming years. Specific measures have to be displayed in the input files for the specific sector. For instance shutting down of one cement plant in 5 year has to displayed in the production figures, which would naturally lead to lower emissions from subcategory starting the year of shutting down of the plant. There are number of measures planned in the Energy sector.

Last step of the model is computation if the projection figures for specific categories for 20 years onwards.

Verifying of the outputs from both computational models is done by evaluating of the differences between results provided by other available models. The structure of the whole approach is presented in the Figure 2.

Further, this thesis is providing a structure of the reporting of projection for the European Commission. Currently, there is no official set up structure, which would lead to the transparent and concise submission. The structure has to follow logical distinction between different sectors in the inventory, both for projections part and policies and measures part.

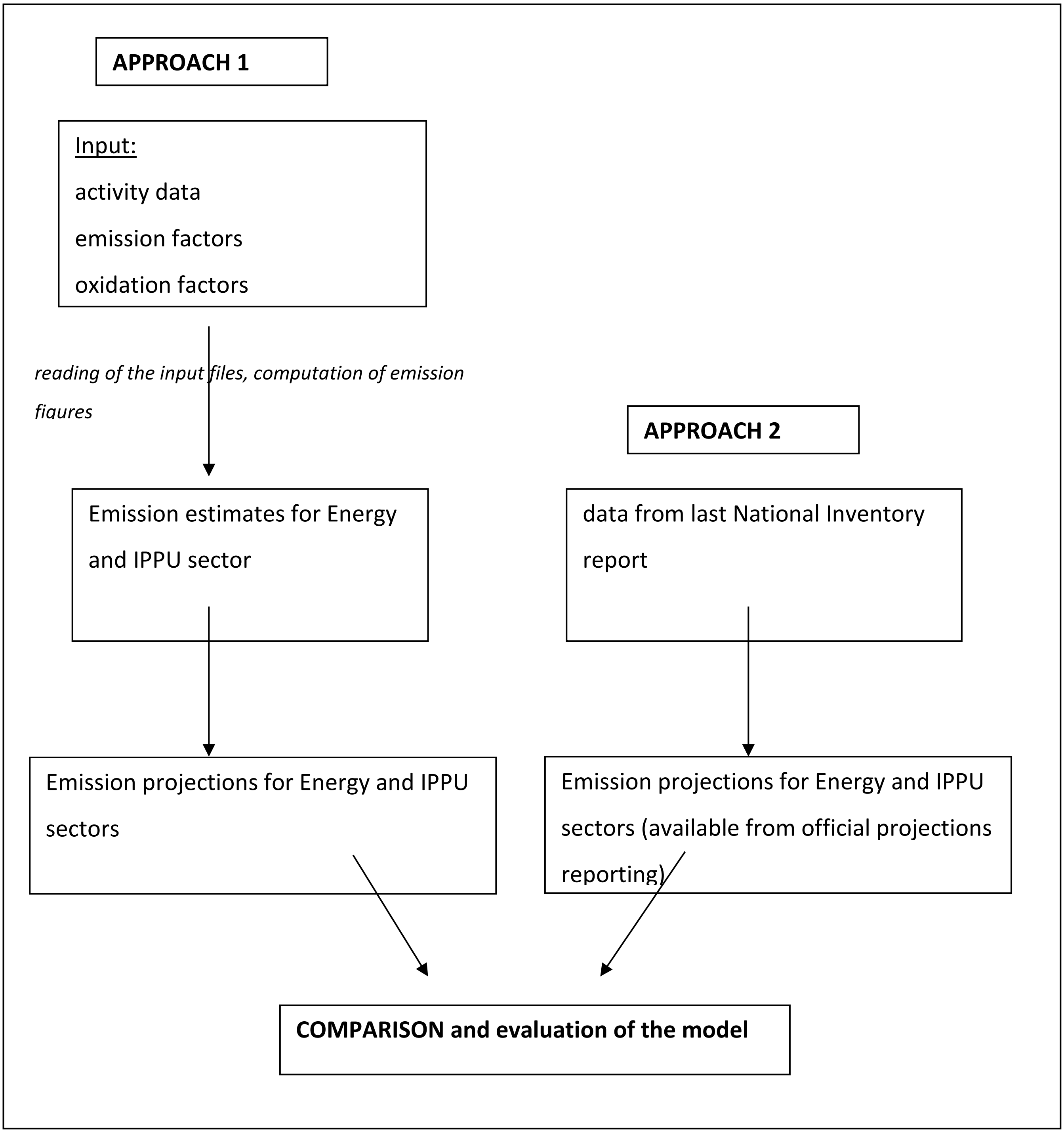

Figure 2 Structure of the model for emission projections for sectors Energy and Industrial Processes and Product Use

4.1. Data inputs for the computational model

Inputs for the projection model include calculated emission level from the last reported inventory submitted to UNFCCC. As the base year the last available reported year is used. The extrapolation method is be used for the 'with existing measures' scenario (WEM). WEM scenario will use the development of the emission in the time series in the specific subcategory.

For the 'with additional measures' (WAM) scenario the model need input of expected plans for energy production and transfers to other type of fuels as well as possible transfer towards higher usage of the renewable sources (Celik at al., 2005). For the industrial processed is necessary to take in account planned production figures of different industrial products. Generally all planned policy measures have specific impact on the emission levels, which will be specifically included in the models. All the planned figures as well as transfers to other type of energy production are part of the input parameters to the projection model.

4.1.1. Energy sector

Since majority of activity data, which is necessary to use as input to the model, is in format of .xls tables, it is necessary to develop environment, which is able to read specific input files. For the case of Energy sector the structure of data differs for each type of fuels combusted, i.e. the structure for all solid fuels is identical.

The base data necessary for emission estimates (so called activity data) is amount of the fuel combusted in the relevant category within the year. This data are available from the Czech Statistical Office, which is then reporting the official Energy balance of the Czech Republic to the Eurostat, IEA and OECD. For estimation of fugitive emissions from fuels the activity data is the amount of mined coal or extracted oil or natural gas.

Next step in emission calculations is incorporation of specific emission factors and eventually other necessary computational factors. Emission factor describes amount of the greenhouse gas (in mass units) released by combustion of 1 TJ (or any other energy unit) of the fuel. Solid and liquid fuels are in the official statistics provided in kilotons; the conversion to energy unit (e.g. TJ) is necessary:

$$\boldsymbol{AD\ (TJ) = AD\ (kt) \times NCV,} \qquad \textbf{Equation 3}$$

where NCV means net calorific value of the specific fuel.

Calculation of CO_2 emissions requires oxidation factors as well. While combusting efficiently, maximum amount of carbon in the fuel is oxidised. However for few types of fuel a little part of the carbon contained in the fuel escapes oxidation (Wu et al., 2017). This fraction is usually very small. For instance the Revised 1997 IPCC (1997) provides oxidation factor for gaseous fuels 0.995, i.e. 0.005 percent of the gas combusted was oxidized. However the updated methodology (IPCC, 2006) provides all oxidation factors equal 1, since the oxidized fraction is usually negligible. While using factor 1 the possible underestimation of the emission level is impossible, which is the purpose of this given default value. However for some type of fuels the factor 1 overestimates emissions; in case the country is having its own analyses of the fuels used, it is recommended to use them for computation of the emission levels.

Default emission factors, net calorific values as well as the oxidation factors are listed in the IPCC methodology (IPCC, 1997, IPCC, 2006). However the countries are recommended to develop their country specific emission or oxidation factors as well as the net calorific values. The Czech Republic is currently using country specific emission factor for coking coal, bituminous coal and lignite (CHMI, 2016) as well as for the LPG and refinery gas (Krtkova et al., 2014). For the natural gas the Czech Republic developed correlation curve between the net calorific value and emission factor which allows determination of the specific emission factor for the Czech Republic for the specific year (Krtkova et al., 2014). Emission factors for different gases and fuels are presented in Annex 2. Even though country specific emission factors are usually not too different from the default ones, use of country specific emission factors, which takes into account national conditions, should considerably enhance the accuracy of the greenhouse gas inventories. From this reason it is proper to make the effort to develop country specific emission factor using as many as possible specific data typical for the Czech Republic. Country specific emission factors are used for Natural Gas, Refinery Gas, Liquefied Petroleum Gas, Coking Coal, Bituminous coal, Lignite and Gas works Gas. Further, country specific oxidation factors for Bituminous Coal, Lignite and Brown Coal briquettes was also developed The following equation describes the approach of emission calculation

$$\boldsymbol{E\ [kt] = (AD\ [TJ] \times EF\ [\tfrac{kg}{TJ}] * OxF)/1000} \qquad \textbf{Equation 4}$$

where E yields for emissions, AD for activity data (amount of the fuel combusted), EF for emission factor and OxF for oxidation factor. The calculated data has to be sorted out in the required categories by IPCC (2006). The required categories and subcategories are listed in the Annexes 1a and 1b.

Computation model of greenhouse gas emissions was developed using interconnected .xls sheets. Input data are provided by CzSO in official Eurostat/IEA/OECD annual questionnaires, which include information about consumption of different kind of fuels in the specific sectors. The input files provide data for solid fuels, liquid fuels, gaseous fuels, renewable fuels and biofuels. Further, other fuels are combusted for energy purposes, mainly waste. This is waste combusted for the purpose of heat and electricity production. List of fuels is basically following requirements of the IPCC 2006 Guidelines. Table 1 provides list of the fuels reported in the official CzSO questionnaires.

Table 1 Fuels available in the official CsZO questionnaires

Liquid Fuels	Solid Fuels	Gaseous Fuels	Renewable Fuels
Refinery Gas	Anthracite	Natural Gas	Wood/Wood Waste
LPG	Coking Coal		Gaseous Biomass
Naphtha	Other Bituminous Coal		Charcoal
Gasoline	Brown Coal + Lignite		
Kerosene Jet Fuel	Coke		
Other kerosene	Coal Tars		
Diesel Oil	Brown Coal Briquets		
Heating and Other Gasoil	Gas Works Gas		
Fuel Oil – Low Sulphur	Coke Oven Gas		
Fuel Oil – High Sulphur			
Residual Oil			
Lubricants			
Other Oil			

The original data are then transferred to the excel file, which respects the structure, however further, it includes also relevant subcategory shortcut. These shortcuts are used in the in the following step to combine the initial data in the required category structure. Further, the data has to be converse into the energy units (e.g. joules). When the activity data is structured in the requested categories, the emissions of CO_2, CH_4 and N_2O can be calculated. For that relevant set of emissions factors is needed, in the case of CO_2 also oxidation factor is used. In the final step of the calculation the activity data and emissions are summed up to the structure accepted by the official reporting tool developed by UNFCCC – CRF Reporter. The structure of reporting of emissions is based on the groups of fuels – solid fuels, liquid fuels, gaseous fuels, biofuels and other fuels. Currently, the official questionnaires, provides data for the time series 1990–2016.

For the projections of future emission levels, the same model is used emissions of greenhouse gases, which are arising from the stationary combustion. The design of the calculation follows the same design, as it is followed for the emissions estimation used for the emission inventory reporting (as explained above). It implies, that expected consumption of the fuels has to be applied in the model. Since the Czech Republic has its own coal mines, the coal is dominant especially in the sector of public heating and electricity production. It is expected to still play major role also in 2020. However, in further year decline of the coal usage for the purposes of energy generation is expected, also planned by specific policy instruments. However, the amount of electricity and heat production has to be maintained, which means, that coal has to be replaced by different fuels. Major expectations are for using of the natural gas. The natural gas has approximately 50% lower emission factor of CO_2, than the coal. By replacing the coal by natural gas, emissions are decreasing.

Further, National Renewable Energy Action Plan is operating in the Czech Republic. It implies that the share of renewable fuels on the total production of energy should by 2020 be at least 13% and the share should be ideally rising. Hence, more significant inclusion of renewables in the inventory is also decreasing the amount of the CO_2 emissions in the total inventory. It is necessary to point out, that CO_2 emissions arising from the combustion of renewable fuels are not accounted in the total inventory emission budget. The emissions from biomass are all reported under the sector Land Use, Land Use change and Forestry. If the CO_2 arising from the biomass combustion would be included, it would lead to the double-counting of emissions. The expected development of the fuels consumed was applied for the calculation of projections. Table 2 presents data, which were inserted in the model for emissions estimation.

Table 2 Expected domestic coal mining

Category of coal (company – mine)	**Maximum mining (units)**	**2016**	**2020**	**2025**	**2030**	**2035**
Hard coking coal	PJ	116.6	35.1	0.0	0.0	0.0
	thousand t	4,400	1,300	0	0	0
Hard steam coal	PJ	79.5	24.3	0.0	0.0	0.0
	thousand t	3,000	900	0	0	0
Brown steam coal (SD – Libouš)	PJ	166.8	115.0	115.0	109.2	69.0
	thousand t	14,500	10,000	10,000	9,500	6,000
Brown steam coal (SD – Bílina)	PJ	134.0	134.0	121.4	111.5	90.3
	thousand t	9,500	9,500	8,600	7,900	6,400
Brown steam coal (CC – Vršanská uhelná)	PJ	62.4	67.6	67.6	67.6	62.4
	thousand t	6,000	6,500	6,500	6,500	6,000
Brown steam coal (Severní energetická)	PJ	59.0	45.0	0.0	0.0	0.0
	thousand t	3,280	2,500	0	0	0
Brown steam coal (SU – total)	PJ	69.4	53.8	50.2	50.2	50.2
	thousand t	5.600	4.500	4.200	4.200	4.200

Further, scenarios explained as well as policy instrument was reflected in the primary data development in the future (eg. share of the renewables). The model is then able to reproduce the calculation already set up for the emission inventory calculation.

It is crucial to provide connection between different files in one directory. The interconnection was programmed from the initial questionnaire till the final template required for the reporting of projections for the European Commission. Figure 3 is presenting approach of the developed emission model.

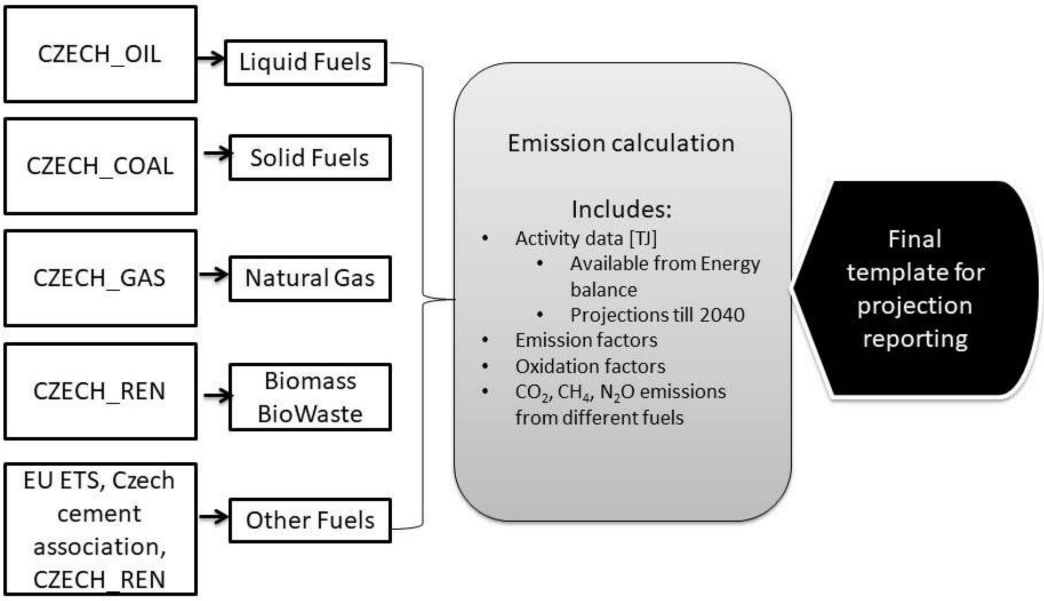

Figure 3 Structure of emission calculation and projection model

4.1.1.1. Natural Gas

Carbon dioxide emissions from combustion of natural gas constitute significant contribution to the total CO_2 emission in the Czech Republic's greenhouse gas (GHG) inventory. IPCC (Intergovernmental Panel on Climate Change) Guidelines (Vol. 2 Workbook) (IPCC, 1997) provide default emission factor for natural gas combustion which is considered to be a general value acceptable for all countries. Introduction of this emission factor into the IPCC methodology was based on the study of Marland and Rotty (1984) and its usability was also discussed and supported by Harmelen and Koch (2002). The emission factor was developed based on the representative group of results of measurements of natural gas composition, its net calorific value and density. These results were provided by the company distributing natural gas in the Czech Republic (NET4GAS, Ltd.). Principles of this approach result from the research described in the paper from Kolář et al. (2004), from the basic principles provided in European Standard EN ISO 6976 (EN ISO 6976:2005) and from the work of Čapla and Havlát (2006).

IPCC methodology (IPCC, 1997, 2000, 2006) provides default emission factors for natural gas combustion which is related to the energy content of fuel (usually TJ), which is possible to obtain from net calorific value. The default emission factors given in the Revised 1996 Guidelines (IPCC, 1997) and the one given in IPCC 2006

Guidelines (IPCC, 2006) are only a bit different: while in the Revised 1996 Guidelines the oxidation factor corresponds to 0.995 (99.5%), in the 2006 Guidelines the default oxidation factor is equal to 1 (100%). Table 3 shows the difference between emission factors provided by these two default approaches.

Table 3 Default emission factors provided by Revised 1996 Guidelines IPCC (1997), IPCC (2006), IPCC (2006)

	Emission factor [t CO_2/TJ]	**Oxidation factor**	**Resulting emission factor [t CO_2/TJ]**
Revised 1996 Guidelines	56.1	0.995	55.81
IPCC 2006 Guidelines	56.1	1.000	56.1

4.1.1.1.1. Emission factors used by Annex I Parties of UNFCCC

Figure 4 shows implied emission factors1 used by Annex I Parties of UNFCCC as are presented in the officially submitted CRF (Common Reporting Format) tables of 2013 submissions. The emission factors depicted in Figure 1 were used by Annex 1 Parties for calculations of CO_2 emissions raised from Natural Gas combustion in 2011. Dotted line in the Figure 1 indicates default value of emission factor 56.1 t CO_2/TJ. Similar approach of comparison of implied emission factors used by Annex 1 Parties was applied by Pulles and Hongway (2011) for gasoline and diesel oil.

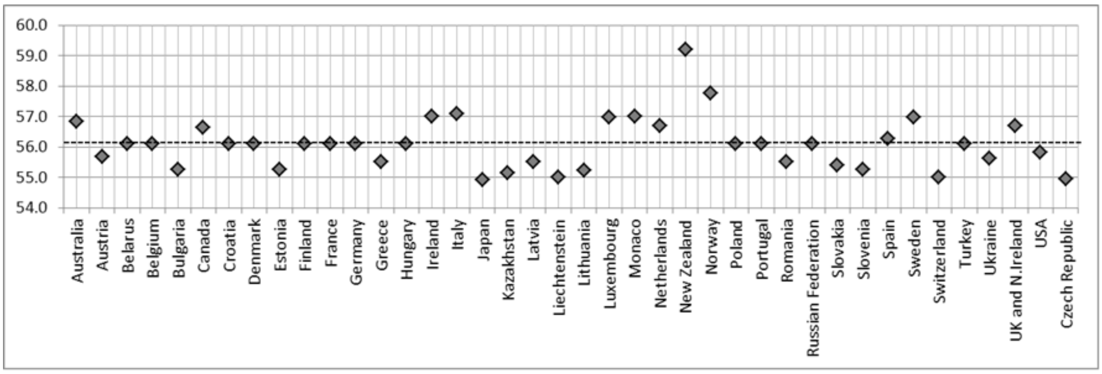

Figure 4 Implied emission factors used by Annex I Parties

From the Table 3 is apparent that both methodologies use the same emission factor. The difference is only in default oxidation factor and so the final emission factor is slightly different (Table 3). It is then necessary to expect that default

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[1] Implied emission factor" is the expression used in CRF tables for the ratio of emissions and activity data. This factor is used mainly for the control purposes and is not use for computations. The implied emission factors are (contrary to the emission factors used for computations) publicly available from the CRF tables. In the case of gaseous fuels, where it is usually depicted only natural gas, the implied emission factor is basically equal to the emission factor used for computations of emissions.

emission factors (including oxidation factor) will be in range from 55.8 to 56.1 t CO_2/TJ.

There is group of countries using emission factors from the mentioned interval which is apparent on the Figure 4 – Belarus, Belgium, Croatia, Hungary, Poland, Russian Federation and Turkey. These countries used also default oxidation factor 99.5%. Besides there are few countries, e.g. Spain or Germany, which have developed country specific emission factor but their emission factor is really close to the default emission factor. It is apparent that most of the Annex 1 countries has developed their country specific emission factor lower than the default emission factor. To this group belongs for instance Switzerland and Slovakia, the lowest emission factor is used by Japan. Also the country specific emission factor for the Czech Republic is lower than the default one. Since Slovakia and Czech Republic both use similar natural gas (majority comes from the Russian gas fields), the country specific emission factors should be quite similar. In Slovakia the company "SPP – distribúcia, a. s.", which distributes the natural gas, provides monthly data about natural gas composition as well as its physical properties. The country specific CO_2 emission factor for natural gas combustion in stationary sources used by Slovakia for emissions in 2011 was 55.11 t CO_2/TJ (GHG emission inventory, SHMU 2013). The emission factor used by the Czech Republic for 2011 emissions equals 54.96 t CO_2/TJ. These emission factors includes also oxidation factor 99.5% (IPCC, 1997). On the other hand there is group of countries which use for calculations higher country specific emission factor than from the "default interval" 55.8–56.1 t CO_2/TJ. Representatives of this group are Netherlands and Luxembourg. The highest emission factor in the group of Annex 1 countries was developed by New Zealand. For the comparison of emission factors was necessary to distinguish whether the countries represent activity data in TJ based on expression by using net calorific value or gross calorific value. Australia, Canada, Japan, New Zealand and USA are using for expression of their activity data gross calorific values and implied emission factor is then also influenced. Based on the methodology (IPCC, 1997, 2006) are the activity data expressed by using net calorific value 0.9 times lower than activity data expressed based on gross calorific values. For the above mentioned countries was then necessary to divide implied emission factors by coefficient 0.9.

4.1.1.1.2. Relationships for computation for CO_2 emission factor related to its mass or volume of natural gas

In derivation of relationships for the calculation of the CO_2 emission factor, the volume of natural gas must be expressed under exactly defined conditions (temperature, pressure). The mass and mole fractions are related by the following equation

$$\boldsymbol{w_i/y_i = m_i \times n/(m \times n_i) = M_i/M} \qquad \textbf{Equation 5}$$

where w [kg/kg] is the mass fraction, y [mole/mole] is the mole fraction, m [kg] is the mass, n [mole] is the amount of substance, M_i [kg/kmole] is the molecular weight, M [kg/kmole] is the average molecular weight of natural gas and i is a component index. The mass fraction of carbon W_{c_i} is computed from the relationship

$$\boldsymbol{W_{c_i} = m_{c_i}/m_i = N_{c_i} \times M_c/M_i} \qquad \textbf{Equation 6}$$

where m_{c_i} [kg C] is the mass of carbon in the i'th component of natural gas, N_{c_i} is the number of carbon atoms in the molecule of the i'th component and M_c [kg/kmole] is the carbon atomic weight.

After rearrangement of the equation and dividing both sides of the equation by , is obtained

$$\boldsymbol{m_{c_i}/m = w_i \times N_{c_i} \times M_c/M_i} \qquad \textbf{Equation 7}$$

Summation over all the components yields the final relationship for the emission factor related to the mass

$$\boldsymbol{CEF_m = W_c = \sum w_i \times N_{c_i} \times M_c/M_i} \qquad \textbf{Equation 8}$$

where CEF_m [kg C/kg] is the carbon emission factor related to the mass and W_c [kg C/kg] is the mass fraction of carbon in natural gas.

Multiplication by density d yields the emission factor for carbon related to the unit of volume

$$\boldsymbol{CEF_v = W_c \times d} \qquad \textbf{Equation 9}$$

The density can be expressed either by the density measured experimentally or by the density calculated on the basis of the equations of state. If it is assumed that under normal conditions natural gas behaves like an ideal gas, the density can be determined from the equation

$$\boldsymbol{d = m/V = M/22.41} \qquad \textbf{Equation 10}$$

where 22.41 Nm^3/mole is the molar volume of an ideal gas under normal conditions (101.3 kPa, 0 °C). The assumption about an ideal gas is an adequate approximation for natural gas where the main component is methane.

In technical practice so called “trade conditions” (101.3 kPa, 15 °C) are more widely used than normal conditions. Also CzSO gives its annual consumption primary data of natural gas in volume under “trade conditions”2. Therefore in this paper just trade conditions were considered when expressing volume, density, etc.

4.1.1.1.2.1. Principles of determination of CO_2 emission factor related to the energy content of natural gas

The net calorific value of natural gas can be computed on the basis of the molar composition according to

$$\boldsymbol{Q_m = \sum w_i \times Q_{m_i}} \qquad \textbf{Equation 11}$$

$$\boldsymbol{Q_v = Q_m \times d} \qquad \textbf{Equation 12}$$

where Q_m [MJ/kg] is the net calorific value of natural gas related to its mass, w [kg/kg] is the mass fraction, Q_{m_i} [MJ/kg] is the net calorific value of different components of natural gas related to their mass, Q_v [MJ/m^3] is the net calorific values of natural gas related to its volume and d [kg/m^3] is its density. Table 2 lists the net calorific values Q_{m_i} of the basic components of natural gas.

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[2] Under “trade conditions” density of gas is a bit lower then under the normal conditions, by the coefficient 273.15/(273.15+15). Similarly, the volume of gas under trade conditions is (273.15+15)/273.15 times higher than under normal conditions.

Table 4 Net calorific values of the basic components of natural gas (ČSN EN ISO 6976, 2006)

Net calorific values of basic components of Natural Gas [MJ/kg]	
methane	50.035
ethane	47.52
propane	46.34
iso-butane	45.57
n-butane	45.72
iso-pentane	45.25
n-pentane	45.35
sum C>6 (like heptane)	44.93

The carbon emission factor for natural gas related to its energy content is computed according to

$$CEF_{TJ} = CEF_m / Q_m \quad \textbf{Equation 13}$$

$$\mathbf{EF\ (CO_2) = \ CEF_{TJ} \times M_{CO_2}/M_c} \quad \textbf{Equation 14}$$

where CEF_{TJ} [t C/TJ] is the carbon emission factor related to the energy content.

Application of the mentioned equation can be showed on the following example. In the October 2010 were by the NET4GAS company determined parameters of the natural gas (molar composition, net calorific value Q_v and density d) showed in Table 5. Calculated density for this natural gas equalled 0.7002 kg/m^3 (considering “trade conditions”), which is in a good agreement with the density provided by the distributor (0.7014 kg/m^3). Carbon mission factor related to the mass equalled 0.7391 kg C/kg and carbon emission factor related to the volume equalled 0.5175 kg C/m^3. For the recalculation of both emission factors to the CO_2 is used the rate of molecular masses $\mathrm{M_{CO_2}/M_c}$ = 44.010/12.011.

Table 5 Provided parameters of the natural gas, trade conditions (15 °C, 101.325 kPa), special case for October 2010

Parameters of the natural gas		
methane	[mol %]	97.164
Ethane	[mol %]	1.306
propane	[mol %]	0.423
iso-butane	[mol %]	0.067
n-butane	[mol %]	0.067
iso-pentane	[mol %]	0.009
n-pentane	[mol %]	0.014
sum C>6 (like heptane)	[mol %]	0.002
CO_2	[mol %]	0.143
N_2	[mol %]	0.805
SUM	[mol %]	100.000
net calorific value	[MJ/m^3]	34.390
density	[kg/m^3]	0.7014

Expression of emission factors related to TJ in accordance with IPCC (1997, 2006) provides following values calculated entirely from the composition of natural gas:

$$Q_m = 49.036 \text{ MJ/kg} \qquad Q_v = 34.333 \text{ MJ/m}^3$$

$$CEF_{TJ} = 15.073 \text{ t C/TJ} \qquad EF\ (CO_2) = 55.228 \text{ t CO}_2\text{/TJ}$$

In case of using density and net calorific value provided by NET4GAS company instead of the calculated variables the results are following:

$$Q_m = 49.032 \text{ MJ/kg} \qquad Q_v = 34.390 \text{ MJ/m}^3$$

$$CEF_{TJ} = 15.074 \text{ t C/TJ} \qquad EF\ (CO_2) = 55.231 \text{ t CO}_2\text{/TJ}$$

From the comparison of both approaches is obvious, that resulting emission factors and correspondent net calorific values are very close in both cases.

4.1.1.1.2.2. Use of correlations between emission factor and net calorific value

A similar method of computing EF (CO_2) and Q_v for 10 characteristic samples of natural gas was used in the article (Čapla and Havlát, 2006). Samples 1 – 4 were chosen based on their place of origin: sample 1 – natural gas from Russian gas fields distributed in the Czech Republic in 2001; sample 2 – natural gas from Norwegian gas fields in the North Sea; sample 3 – natural gas coming from Dutch gas fields; sample 4 – natural gas mined in Southern Moravia. Samples 5 – 10 represented the composition of the natural gas distributed in the Czech Republic in 2005 – 2006. This extensive dataset was used to determine the regression curve, which was similar to the curve

$$\boldsymbol{EF(CO_2) = 0.269 \times (Q_v/3.6)^2 - 2.988 \times (Q_v/3.6) + 59.212} \qquad \textbf{Equation 15}$$

which was tightly fit to all 10 points. In this correlation expression Q_v represents the net calorific value related to the volume at “trade conditions” (15 °C, 101.3 kPa). The calculations of the regression curve for the samples 5–10 indicated in particularly close range of Q_v: 34.11–34.27 MJ/m^3. The lowest net calorific value (31.31 MJ/m^3) was determined for sample number 3 (Dutch field) and the highest (38.28 MJ/m^3) for Norwegian gas type. The low net calorific value of Dutch natural gas is caused by relatively high content of nitrogen; the high net calorific value of the Norwegian natural gas is a result of the higher content of C2, C3 and C4 hydrocarbons (especially ethane).

Assessment of the new correlation relation

The above-described methodology was tested on a relatively small dataset. To achieve sufficiently reliable correlation, this methodology had to be tested on a dataset which would provide composition of natural gas in sufficiently long time series. In cooperation with Czech Statistical Office a dataset comprising analyses of natural gas composition was received. These analyses are continuously evaluated in the laboratory of NET4GAS, Ltd. The samples were taken in the border transfer station Lanžhot, from where is the natural gas delivered into the transit system in the axis east-west for the transition of natural gas across the territory of the Czech Republic. Transit pipeline is also the main pipeline for the distribution of natural gas in the area of the Czech Republic. About 80% of all natural gas delivered to the Czech Republic is transferred across this border transfer station (BTS).

On the border transfer stations are build the laboratories, which are supplied by modern technics for the determination of gross calorific values (GCV) and for the analysis of natural gas. The laboratories are operated by NET4GAS, Ltd. GCV determination is carried out by calorimetry method, the analyses of natural gas are conducted by chromatography. Since 2006 is in ČR valid the European Standard EN ISO 6976 (EN ISO 6976:2005), which allows the determination of calorific values by computation from its composition. This standard in used for the verification of GCV determined by calorimetric method.

Daily average values of the natural gas composition from the first day in the month were available for evaluation of the CO_2 emission factor. The dataset of these analyses began on 1st January 2007 and the last data are from 1st September 2011. Furthermore data for 1st February 2012 were also available. The report on each analysis contains data on the molar composition of the natural gas, physical characteristics (including net calorific values and density)and conditions during which the analysis was performed. Overall, 58 analysed samples were available. Figure 5 depicts the trend of net calorific values in time based on the available dataset: one value is reported directly by the distributor (NET4GAS, Ltd.), second value is calculated from equations (11, 12). It indicates a good match between the two depicted values; the mean relative difference is almost constant and reaches an average value of 0.16%. This difference is probably caused by the fact that the calculation of net calorific values is based on the assumption of ideal gas behaviour, although in the real case this assumption does not have to be entirely fulfilled. For this reason, the net calorific values from the NET4GAS, Ltd. reports were used for calculation of the emission factor. These reports contain data related to the reference temperature 20 °C; thus, it was necessary to recalculate net calorific values and densities for 15 °C (i.e. trade conditions).

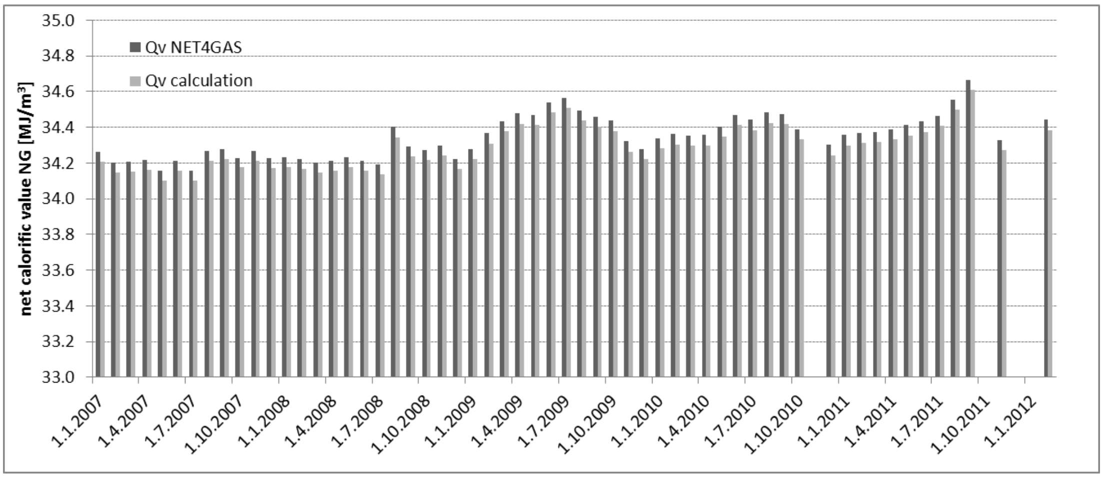

Figure 5 Trend of net calorific values in time

Similarly as for net calorific values were also relative differences of measured and calculated densities determined. The mean relative deviation was for this case determined at the level of 0.18%. Also for this case the calculated values were a bit lower than the values provided by the Net4GAS, Ltd. When comparing (i) emission factors calculated only from composition of natural gas and (ii) emission factors calculated from composition and obtained net calorific values and densities, there were discovered very small differences, in average about 0.02%. This can be explained by the fact, that the differences for net calorific values and densities have compensated each other (please see the example of calculation in the chapter 4). However from the reasons listed above (possibility of small deviations from the ideal gas behaviour), for the determination of correlation equation the values of emission factors calculated based on the net calorific values and densities provided by the NET4GAS, Ltd. were used.

The results of the emission factor calculations are depicted in Figure 6. This figure shows the correlation equation calculated by linear regression from the NET4GAS, Ltd. dataset

$$\mathbf{EF}\ (\mathbf{CO_2}) = \ \mathbf{0.787}\ \times \boldsymbol{Qv} + \mathbf{28.21} \qquad \textbf{Equation 16}$$

where Q_v [MJ/m^3] is the net calorific value of natural gas at 15 °C and pressure of 101.3 kPa (trade conditions). Besides the correlation factor R2 also standard deviation was evaluated, which relative value was 0.065%. Mean relative difference of each point from regression curve is 0.05%. Both these values can be understood as indicator of uncertainty of the emission factors calculated based on the equation (16). This indicator of uncertainty is adequately low. It can be stated that accuracy of determination of emission factors for combustion of natural gas from its net calorific values based on the equation (16) is very good.

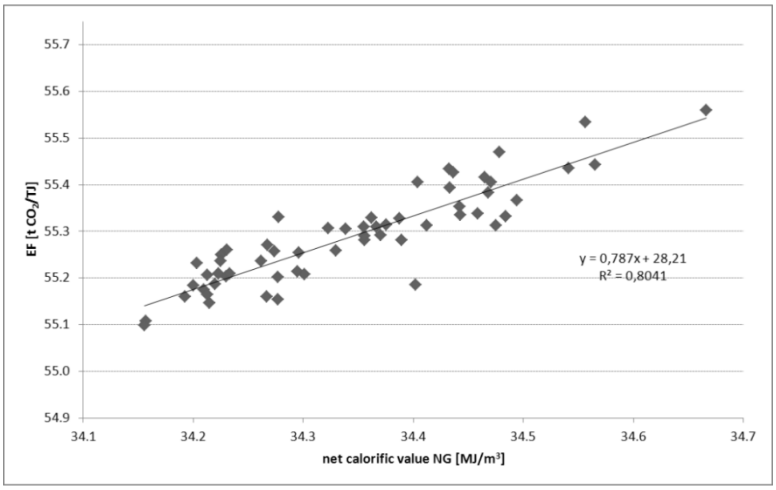

Figure 6 Results of the emission factor calculations

The correlation presented above was compared with two other ones. The first equation was evaluated during the initial phase of the research when it was necessary to test the method of calculating emission factors and possibility to find suitable correlation with net calorific values. The dataset used for this purpose was obtained from RWE Transgas and contained 14 analysed samples of natural gas from years 2003, 2004 and 2009. Using linear regression the following correlation was evaluated from this dataset

$$\mathbf{EF}\ (\mathbf{CO_2}) = \ \mathbf{0.6876}\ \times \boldsymbol{Qv} + \mathbf{31.619} \qquad \textbf{Equation 17}$$

The second correlation for comparison is the equation (15) taken from the paper of Čapla and Havlát (2006).

Figure 7 depicts graphical comparison of all three correlations. It indicates good correspondence between all three cases, especially in the region of 34.1–34.3 MJ/m^3, where the deviation between the results is less than 0.3%.

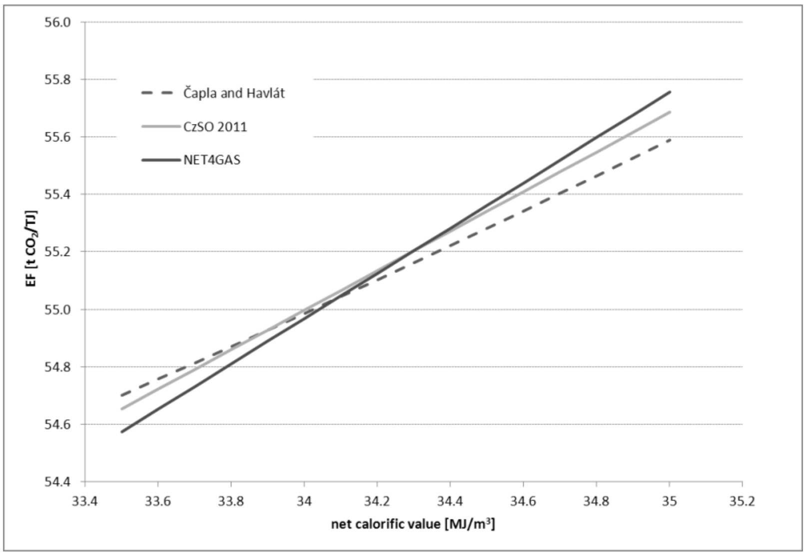

Figure 7 Comparison of all three correlations

4.1.1.1.3. Range of real net calorific values of natural gas and proposition of emission factors

Each year in its energy balance, the Czech Statistical Office reports the average value of net calorific value of natural gas. Figure 5 indicates the trend of these calorific values. It is apparent that net calorific values continuously slightly increasing. The dashed line in Figure 8 indicates the lowest net calorific value determined in the dataset provided by NET4GAS, Ltd. in 2007–2012. For the period 1990–2005 all the net calorific values are lower than 34.1 MJ/m^3. For this reason, it is more accurate to use the correlation obtained from the dataset representing the data before 2006, i.e. the correlation evaluated by Čapla and Havlát (2006).

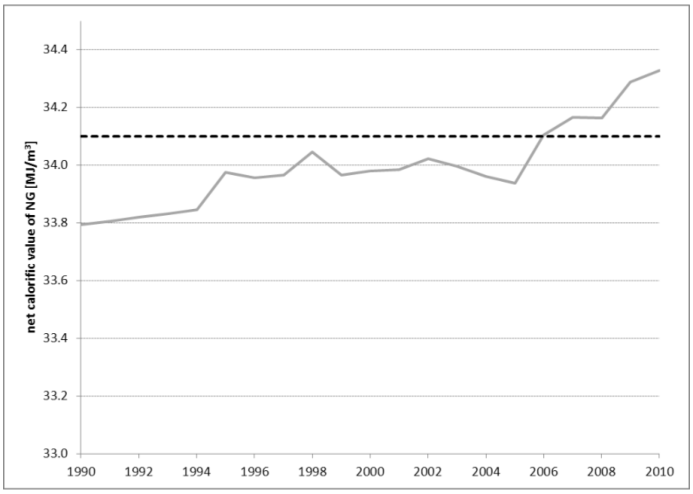

Figure 8 The course of the net calorific value during the time-series

The correlation (12) based on the dataset from NET4GAS, Ltd. should be more suitable since 2006. Figure 9 depicts the correlation curve combined on the basis of both correlations. It is given for the whole range of net calorific values, which was identified for the natural gas in the Czech Republic in the 1990–2010 period. The value 34.1 MJ/m^3 is depicted by the dashed line.

Evaluation of CO_2 emission factors for natural gas combustion is based on the computational approach described above. There are two correlation relations; each of them is used for a different range of net calorific values. As depicted in Figure 6, both correlations follow each other closely. Table 4 lists all the calculated emission factors for both correlations; the recommended values are in bold.

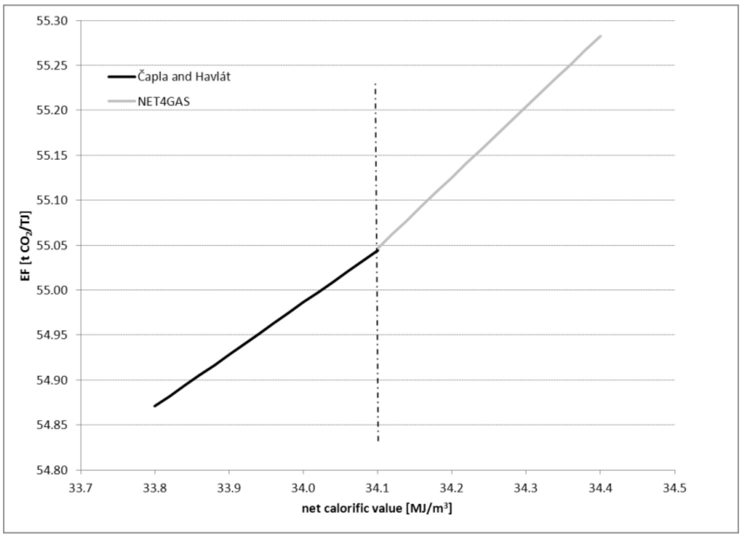

Figure 9 Combined correlation curve

The deviations between the two calculations are less than 0.15%. The values written in bold were used for recalculation of CO_2 emissions from natural gas combustion for the 1990–2010 time-series. Former submissions employed the default emission factor 56.1 t CO_2/TJ, which overestimated the CO_2 emissions from natural gas combustion, especially at the beginning of the nineteen nineties (about 2.4% in 1990).

For 2011 the correlation relation based on the NET4GAS, Ltd. dataset was used (equation 18):

$$\mathrm{EF}\,(\mathrm{CO_2}) = \mathbf{0.787} \times \boldsymbol{Qv} + \mathbf{28.21}$$

Equation 18

It is important to prove that the emission factor is suitable also for the years at the early nineties; however from the available data there was no evidence, that the average composition of natural gas was the same at the beginning of reported time-series. The data from the beginning of nineties are unfortunately not available for the authors. On the other hand the Czech Statistical Office reports every year average net calorific value of different kind of fuels, among which belongs also natural gas. Then it is more reliable to use this quantity to evaluate country specific emission factor each year based on the correlation between net calorific value and emission factor. The country specific emission factor for natural gas combustion was developed using the calculation based on the representative sets of data of natural gas composition, including measured densities and net calorific values.

Final emission factors for each year from the period 1990–2010 for the purpose of the Czech national inventory are given in Table 6(marked in bold). Also for next years the emission factors will be evaluated based on the equation (16) with the use of net calorific values provided by CzSO. The basis of development of the country specific emission factor every year is in the relationship of the emission factor to the net calorific value. This approach enabled determination of the specific emission factor for each specific year.

Table 6 Comparison of both recommended correlations

year	Average net calorific value of Natural Gas reported by CzSO	EF CO_2 calculated on the basis of Čapla and Havlát correlation	EF CO_2 calculated on the basis of NET4GAS, Ltd. analyses correlation
	[MJ/m^3]	[t CO_2/TJ]	[t CO_2/TJ]
1990	33.794	54.87	*54.81*
1991	33.807	54.87	*54.82*
1992	33.820	54.88	*54.83*
1993	33.832	54.89	*54.84*
1994	33.845	54.90	*54.85*
1995	33.975	54.97	*54.95*
1996	33.957	54.96	*54.93*
1997	33.966	54.97	*54.94*
1998	34.046	55.01	*55.00*
1999	33.965	54.97	*54.94*
2000	33.980	54.97	*54.95*
2001	33.986	54.98	*54.96*
2002	34.023	55.00	*54.99*
2003	33.997	54.98	*54.97*
2004	33.962	54.96	*54.94*
2005	33.938	54.95	*54.92*
2006	34.105	*55.05*	55.05
2007	34.167	*55.08*	55.10
2008	34.164	*55.08*	55.10
2009	34.288	*55.16*	55.19
2010	34.328	*55.18*	55.23

It is apparent, that the default emission factor (56.1 t CO_2/TJ) slightly overestimates the CO_2 emissions, e.g. by about 2.4% in 1990 and 1.6% in 2010.

4.1.1.2. Refinery Gas

Refinery Gas is produced during the oil distillation or during processing of oil products (for instance cracking process). Refinery Gas use in the Czech Republic is mostly composed from hydrogen (around molar 40%), methane (around molar 25%) and other aliphatic hydrocarbons (C2-C7), which share in the refinery gas composition is decreasing which higher carbon number. Nitrogen, carbon monoxide and carbon dioxide are also present in the refinery gas. The composition of refinery gas depend on the conditions in the respective refinery, so it is heavily country specific. Czech refineries are analysing composition of the refinery gas. Development of country specific emission factors was carried out based on three different data databases, which were supplied by the Czech refinery. The databases included information about refinery gas composition for the 2008 till 2012 in the time step of four days. From the available data were obtained average emission factors and net calorific values for each dataset for each year 2008 till 2012. The approach for the emission factor development is similar to the one presented for the Natural Gas. The results are presented in the Table 7.

Table 7 Emission factors for Refinery Gas for 2008 till 2012

		2008	2009	2010	2011	2012
Data file A						
Net calorific value	MJ/kg	46.88	46.86	47.61	46.98	46.75
Emission factor	t CO_2/TJ	57.62	55.53	53.82	55.51	57.55
% of gas consumption		44.3%	48.5%	44.9%	41.6%	48.3%
Data file B						
Net calorific value	MJ/kg	43.78	43.69	44.28	42.96	44.57
Emission factor	t CO_2/TJ	54.32	55.64	54.29	58.48	55.86
% of gas consumption		30.2%	25.3%	27.9%	30.5%	26.3%
Data file C						
Net calorific value	MJ/kg	47.49	47.25	47.81	47.07	47.32
Emission factor	t CO_2/TJ	52.02	52.24	51.93	53.41	54.06
% of gas consumption		25.5%	26.2%	27.2%	27.9%	25.4%
Weighted averages						
Net calorific value	**MJ/kg**	**46.10**	**46.16**	**46.74**	**45.78**	**46.32**
Emission factor	**t CO_2/TJ**	**55.19**	**54.70**	**53.44**	**55.83**	**56.22**

Since data for 1990–2008 were no available, for there years the average value of emission factor and net calorific values is used, i. e. $EF = 55.08$ t CO_2/TJ, $Q = 46.22$ MJ/kg. The country specific values for the refinery gas are close to the default emission factor $EF = 57{,}5$ t CO_2/TJ (IPCC, 2006).

4.1.1.3. Liquefied petroleum gas

Liquefied Petroleum Gas (LPG) is a mixture of C2 till C2 hydrocarbons, while the significant part are C2 and C4 hydrocarbons. The hydrocarbon ae liquefied for the purpose of use in transport, storage and distribution. It is apparent, that the value of default emission factor in this case is significantly underestimated.

Two mixtures of LPG is available, the so called summer mixture and winter mixture. The composition of LPG must fulfil obligatory composition provided by the norm ČSN 656481. The requested composition is presented in the Table 8.

Table 8 Prescribed intervals of composition of propane – butane based on ČSN 656481; data about the composition of hydrocarbons are listed in mass percentage

Parameter	Summer mixture	Witer mixture
C2-hydrocarbons and inerts – %, max,	7	7
C3-hydrocarbons – %, min,	30	55
C4-hydrocarbons – %	30–60	15–40
C5-and higher hydrocarbons – %, max,	3	2
unsaturated hydrocarbons – %, max,	60	65
sulphide – mg*kg^{-1}, max,	0,2	0,2
Sulphur content – mg*kg^{-1}, max,	200	200

For the purposes of development of country specific emission factor was obtained composition of LPG from the Czech refinery. Typical composition is presented in the Table 9.

Table 9 Composition of LPG used for emission factor computation, data about share of specific components are presented in mass percentage

Gas	LPG summer	LPG winter
C2	0.2	0.1
Propane	38.5	58.7
Propylene	7.2	4.5
Izobutane	25.6	27.9
n-butane	15.7	5.9
Sum of butens	12.2	2.8
C5 and higher	0.6	0.1
Share of the production summer misture:winter mixture = 1 : 1.1		

Since the composition has to be in line with above mentioned norm, variability during the years is not expected. Further, previous version of the norm was consulted and no differences in the composition were observed. It is then safe to assume, that the composition is not changing during the time, further, the major producer of LPG in the Czech Republic is the same for the whole time series.

The developed country specific emission factor for LPG agrees well with the value published 65.6 t CO_2/TJ (Harmelen and Koch, 2002). Relevant net calorific value related to this emission factor is 45.5 MJ/kg (Harmelen and Koch, 2002), which is also in a very close agreement with the developed country specific one.

In comparison to that, default emission factor value is lower 63.1 t CO_2/TJ. It is apparent, that the default emission factor is underestimated, since emission factor for pure ethane would be 61.6 t CO_2/TJ and for pure propane 64.6 t CO_2/TJ, so the default emission factor would reflect mixture of C2 and C2 hydrocarbons, however not mixture of C3 and C4 hydrocarbons.

4.1.1.4. Coking Coal, Bituminous coal, Lignite, Gas works Gas, Brown Coal briquettes

Emissions of CO_2 produced during the combustion of solid fuels in the Czech Republic make a very significant contribution to the overall emissions of greenhouse gases. According to the IPCC methodology, emissions of CO_2 in the Czech national inventory are determined as a product of the consumption of fuels, expressed as the amount of energy [TJ] contained in the fuels determined on the basis of net calorific value, the emission factor for CO_2 [t CO_2/TJ] and the oxidation factor. In the methodology for greenhouse gas (GHG) inventory, IPCC provides the default emission factors for CO_2 for the individual types of fuels (IPCC, 1997, 2006).

The default emission factors tabulated in the IPCC methodology were determined as mean values on the basis of numerous calorimetric and analytical tests of individual types of fuels. However, the default carbon content factors for coal and lignite presented in 2006 Guidelines (IPCC, 2006) are the same as those reported earlier in 1996 Guidelines (IPCC, 1997) and thus these factors may not quite accurately reflect the present situation in the central Europe. The default emission factors are not necessarily applicable for the current national inventory in a specific country, where the nature of the various types of fuels may be different.

In the Czech Republic, where the main part of the CO_2 emissions from solid fuels comes from the combustion of lignite[3] and bituminous coal, it is significant to determine the country-specific emission factors for these two types of fuels.

There is practically no difference in the default emission factors for lignite and bituminous coal in the older and newer versions of the IPCC methodology. However a substantial change appeared in the recommended values for oxidation factor: while the older version (IPCC, 1997) reported a default value of the oxidation factor of 0.98, the new version (IPCC, 2006) uses a default value of 1, which is the maximum possible value and is, in practice, practically unattainable for solid fuels. The default value of 1 was chosen as a conservative estimate, preventing possible

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[3] Term “lignite” in accordance with the IPCC methodology in this paper includes all kinds of lignite and brown coal consumed in the Czech Republic

underestimation of the emission determination. Therefore a country which wants to prevent possible overestimation of the emissions of CO_2 from the combustion of solid fuels has to determine the representative country-specific values of the oxidation factor for the individual types of solid fuels on the basis of local data. IPCC methodology provides the default carbon content factors CC=27.6 [t C/TJ] for lignite and 25.8 [t C/TJ] for bituminous coal, respectively. These emission factors were used until 2006 in the Czech national inventory. On the basis of a recommendation of international expert review team (ERT) of the UNFCCC during the review conducted in February 2007, it was decided to use factors 27.27 and 25.43 [t C/TJ] for the CC values for lignite and bituminous coal; these values can be found in the national study of 1999 (Fott, 1999) and pertain to the condition of the coal base in the Czech Republic in the beginning of 1990s. The necessary data were not available for determination of the oxidation factor and therefore the default value of 0.98 from the 1996 Guidelines was used for the whole time series from 1990 to 2012 for all the solid fuels.

In the last years due to the implementation of the emission trading within EU ETS (Emission Trading Scheme), the operators of the larger plants burning coal began to systematically determine the emission factors for different types of coal, burned in these plants according to the prescribed requirements of European Directive 87/2003 EC including the relevant guidelines, regarding the methodology of monitoring (EU, 2012). Some operators gradually extended this assessment to also include the determination of oxidation factors, whose values depend not only on the type of coal, but also on the nature of the combustion source.

Data of the coal analysis published in 1999 were naturally not so extensive. Further, the coal base has largely changed since the beginning of the 1990s in the Czech Republic – production in less efficient mines has been gradually phased out and the coal in the existing mines is now often extracted at different sites, for example in deeper coal layers.

4.1.1.4.1. Revision and updating of the nationally-specific emission factors

Lately, lignite was extracted mostly in Northern Bohemia (the area around Most), which is the most significant lignite area in the Czech Republic, and to a lesser extent in the Western Bohemian region (the area around Sokolov). Bituminous coal is currently quarried only in the Ostrava-Karvina district in a large coalfield whose greater part is located in the neighbouring country of Poland. Lignite is extracted from surface mines in the Czech Republic, while bituminous coal is extracted from deep mines.

Overview of data sets for updating emission factors

The following four data sets (three different and one combined) were used for the updating emission factors.

“ČEZ” set: The most extensive collection of data with the results of chemical analyses, including calorific values, was obtained from the ČEZ company, which operates most of the coal-fired power plants in the CR, burning mainly energy (pulverized) lignite. The set contains 29 samples of bituminous energy (pulverized) coal and 146 samples of lignite, mainly energy coal and to a lesser extent also sorted coal – 25 samples; this is mostly from Northern Bohemia and, to a lesser extent, from the Western Bohemian region.

“Dalkia” set: This set was obtained from the Dalkia company, which operates mainly power and heating plants, burning mostly bituminous energy coal in the eastern part of the Czech Republic and, to a lesser extent, lignite. The “Dalkia” set contains analyses of mostly bituminous coal (143 samples), together with 36 samples of lignite.

Each sample (data point) from both data sets mentioned above contained results of analysis of collection of partial sub-samples that were put together regularly during a month.

“Combined” set of aggregated data: In order to evaluate the parameters required for determining the country-specific emission factors, the primary data were aggregated as it follows that aggregated items from the above-mentioned sets

("ČEZ" and "Dalkia") were acquired as averages of the net calorific values and the percentage carbon contents from six to twelve analysed samples (i.e. analysis of samples collected monthly).

The primary files, from which were the aggregated set created, had different structure: while ČEZ set was structured according to mines and mining localities, Dalkia set was split by plants and types of combustion facility. These structures were considered while creating the aggregated set of data. For instance one aggregated item obtained from ČEZ set contained average of twelve samples of lignite extracted from one locality in one year, while aggregated point from Dalkia contained average of six samples of lignite combusted in fluidized bed boiler of one heating plant, which were sampled during the heating season (for power plants with whole year operation were available twelve samples).

The "combined" set was extended by 3 aggregated items (yearly average for 2012) to include lignite from the West Bohemian region (Sokolovská uhelná, corp.).

The "Combined" set included three major operators of combustion sources in the Czech Republic and altogether contains 37 aggregated items, of which 19 were from the "ČEZ" set, 15 from the "Dalkia" set and three were obtained as described in the previous paragraph. This set contains 23 aggregated items for lignite (4 of which were from the "Dalkia" set) and 14 for bituminous coal (3 items from the "ČEZ" set, the remaining 11 items were from the "Dalkia" set). 18 aggregated items for lignite come from the more extensive North Bohemian region and 5 items for lignite come from the smaller West Bohemian region.

The range of net calorific values from this set for lignite is between 9.9 and 18.5 MJ/kg, while the range of net calorific values for bituminous coal is between 16.2 and 26.4 MJ/kg.

"ETS" set: The set contains data from the ETS database created in CHMI, which have been saved on certified forms filled in by the operators of energy installations in the Czech Republic under ETS. These forms, containing data for 2011, were provided to CHMI (Czech Hydrometeorological Institute) by the Ministry of Environment. The processing took into account only those installations whose annual emissions exceeded 50 kt CO_2 and which, in accordance with the EU monitoring guidelines, determined the emission factors from the laboratory data. In this way, 34 data points burning lignite and 13 burning bituminous coal were processed.

In this case, the range of net calorific values for lignite was between 10.4 and 18.8 MJ/kg, while for bituminous coal they ranged between 17.1 and 26.8 MJ/kg.

Procedure for evaluating the emission factors

For determination of the country-specific emission factors, it is necessary to obtain data about the carbon content in a given type of fuel and its net calorific value. The carbon content factor (CC) for the individual types of solid fuels is defined as the ratio of the weight of the carbon and the amount of energy in this fuel with mass m

$$\boldsymbol{CC = \frac{m \times w_C}{m \times Q_i^r} = \frac{w_C}{Q_i^r}} \qquad \textbf{Equation 19}$$

where w_C is the mass fraction of the carbon in the fuel and Q_i^r is its net calorific value. It is important to notice that all the variables in the equation (19) are related to the fuel (coal) with its actual water content in the supplied fuel, i.e. in the state, in which the quantity (i.e. mass) is determined: raw – index ^{r}.

As the net calorific value is expressed in MJ/kg = TJ/kt, the carbon content in % mass ($C^r = 100 \times w_C$) and the carbon content factor CC in t C/TJ, the previous equation can be rewritten as:

$$\boldsymbol{CC[t\ C/TJ] = \frac{10 \times C^r[\%]}{Q_i^r[MJ/kg]}} \qquad \textbf{Equation 20}$$

The emission factor for CO_2, EF (CO_2), in [t CO_2/TJ] is obtained by multiplying by the ratio of the molar weights of carbon dioxide and carbon

$$\boldsymbol{EF\ (CO_2) = CC \times 3.664} \qquad \textbf{Equation 21}$$

Fott, 1999 demonstrated that there is a linear correlation between the carbon content C^r[%] in the coal and its net calorific value Q_i^r [MJ/kg].

$$\boldsymbol{C^r = a \times Q_i^r + b} \qquad \textbf{Equation 22}$$

with a correlation coefficient r^2 greater than 0.99. This correlation equation fits the values for bituminous coal and lignite, therefore both types of coal can be described by a single equation (i.e. a single pair of parameters a, b).

Taking into account equation (20), the dependence between the carbon content factor CC [t C/TJ] and the net calorific value Q_i^r [MJ/kg] can be obtained.

$$\boldsymbol{CC = 10 \times (a + \frac{b}{Q_i^r})}$$ **Equation 23**

In this approach, the country-specific parameters *a* and *b* in equations (22) and (23) are evaluated instead of usually used two separate values of the country-specific factor for lignite and bituminous coal.

This procedure was also applied to the current data. The two most representative sets were used for the process: the combined set of aggregated data, hereinafter referred as “Combined”, and “ETS”. At the same time, parameters a and b were evaluated for the “Combined” set by using equation (22) and for the “ETS” set from equation (23).

In Figure 10 it can be seen that, for the combined data set “Combined”, a correlation between the carbon content and the net calorific value can be described for both types of coal with a regression line (see equation (22)) with parameters *a* = 2.4142 and *b* = 4.0291, while the correlation coefficient value r^2 = 0.997 is close to one.

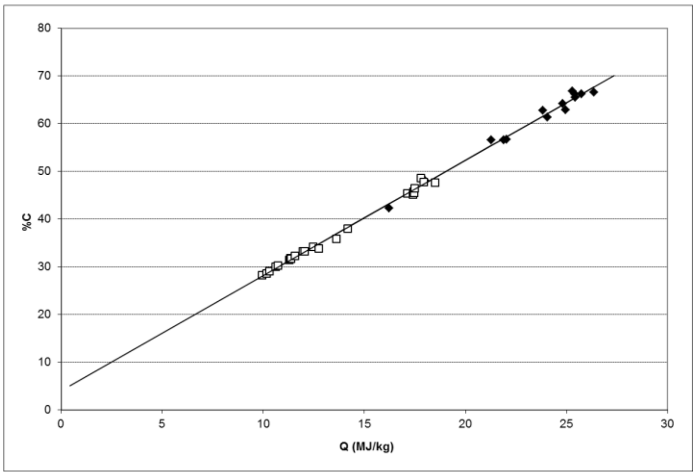

Figure 10 Correlation between the carbon content and the net calorific value from the ‘combined’ set

From the standpoint of the uncertainty of the emission determination, it is necessary to assess the extent to which the carbon content factor values differ from the values determined by the curve (5). This is graphically illustrated in Figure 11.

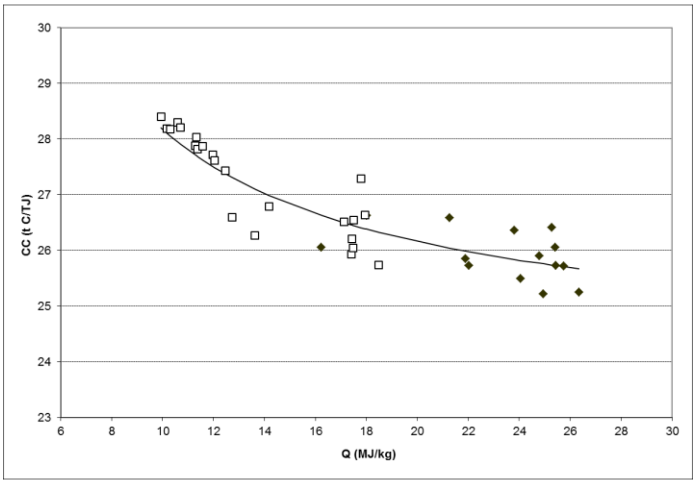

Figure 11 Carbon content factor values

Numerically, the difference between the individual points and the calculated curve can be characterized by the mean relative error, which is 1.14% for lignite and 1.30% for bituminous coal. Nevertheless, the mean relative error for any kind of coal does not exceed 3%. Therefore, the uncertainty in the carbon content factors and thus the uncertainty in the CO_2 emission factors can be considered to be acceptable.

The values of the Q_i^r and CC factors were available in the "ETS" set, but the percentage carbon contents were not given. Therefore, parameters a and b were assessed by non-linear regression, using equation (23). In this way, parameters *a* = 2.4211 and *b* = 3.9539 were determined. In this case, the mean relative error for lignite was equal to 1.59% and that for bituminous coal was equal to 1.73%. Parameters a and b, evaluated from the two sets are very similar. However, statistical indicators characterizing the uncertainty are somewhat higher for the "ETS" set than for the combined set.

Figure 12 compares the CC versus Q_i^r dependences calculated from equation (23) using parameters a and b developed from the "ETS" set and from the "Combined" set. In addition, the figure also depicts two curves taken from the reference (Fott, 1999) designated in that reference as "A+B" and "C". It is obvious that the "ETS" and "Combined" curves are almost identical and that curve "C" has a similar course, while curve "A+B" has a slightly deeper course. Moreover, the figure also illustrates that the relevant default IPCC values are well described by both resultant curves ("ETS" and "Combined").

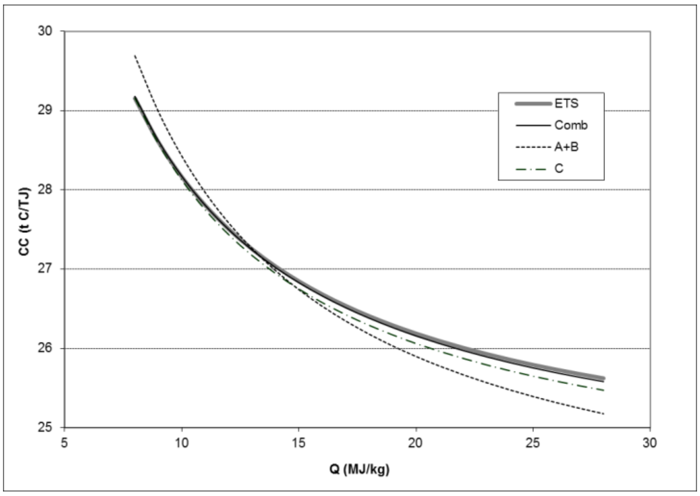

Figure 12 Comparison of the CC versus Qir dependences calculated from equation (23) using parameters a and b obtained from different data sets. IPCC default values for lignite (NVC =11.9 MJ/kg, CC = 27.6 t C/TJ) and other bituminous coal (NCV=25.8 MJ/kg, CC=25.8 t C/TJ) are displayed by circles

4.1.1.4.1.1. Determination of country-specific oxidation factors

Formula for calculation of oxidation factors from the analytical data

The oxidation factor was calculated from the analytical data using the following formula, which was derived from the mass balance of carbon and ash contained in the coal at the input and in the solid residue at the exit of the combustion device (Fott et al., 2006).

The derivation is based on the mass balance of carbon and ash contained in the coal at the input and in the solid residue at the output of the combustion device.

1 kg of coal at the input contains C kg of carbon and A kg of ash. At the output it remains A kg of ash in the solid residue, and C x (1–OF) kg of unburned carbon (while $C\ x\ OF$ kg of carbon is burned).

Mass fraction of carbon in the solid residue at the output can be expressed as

$$\boldsymbol{C,out} = \frac{\boldsymbol{C}\times(\mathbf{1}-\boldsymbol{OF})}{\boldsymbol{C}\times(\mathbf{1}-\boldsymbol{OF})+\boldsymbol{A}} \qquad \textbf{Equation 24}$$

The formula for oxidation factor calculation is then

$$\boldsymbol{OF} = \mathbf{1} - \frac{\boldsymbol{A}}{\boldsymbol{C}\times\left(\frac{\mathbf{1}}{\boldsymbol{C,out}}-\mathbf{1}\right)} = \mathbf{1} - \frac{\boldsymbol{A}\times\boldsymbol{C,out}}{\boldsymbol{C}\times(\mathbf{1}-\boldsymbol{C,out})} \qquad \textbf{Equation 25}$$

where OF is the oxidation factor (with a value somewhat less than 1), A is the mass fraction of ash in the coal, C is the mass fraction of carbon in the coal and C,out is the mass fraction of carbon in the solid residue (ash) at the exit from the combustion device (the mass fractions are values in the interval between 0 and 1, e.g. 40% corresponds to a mass fraction of 0.4). If both forms of ash are present at the exit (slag and fine-grained ash), *C,out* is calculated as the weighted average of the fraction of unburned carbon in both forms of ash (slag and fine-grained ash). Mass fractions *A, C* in the equation (25) may be related either to dry (index d) or raw basis (index *r*), since *Ad/Cd* = *Ar/Cr*.

Data sets used for determination of the oxidation factors and their processing

The "ČEZ", "Dalkia" and "ETS" sets were also used for evaluation of the oxidation factors.

Set "ČEZ": This set contains all the data occurring in the resulting equation (25) used for calculation of the oxidation factor. The results from the processed data from the "ČEZ" set are the following values of the oxidation factors: *OF* = 0.9857 for lignite and *OF* = 0.9696 for bituminous coal, respectively.

Table 1 provides an illustration of the calculation procedure.

"Dalkia" Set: The representative value of *OF* for bituminous coal, obtained from 143 samples of bituminous coal in this set, is 0.9719.

OF for lignite could also be obtained from the "Dalkia" set. However, this set involves only samples of lignite, combusted mainly at insignificant combustion installations (i.e. those with relatively low emissions) and therefore is not too representative. From this reason the calculated average (0.979) can be considered only as approximate value for comparison purposes.

"ETS" Set: The set contains data from the ETS database, created in CHMI (see above). This database contains data provided by the operators of energy installations under ETS, which were checked by accredited verifiers. Processing took into account only those plants (installations), whose emissions exceeded 50 kt and where the relevant oxidation factors were obviously based on chemical analysis. In this way has been processed 10 sources burning bituminous coal and 18 sources burning lignite. The "ETS" set was used to calculate the following representative values of oxidation factors: *OF* = 0.9835 for lignite and *OF* = 0.9708 for bituminous coal, respectively

For lignite, the current country-specific value was taken as the most representative, i.e. the value ***OF = 0.9846***, determined as the average of the two average values from the “ČEZ” and “ETS” sets: $OF = (0.9857 + 0.9835) / 2 = 0.9846$

For bituminous coal, the current country-specific value was taken as the most representative, i.e. the value ***OF = 0.9707***, determined as the average of the three average values from the “ČEZ”, “Dalkia” and “ETS” sets: OF = (0.9696 + 0.9719 + 0.9708) / 3 = 0.9707.

4.1.1.4.2. Method of determining carbon dioxide emissions, using country- specific parameters

Carbon dioxide emissions for specific category sources are determined as a product of the consumed fuel, expressed as the amount of energy contained in the fuel defined on the basis of the net calorific value [TJ], the emission factor for CO_2 [t CO_2/TJ] (see equation (21)) and the oxidation factor. The Czech Statistical Office provides annual fuel consumption data for each category of sources, both in weight units and in energy units determined using the net calorific value. The national inventory research team uses this data as input activity data.

For determination of the CO_2 emission factor, it is necessary to define appropriate emission and oxidation factors for the individual categories and for the whole time series. In updating the country-specific emission factors, the authors decided to determine them as the average of two values: the emission factors calculated from eq. (21) and eq. (23) using the parameters ***a = 2.4142*** and ***b = 4.0291***, determined from the “Combined” file and the emission factor calculated using the parameters ***a =2.4211*** and ***b = 3.9539***, calculated from the “ETS” file. This decision was taken because of the very good correspondence between the relevant curves calculated from equation (23) for these two representative sets.

For the oxidation factors, the former default value of 0.98 was used until 2010, while from 2011 the newly determined country-specific oxidation factor given in chapter 3 was employed. This choice was based the fact that the current country-specific values were determined from the data recorded between 2011 and 2012, while the data for the previous years was not available. However, the newly established country-specific oxidation factors indicate that the previously used value 0.98 corresponds better to reality than the default value of 1 pursuant to the 2006 Guidelines (IPCC, 2006).

The resultant country-specific factors for lignite and bituminous coal are presented in Tables 2 and 3. The net calorific values obtained from the Czech Statistical Office for subsectors 1.A.1 (Energy Industries), 1.A.2 (Manufacturing Industries and Construction) and 1.A.4 (Other Energy Production) are shown in the upper part of the two tables. These net calorific values were used not only for expression of activity data in TJ, but also for evaluation of the Carbon Content factors (CC), which are lower than the IPCC default values for CC . In all cases the relative differences are less than 2%.

The country-specific overall emission factors that also include the oxidation factors are expressed as the product $EF(\mathrm{CO_2}) \times OF$, where $EF(\mathrm{CO_2})=CC\times 3.664$, please see eq. (21).

4.1.1.4.2.1. Impacts of country specific emission and oxidation factors on uncertainty of GHG inventory

Impact of application of country specific emission and oxidation factors is evaluated using uncertainty assessment.

For evaluating uncertainties of CO_2 emissions from lignite and bituminous coal the data set “ETS” was used (see section 2.1). This set includes data officially monitored and reported by operators of combustion installations under EU ETS in accordance with the Commission Regulation 601/2012. This Regulation (EU, 2012) strictly requires keeping prescribed limits of uncertainties for emission factors and activity data. Taking into consideration these prescribed uncertainty limits, the approach 1 presented in IPCC 2006 Guidelines for uncertainty quantification was applied. In this way the uncertainties for lignite (1.36%) and for bituminous coal (1.74%) were evaluated.

When considering weighted average of amounts of bituminous coal and lignite used in the last reported inventory, the uncertainty of GHG emissions from stationary combustion of solid fuels is 1.47%. When applying the updated values in the national GHG inventory of the Czech Republic, the total uncertainty of the whole inventory decreases from 3.36% to 3.17%.

Even though the Czech Republic has used some older country specific emission factors earlier, using of updated values as well as the development of country specific oxidation factors substantially decreases the uncertainty of the whole inventory of greenhouse gases.

4.1.2. Industrial processes and other product use

Emissions from the Industrial Processes arise from the other processes than combustion of fuels. The activity data consist of amount of the product produced, e.g. amount of cement produced for the specific year. Furthermore the emission factor is required as well. In the Industrial Processes the emission factor express amount of greenhouse gas (in kt) released by production of specific amount of the product (in mass unit, e.g. t, kt). For instance how much of CO_2 arise from production of one ton of cement. The factor of recovery has to be considered as well in the final emission levels consideration. Usual approach of emission computation is expressed by equation

$$\boldsymbol{E\ [kt] = (AD\ [kt] \times EF\ [\tfrac{t}{kt}])/1000} \qquad \textbf{Equation 26}$$

eventually minus amount of recovered gas.

For Industrial Processes and Product Use sector are used emission factors for specific products – e.g. types of lime or ceramics or process of synthesis of nitric acid. Emission factors for specific processes are presented in Annex 2b. Annex 2b however contains only categories, where Tier 1 method of calculation is used, i.e. activity data is multiplied by the emission factor. There are more processes which emission estimates requires more comprehensive procedures (CHMI, 2014, 2016, 2017, 2018).

In the sector Industrial processes and product use there are number of Tier 3 and country specific methods used. Tier 3 level of computation is used for the categories Cement production and Lime production, Tier 2 method is used for the category

Iron and Steel. Further development is planned for the sectors of Glass production, Ceramics production as well as for specific categories from chemical industry, e.g. for category Nitric Acid Production or Ammonia Production.

In the IPPU sector the emission calculation differs in specific subcategories, mainly due to inclusion in the EU ETS emission scheme. Only part of the CO_2 or N_2O emission are obligatory reported under the Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

EU ETS emission data are used for the reporting of emissions in 2.A.1 Cement production, 2.A.1 Lime production, 2.A.3 Glass production and 2.B.2 Nitric Acid. Further, for some categories, not all facilities producing relevant product is included under EU ETS. However, even like that the data are used and usually specific emission factor is the developed based on the EU ETS data. The country specific emission factors are then used and applied on the officially reported data from the Czech Statistical office for the total production of the specific product. N_2O emissions are reported from the Nitric Acid production since 2013, also N_2O emissions from caprolactam production. This data are then reported in the official GHG inventory. In the Czech Republic, there is only minor production of caprolactam and as such, in the EU ETS it is not reported separately, however as a part of bulk chemicals.

For the sector, which are reported under the EU ETS emission trading scheme the approach for the projections of emissions can be directly to project the emissions. The projected amount of activity data mutlitplied by average emission factor is then used for verification purposes.

For the cement and lime production the emission factors are not varying significantly during the time. The weighted average is a good approach to estimate the emission factor for the future submissions. Ministry of industry and trade published expected production of cement, limestone and dolomite. Slight increase in clinker production is expected, which follows from construction of the new nuclear units. Following the decreasing trend of coal use, decrease of the lime in desulphurization process is expected.

The trend in chemical industry is affected by the accident in the refinery plant in 2015 in ethylene unit. New ethylene unit is under construction and is expected to start production in 2019. Another accident however happened in March 2018 which would affect production and thus also emissions arising pro the chemical industry. Otherwise no closure of the current chemical facilities is expected or planned.

The most significant from the metal industries in the Czech Republic is production of iron and steel. Since there is long history in this type of processes, there is no expectation for declining of the production. However, the production of iron and steel is reflecting the economic situation. After the economic recession in 2008 a decrease in production, and thus emissions produced, is apparent. However, after 2013 the amount of iron and steel produced got increased and the intention is to keep it in the future as well.

Iron is produced in the Czech Republic in two large metallurgical facilities located in the cities of Ostrava and Třinec in the Moravian-Silesian Region, in the north-eastern part of the Czech Republic. Both these metallurgical works employ blast furnaces and also lines for the production of steel, coking furnaces and other supplementary technical units. Another large steel plant is located immediately next to the metallurgical works in Ostrava, taking raw iron (in the liquid state) from the nearby blast furnaces (located in the area of the Ostrava metallurgical works).

The CO_2 emissions from iron and steel production are calculated using the national approach which can be considered as Tier 2. However, Tier 2 emission estimations based in IPCC (2006) include recommendations to also include emissions arising from combustion of Blast Furnace and Oxygen Steel Furnace Gas in other than metallurgical complexes (for instance in Energy category 1.A.1.a). However, it is expected in the Czech Republic that all Blast Furnace and Oxygen Steel Furnace Gases are combusted directly in the metallurgical complexes. This means that the national approach to emission estimations contains a few aspects from Tier 1, as some parts of the equation are available for the computation. An important aspect of the computation is the amount of carbon in the reducing agent (i.e. in metallurgical coke) and thus also the amount of carbon in scrap and in steel. Further, small amount of Bituminous Coal in 2014, 2015 and was also used as reducing agent in the blast furnace, as well as Coal Tar in years 2007 till 2013. Thus, the approach used is considered to be as close to Tier 2 based on IPCC (2006) as possible. In the carbon balance the amount of carbon in coke, bituminous coal (in 2014–2016) and coal tar (in 2007–2013) used in blast furnaces. Further amount of carbon in sinter, pig iron and steel are part of the emission estimation. The total amount of total carbon produced in the process is following equation

$$\boldsymbol{C_{total}} = (\boldsymbol{C_{coke}} + \boldsymbol{C_{bituminous\ coal}} + \boldsymbol{C_{coal\ tar}} + \boldsymbol{C_{scrap}} + \boldsymbol{C_{electrodes}}) - \boldsymbol{C_{steel}} \qquad \textbf{Equation 27}$$

Coke Oven Gas is not in the official CzSO data reported in transformation processes, so it is used only for warming up, so the emissions are reported under 1.A.2.a. Blast Furnace Gas is used for warming the air for the blast furnace.

99% of produced pig iron is used immediately in the facility for steel production. Iron ore charge for blast furnaces is ensured from three quarters by sintering of sinter fines in our own Sinter Plant and the remaining portion of iron ore charge is formed by pellets, lump ores and also secondary materials. Blast furnace coke is supplied from the neighbouring Coke Oven Plant, part of blast furnace coke and liquid fuel is purchased from external sources. Produced hot metal and sinter is used for internal consumption only. Steel is here homogenised, additionally alloyed to the exact chemical composition, heated to the appropriate casting temperature and desulphurized, and modification of inclusions is performed using filled profiles. After this out-of-furnace processing molten steel is sequentially cast on three continuous casters into billets, slabs or small slabs. Finishing lines represents two section-rolling mills and a wire-rod mill, which provide a wide assortment of profiles and wire rod.

Expected amount of non – energetically used fuels is related to the expectation under energy sector and relevant projections of the fuels which are used in non-energy processes. The details of the reporting of non-energy use of fuels are published in Krtková et al., 2018.

It follows from the information provided above, that the projection estimation is carried out by the same calculation as it is used in annual inventories, however the computational files are extended with the projected emissions and activity data. The computational files are interconnected and are also able to automatically report the data in the final template for projections reporting.

Regulatory action to control F-gases is taken across the European Union and worldwide. The EU has adopted two legislative acts: the "MAC Directive" on air conditioning systems used in small motor vehicles (EU 2006), and the "F-gas Regulation" which covers all other key applications in which F-gases are used. A new F-gas regulation was adopted in 2014; the main goal of new regulation is to cut emissions of F-gases by 2/3 by 2030 compared with 2014 levels (EU 2014). An amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer adopted in 2016 in Kigali adds hydrofluorocarbons (HFCs) to the list of substances controlled under the Montreal Protocol to be phased down. Under the Kigali amendment, it is required to reduce the usage of HFCs by 80–85% to 2040 (UNEP 2016).

As a Party to the United Nations Framework Convention on Climate Change (UNFCCC) and under Regulation (EU) No 525/2013 of the European Parliament and of the Council, the Czech Republic is required to prepare and regularly update national greenhouse gas inventories (UNFCCC, 2013, EU, 2013). Emissions of F-gases for the annual national inventory report are calculated according the latest methodology prepared by the Intergovernmental Panel on Climate Change (IPCC). Emission estimates of F-gases are prepared according to IPCC 2006 Guidelines, Vol 3, Part 2 (IPCC, 2006). The base year for emission estimates of F-gases is 1995, but in some applications F-gases were used before 1995 or later and thus this article is oriented toward emission trends over the 1990–2015 period.

Four types of F-gases are used in various applications: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). Emissions from all these types of F-gases occur in the Czech Republic. HFCs and PFCs are mainly used in refrigeration and air conditioning systems, SF_6 is mainly used for electric insulation and current interruption in equipment used in the transmission and distribution of electricity, and NF_3 has been used for manufacturing semiconductors since 2012 (CHMI, 2017).

4.1.2.1. Reporting of non-energy use of fuels

In many countries, energy sector plays major role in the greenhouse gas emissions. It usually covers about 70% to 90% of greenhouse gas emissions in CO_2 equivalent of the total emissions. The attention is therefore drawn to this sector in order to manage accurate, consistent, comparable, complete, and transparent reporting of greenhouse gas emissions which arise from this sector. There are a number of specifics that have to be treated carefully while compiling the inventory. One of them is overlap of some of the processes with 'Industrial processes and other product use' sector (IPPU), especially in the case of fuels used in different industrial production.

Emissions of CO_2 from fuels in the inventories of greenhouse gases are arising not only from the combustion, but also from its non-energy use. The inventory compilers have to carefully make sure that these emissions are not accounted twice in the inventory. As IPCC 2006 Guidelines state, when activity data for fuel used represents the deliveries to enterprises or main subcategories, there is high risk of double counting of such emission. Therefore combustion statistics are preferred option for the activity data in this case (IPCC, 2006).

The share of CO_2 from non-energy use is increasing over time; from the global perspective from 1% in 1970 to 3% in 1995. Similarly, the share of CO_2 from feedstocks in the total emissions from non-energy use has increased from about 55% in 1970 to 80% in 1995 globally (Jos and Peters, 2005). Depending on the country, the share of non-energy use of fossil fuels in total energy balance varies, depending on the importance of refineries and basic chemical industries (Neelis et al., 2005, Patel et al., 2005).

A number of hydrocarbons are used for non-energy desires, for instance petrochemical feedstocks, lubricants, solvents, and bitumen. The carbon in the fuel is either oxidised to CO_2, or it is stored in the product. It is possible, that the carbon is stored in the product for decades, or even centuries (IEA, 2017).

4.1.2.1.1. Reporting of Non-energy Use of Fuels under IPCC 2006 Guidelines

From the 2015 submission onward, it is required to use the Reference Approach in line with IPCC (2006). The main difference between the new reference approach and the old one, used to date (IPCC, 1997), is that instead of the concept of "long-term stored carbon" (stored carbon), used for some non-energy fuels, now a new, broader concept – "excluded carbon" is used, which includes not only the stored carbon, but also carbon used and emitted as CO_2 in other sectors, not only in the Energy Sector (1.A) (most often in the sector 2 IPPU). The reference approach, as a top-down independent estimate of CO_2 emissions from fuel combustion, serves basically as verification of the sectoral approach, i.e. what is used in the inventory for estimation of emissions from the energy sector; therefore it is important that CO_2 accounted for in other sectors is not part of the comparison of the two approaches. This means that the "excluded carbon" is deducted from the total carbon, calculated on the basis of the apparent domestic consumption (Apparent consumption). This is mainly necessary for carbon contained in fossil fuels used as:

- raw materials for further treatment in the industry (feedstocks),
- reductants
- non-energy products.

An overview of materials containing "excluded carbon" is shown in Table 10.

For fuels which are used in sectors other than the Energy Sector (i.e. non-energy fuels: for example coke or naphtha), it is necessary to know the quantity of the particular material that is used outside the Energy Sector (e.g. as feedstock or reductant).

Table 10 Products used as feedstocks, reductants, and for non-energy products (IPCC, 2006)

Feedstocks	Naphtha
	LPG (propane – butane)
	Oils used as feedstocks
	Refinery gas
	Natural gas
	Ethane
Reductants	Metallurgical coke and petroleum coke
	Coal and coal tar/pitch
	Natural gas
Non-energy products	Bitumen

	Lubricants
	Paraffin waxes
	White spirit

The IPPU sector consists of a number of subcategories, where the non-energy use of fuels can occur.

4.1.2.1.1.1. Feedstocks and non-energy use of fuels

The IPCC Guidelines (2006) clearly sets the borderlines between the Energy and Industrial Processes and Product Use sectors. Compared to the previous methodology version (IPCC, 1997), emissions from non-energy use of fuels are reported mainly in the IPPU sector. To prevent double counting or omission of resources, it is necessary to carefully carry out a comprehensive check of CO_2 emissions in sectors Energy – combustion and IPPU, for those kinds of fuels that are used for both energy and non-energy purposes.

Non-energy fuels are divided into three categories:

Raw Materials for the Chemical Industry (Feedstocks). These fossil fuels are used in particular in the production of organic compounds and to a lesser extent in the production of inorganic chemicals (e.g. ammonia) and their derivatives. For organic substances, part of the carbon contained in the feedstock normally remains largely stored in these products. Typical examples of raw materials are feedstocks for the petrochemical industry (naphtha), natural gas, or various types of oils (e.g. the production of hydrogen for the subsequent production of ammonia by partial oxidation).

Reductants. Carbon is used as a reductant in metallurgy and inorganic technologies. Unlike the previous case, here, when using fossil fuel as reductant, only a very small amount of carbon remains fixed in the products for a longer time and larger part of the carbon is oxidized during the reduction process. Metallurgical coke is a typical reductant.

Non-energy products. Non-energy products are materials derived from fuels in refineries or coke plants which, unlike the previous two cases, are used directly for their conventional physical properties, specifically as lubricants (lubricating oils and petrolatum), diluents and solvents, bitumen (for covering roads and roofs) and paraffin. Emissions of CO_2 and other GHG occur only to a limited extent in the IPPU category (e.g. during the oxidation of lubricants and paraffin). Substantial emissions occur during their recovery and during their disposal by incineration (in the Energy Sector and in Waste) (CHMI, 2017).

The IPCC Guidelines (2006) provide a general framework methodology for the Reference Approach/Sectoral Approach comparison using so called excluded carbon. However, this general framework is appropriate only for solving simple problems associated with non-energy use of fuels. There are many other complex types of productions or methods of non-energy fuels use that require a specific approach to addressing them. This paper focuses on ways how to address non-energy use of fuels and it lists the links between non-energy use and IPPU categories. An example of the three neighbouring countries presents the methods of solution for various complex productions as well as for the different types of available data in the country.

4.1.2.1.2. Reporting of Non-energy Use of Fuels in the Inventory of the Czech Republic

Emissions from feedstocks in the chemical industry are reported in subsector 2.B, Chemical Industry, from reductants primarily in subsector 2.C, Metal Industry and from non-energy products, used mainly for purposes other than combustion (e.g. lubricating oils) in subsector 2.D, Non-energy Products from Fuels and Solvent Use. Some types of liquid fuels are designed mainly for non-energy use. This is primarily naphtha; Liquefied Petroleum Gas (LPG) might also be the case.

Another important type of liquid fuels consumed for non-energy purposes of fuels is a group designated as Other Oils. Their most significant share is Other Petroleum Products, which find application in the production of hydrogen by partial oxidation with steam for subsequent production of ammonia. Another part of it is also included under Solvent Use.

White Spirit and Paraffin Wax are usually less important categories and they are indeed used only for non-energy purposes in 2.D.

Liquid fuels used especially for non-energy purposes also include bitumen and lubricants. While there are practically no emissions of CO_2 in the use of bitumen (stored carbon), in the use of lubricants part is oxidized to CO_2 (reported in 2.D). Solid fuels for non-energy purposes are mainly used as reductants. These include coke (Coke Oven Coke) in the production of iron and steel (2.C). Further, Coal Tar is used as well.

In many countries, natural gas (NG) is also used as a feedstock. It has not been used in the Czech Republic until recently and since 2008 Czech Statistical Office has indicated that approximately 1% of annual consumption of natural gas in the Czech Republic is used for non-energy purposes in the chemical industry. This non-energy use is reported under 2.B.10 (for the use of non-selective catalytic reduction).

Fuels for non-energy use are not accounted for in the Sectoral approach in category 1.A. In the Reference approach, non-energy use is deducted from the apparent consumption as excluded carbon.

4.1.2.1.3. Reporting of Non-energy Use of Fuels in the Inventory of the Slovak Republic

In Slovakia, several types of fuels are used as feedstocks and for non-energy use. When categorization of non-energy fuels as described above (Table 10) is used then all of these categories apply in Slovakia:

- Feedstocks: naphtha, refinery gas, natural gas
- Reductants: coking coal, other bituminous coal, coke, petroleum coke
- Non-energy products: lubricants, paraffin wax and white spirit, bitumen.

Reporting of these fuels is summarized in Table 11.

Table 11 The allocation of non-energy use of fuels in the IPPU sector in Slovakia

Fuel	Used and reported in categories
Natural gas	2.B.1 Ammonia Production 2.B.8 Petrochemicals 2.B.10 Hydrogen Production 2.C.1 Iron and Steel Production
Naphtha	2.B.8 Petrochemicals
Lubricants	2.D.1 Lubricants Use
Paraffin wax and white spirit	2.D.2. Paraffin Wax Use
Bitumen	2.D.3 Solvents Use
Refinery feedstocks	2.B.8 Petrochemicals
Petroleum coke	2.C.3 Aluminium Production

Fuel	Used and reported in categories
Coking coal	2.B.5 Carbide Production 2.C.1 Iron and Steel Production 2.C.2 Ferroalloys Production
Other bituminous coal	2.B.5 Carbide Production 2.C.1 Iron and Steel Production 2.C.2 Ferroalloys Production
Coke	2.C.1 Iron and Steel Production

Non-energy products as lubricants, paraffin wax, and white spirit evolve a part of the stored carbon in the form of CO_2 and they are reported accordingly (please see Table 11). On the other hand, the use of bitumen does not create the emissions of CO_2; all carbon in bitumen is stored permanently.

Natural gas is used for several purposes in Slovakia. Main part of non-energy use of natural gas serves as a feedstock for ammonia production. In this case the natural gas serves not only as a feedstock but also as fuel for heating. The whole amount of the natural gas used is excluded from the reference approach and reported in IPPU (2.B.1). Another significant non-energy use of the natural gas is a hydrogen production. It is produced by steam reforming of natural gas, which is the same process as in ammonia production. Therefore the same approach has been followed and all CO_2 emissions are reported in IPPU (2.B.10).

Petroleum coke is used for production of aluminium. Petroleum coke is mixed with tar and filled in the casting forms in order to produce pre-baked anodes. The respective amounts of petroleum coke used are reported in statistics for reference approach; therefore they are subtracted from the reference approach and reported in IPPU sector (2.A.3). The tar used is not presented in statistics; therefore it is not deducted from reference approach while it is still reported in IPPU sector.

Coking coal and other bituminous coal are used for the production of calcium carbide, ferroalloys, and iron and steel. The reporting of non-energy use of these fuels is quite simple for calcium carbide and ferroalloys production. The fuels used as material feedstock to the process are excluded from the reference approach and they are reported in the respective category of IPPU. Iron and steel production is a complex process. Use of the coking coal, other bituminous coal, and coke results in the carbon stored in the products, CO_2 emissions, and the production of other fuels (blast furnace gas and coking gas) that are used for energy purposes in the plant.

The calculation of the carbon that should be excluded from the reference approach is based on the simplified scheme depicted in Figure 13.

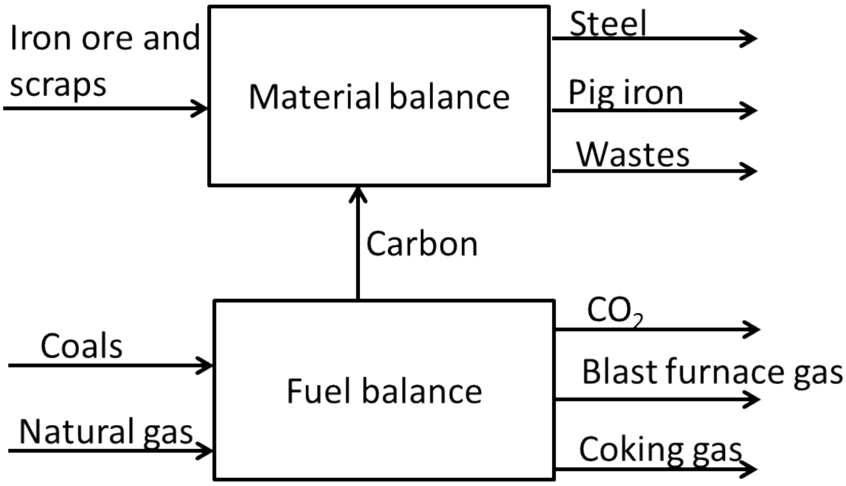

Figure 13 Scheme of the calculation of carbon stored in the products from iron and steel production

The “Carbon” flow in Figure 13 represents the amount of carbon that is stored in products (main products and by-products). This amount can be obtained from the difference between carbon contained in all products and in raw materials (iron ore and scraps). It should be mentioned that “Pig iron” flow represents the amount of pig iron that is not processed into steel. Based on the scheme in Figure 13, the carbon that is excluded from the reference approach is the sum of the carbon that is stored in products and carbon contained in CO_2 emissions. These emissions are reported in IPPU (2.C.1).

Another complex solution occurs at ethylene production. The simplified scheme is shown in Figure 14.

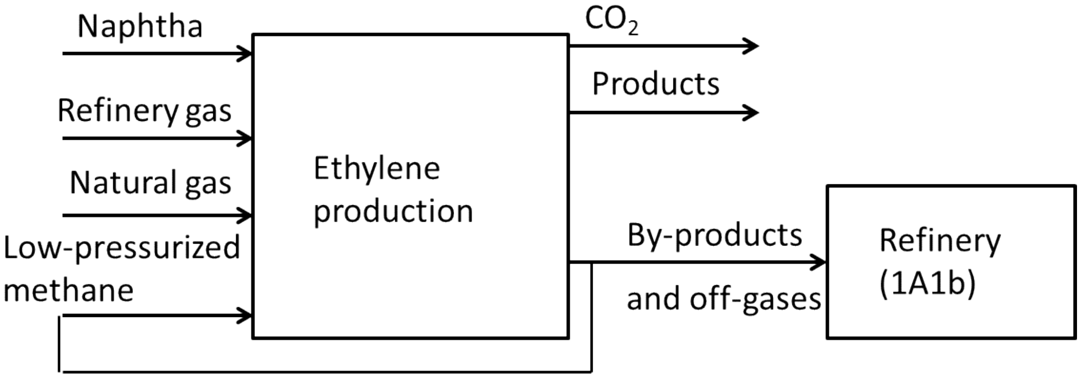

Figure 14 Scheme of the ethylene production

Naphtha, refinery gas, low-pressurized methane, and natural gas are used as feedstocks. During the reaction in the ethylene unit a refinery gas with high content of methane is formed. This methane is separated from the refinery gas and creates an inner loop in the process. Therefore the low-pressurized methane cannot be excluded from the reference approach. The rest of refinery gas (after separation of methane) is going into refinery and it represents an input stream for emission estimates in the Energy Sector (1.A.1.b category). On the other hand, another stream of refinery gas is outgoing from refinery and it represents the input stream in the ethylene unit (Figure 14). Also the naphtha stream originates in the refinery. The total amount of carbon excluded from reference approach is the difference between the carbon contained in input flows (naphtha, excess refinery gas, natural gas) and the carbon in off-gases going to the refinery. Part of it is stored in products (ethylene and propylene) and the rest is evolved as CO_2 emissions that are reported under IPPU (2.B.8). This approach (including the inner loop into the calculation of emissions) is chosen because of comparability with the EU ETS report where the emission estimates are calculated on the basis of fuel combustion.

4.1.2.1.4. Reporting of Non-energy Use of Fuels in the Inventory of Hungary

Similar to other countries, all three categories of non-energy use, i.e. as feedstocks (especially naphtha, LPG, gasoil, natural gas, tars), as reductants (especially coke oven coke, coke oven gas, natural gas), and as non-energy products (especially lubricants, paraffin wax and white spirit, bitumen) occur in Hungary. Their allocation in the inventory is summarized in Table 12.

Table 12 The allocation of non-energy use of fuels in the IPPU sector in Hungary

Fuel	Used and reported in categories
Natural gas	2.B.1 Ammonia Production, Hydrogen Production, Nitric Acid Waste Gas Scrubbing 2.B.8 Petrochemicals 2.C.1 Iron and Steel Production
Naphtha	2.B.8 Petrochemicals
Lubricants	2.D.1 Lubricants Use 1.A.3.b Road Transport
Paraffin wax	2.D.2. Paraffin Wax Use
Gas-Diesel oil	2.B.8 Petrochemicals
White spirit	2.B.8 Petrochemicals
LPG	2.B.8 Petrochemicals

Other oil products	2.B.8 Petrochemicals
Coke	2.C.1 Iron and Steel Production
COG	2.C.1 Iron and Steel Production
BFG	2.C.1 Iron and Steel Production

Although the International Energy Agency (IEA) Annual Questionnaires that serve as basis of the inventory preparation clearly separate energy and non-energy use of fuels, the data cannot be used without further modification by the inventory compilers. In the following two cases the original IEA energy balance is modified with additional data obtained from the firms concerned.

- The allocation of natural gas is different in the inventory than according to the IEA for the reasons described below. In the inventory, a balance (energy use + non-energy use reported in the IEA energy balance minus all natural gas accounted for in the IPPU sector) for all natural gas used in the chemical industry is calculated. The remaining part of the natural gas that is not accounted for in the IPPU sector is allocated in the category 1.A.2.c of the Energy Sector.
- In case of other (oil) products, and also for naphtha LPG, the IEA Annual Questionnaires allocation is not consistent for the whole time-series; part of the total consumption reported as energy use and part classified as non-energy use in the energy statistics are not consistent in time-series. However, the IPCC 2006 Guidelines advice to allocate all such emissions to the IPPU sector irrespective of whether they arising from energy or non-energy use of fuel.

Feedstocks in Hungarian Inventory

Ammonia production: Nowadays, there are only two ammonia plants in Hungary. In the inventory, the reporting scheme of the largest emission trading scheme (EU ETS) plant is basically followed, which is in line with the IPCC Guidelines (2006). It means that all natural gas used for ammonia production (either classified previously as technological gas or as fuel) is allocated in the IPPU sector. Only a smaller amount of natural gas combusted in boilers and used for example for dolomite mills or heating of buildings is accounted for in the energy sector.

H_2 production: Natural gas used for H2 production outside the ammonia plants is also allocated in the category 2.B.1, because one of the ammonia production plants uses hydrogen (that is produced from natural gas by another plant) for ammonia production. On the other hand, the hydrogen plant of the Hungarian oil refinery is not allocated in the 2.B.1 category but in the Energy Sector. Similarly, petroleum coke use for catalyst regeneration and the resulting CO_2 emission are accounted for in the Energy Sector (1.A.1.b), and the corresponding amount of petroleum coke remains in the reference approach.

Olefin production: Yearly (500–600) kt of ethylene and propylene is produced in the largest petrochemical plant of Hungary, which serve as feedstock for basic plastics (polyethylene, polypropylene) production. As a recent development, butadiene is recovered as a by-product of the ethylene production. For olefin production, mostly naphtha, LPG, and gasoil are used. In the inventory, the EU ETS report of the plant is directly used. The EU ETS monitoring regulation allows for facilities for production of bulk organic chemicals to choose between the mass balance methodology that is based on the amount and the carbon content of material entering or leaving the facility and the standard methodology that is based on fuel use. This plant follows the latter approach; therefore the EU ETS reports do not provide information about carbon stored in the products. On the other hand, the time-series of non-energy use of oil products (as raw material in petrochemical production) is present in IEA EnStat, even though in a not fully consistent manner as described above. These data have been taken into account and all of the carbon from these sources was excluded from Energy Sector and reported in IPPU.

Carbon black production: The plant uses mainly tar (“quench oil”) coming from the refinery or as a by-product from the olefin plant with some imported amount. In addition, natural gas is used in production process. In the mass balance approach applied by the plant, the carbon content of a small amount of imported carbon black, some toluene, waste oil, and potassium carbonate are taken into account. In the inventory, ETS data are directly used.

Vinyl chloride monomer (VCM) and toluene diisocyanate (TDI) production: VCM is the key material for PVC production. Ethylene dichloride (EDC) is the intermediate product during VCM production, where the EDC cracking furnace uses natural gas. TDI is an aromatic diisocyanate and a key polyurethane raw material. During TDI production natural gas is used for combustion of by-products and the generated heat is used for other chemical processes in this plant.

Based on the information from the energy statistics provider, all naphtha, and most LPG, gasoil, and all relevant other oil products allocated to the chemical and petrochemical categories in the energy statistics (either for energy or for non-energy uses) are used up in the above described petrochemical production processes, therefore the emissions from the EU ETS reports of the three relevant large plants are included without any modification in the category 2.B.8, Petrochemical and Carbon Black Production, so 100% share of ETS emissions is achieved in this category. Consequently, the above oil products are removed from the reference approach irrespective whether they are allocated to the energy or non-energy consumption in the energy statistics.

Reductants in Hungarian Inventory

Iron and steel production: In the used approach, basically all emissions from the blast furnace and the sinter plant are allocated to the IPPU sector. It means, for example, that all coke-related emissions are accounted for in the category 2.C.1 (IPPU, Iron and Steel Production). Thus all coke allocated in the energy statistics to iron and steel production or transformation in blast furnaces categories is removed from the reference approach. By doing so, recovered blast furnace gas combusted for electricity purposes needs to be taken into account. The respective amount of blast furnace gas and the corresponding carbon are subtracted from 2.C.1 and allocated to 1.A.1.a category of the Energy Sector.

4.1.2.2. Fluorinated gases

Emissions from use of fluorinated greenhouse gases (F-gases) used as substitutes for ozone depleting substances rapidly increase since 1995 when emission estimates began. In the Czech Republic, F-gases are used mainly in refrigeration and air conditioning system (category 2.F.1, IPCC, 2006). Emissions from refrigeration and air conditioning systems in the Czech Republic were approximately 11,300 times higher in 2015 than in 1995. Because of the high importance of these emissions, the calculation model called Phoenix was developed. Calculation model consists from four main parts: input, divider, emission estimates and output. Input contains information about amount of F-gases used for 1st fill and service of equipment, information about emission factors and legislative changes. Divider divides data to the sub-categories under category 2.F.1 according examined percentage share. Emissions from filling of new equipment E_{charge}, emissions during lifetime $E_{lifetime}$ and emissions at decommissioning E_{end} of life are calculated in part called emission estimates. Output represents brief overview of the emission trends from sub-categories and overall trend of emissions from refrigeration and air conditioning (Ondrušová and Krtková, 2017, 2018).

The model is following the required policy (EU, 2006, EU, 2014) and thus is having feature with possibility of not using some gas, which use is going to be restricted starting relevant years.

4.1.2.2.1. Data sources

F-gases or blends containing F-gases are not produced in the Czech Republic but are imported into the country, and thus information about the imported/exported amount of F-gases is important for the purpose of the national inventory. Data about direct import/export, use and destruction are obtained from ISPOP ("Integrated system of reporting obligations"), F-gas register (Questionnaire on production, import, export, feedstock use and destruction of the substances listed in Annexes I or II of the F-gas regulation (EU 2014)) and the Customs Administration of the Czech Republic. ISPOP is the national system of environmental reporting, while the F-gas register contains information about F-gases imported into the EU from non-EU countries and F-gases exported from the EU to non-EU countries. Unfortunately, neither register provides information about the specific use of F-gases in the country. All the importers, exporters and users are requested to complete a specific questionnaire on export and import of F-gases and to support the questionnaire by additional information on the quantity, composition and use. These data are verified by the Czech sectoral expert on F-gases; the verified data are used for emission estimates (CHMI, 2017).

4.1.2.2.2. Categories of F-gases use according IPCC

Three categories are specified according to IPCC 2006 Gl. (IPCC 2006) under which emissions from use of F-gases are reported (2.E Electronics Industry, 2.F Product Uses as Substitutes for Ozone Depleting Substances and 2.G Other Product Manufacture and Use). The emission estimates for each sector are based on different approaches and thus emissions are calculated separately for each subcategory and even for each gas separately.

4.1.2.2.3. Emissions from Electronics Industry (2.E)

The Electronics Industry in the Czech Republic currently emits the following gases: NF_3, CF_4, and SF_6. These gases are used for manufacturing semiconductors. The GWP of these gases is very high; for example SF_6 is the strongest greenhouse gas with GWP equal to 22,800. SF_6 is used in the semiconductor industry for etching structures and for cleaning reaction. The main contributors to SF_6 emissions in the Czech Republic are the huge energy companies.

Emissions from this category are calculated using the Tier 2a methodology described in IPCC (2006). Company-specific data obtained from questionnaires and information on emission control technologies are used for emission estimates. Emissions are calculated for each gas separately with using the default emission factors described in IPCC (2006). The default emission factors are based on direct measurements, the literature and expert judgements. Total emissions from the Electronics Industry are calculated as the sum of the emissions from the specific gases used in a process and emissions of by-products multiplied by the appropriate GWP factor.

The emission trend is depicted in Figure 15. It can be seen that emissions from the Electronics Industry are not stagnant and fluctuate over time due to changes in the semiconductor market. For example, the decrease of emissions for 2011–2012 was caused by stopping use of the gases SF_6 and CF_4. CF_4 has not been used in this country since 2010, but small amounts of emissions still occur. SF_6 has been used again since 2013. In 2015, emissions from the Electronic Industry amounted to 18.97 kt CO_2 eq., which was 0.016% of total net emissions in the Czech Republic, which equalled 120,486.14 kt CO_2 eq. Emissions decreased by 5.15% compared to 2014 and were 16.64 times higher than in 1997 (CHMI, 2017).

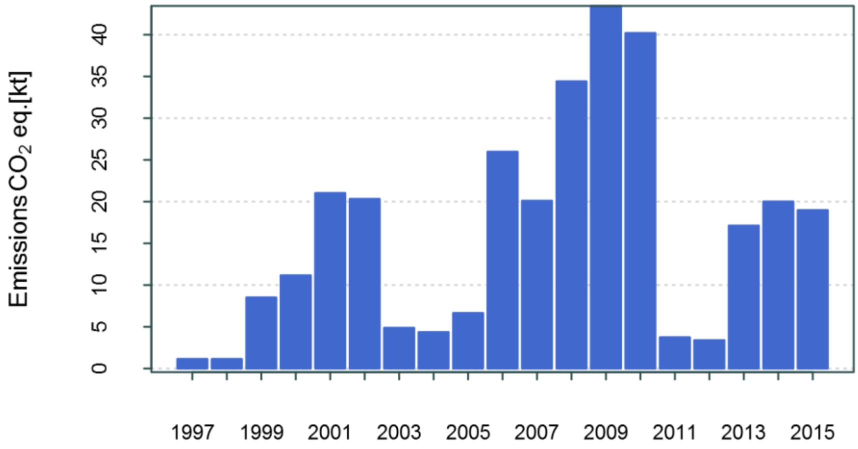

Figure 15 Trend of greenhouse gas emissions from category 2.E, CO_2 eq. [kt]

4.1.2.2.4. Emissions from Product Uses as Substitutes for Ozone Depleting Substances (2.F)

The category of Product Uses as Substitutes for Ozone Depleting Substances category includes emissions from the use of HFCs and, to a limited extent, PFCs in the following application areas: 2.F.1 Refrigeration and Air Conditioning, 2.F.2 Foam Blowing Agents, 2.F.3 Fire Protection, 2.F.4 Aerosols and 2.F.5 Solvents. Emissions from application areas which are also the subcategories defined according IPCC (2006) are calculated by specific method and emissions for each gas are calculated separately. Total emissions from each subcategory are calculated as the sum of emissions of F-gases reported under the subcategory multiplied by the appropriate GWP factor.

Data for emission estimates are obtained from ISPOP, the F-gas register, the Customs Administration of the Czech Republic and a questionnaire on the export and import of F-gases. The questionnaire on the export and import of F-gases is provided by the Czech sectoral expert. Information from the questionnaire represent a key source of data, because data obtained from ISPOP or the F-gas register do not provide information about the specific use of F-gases and thus it is very difficult to choose the correct category under which selected F-gas should be reported.

According to IPCC (2006), two types of emission estimates are defined – the potential and actual emission methods. The potential emission method is not used for emission estimates in the national inventory because it does not take into account the accumulation or possible delayed release of F-gases in various products or equipment, which may lead to inaccurate emission estimates. The actual emission method takes into account the time lag between consumption of F-gases and emissions. After chemicals are placed in the new equipment, leakages occur over time and, in some cases, the chemicals have not been released until the end of lifetime. For example, leakages of the refrigerant from household refrigeration are very small or none during the lifetime of the system and most of the refrigerant is released during disposal, which occurs many years after production. The cumulative difference between consumption of the chemicals and release of the chemical is known as a bank. The size of the bank is estimated by evaluating the historic consumption of chemical and applying the appropriate emission factor.

The Czech Republic uses two approaches for emission estimates from categories defined under the Product Uses as Substitutes for Ozone Depleting Substances category: the emission-factor approach at the application level called Tier 1a and the emission-factor approach called Tier 2a. Data for the Tier 1a approach represent annual consumption data, which are calculated as follows:

$$\boldsymbol{Net\ consuption = Imports - Exports - Destruction} \qquad \textbf{Equation 28}$$

Emissions are then calculated according to:

$$\boldsymbol{Annual\ emissions = Net\ consuption \cdot Composite\ emission\ factor} \qquad \textbf{Equation 29}$$

where the composite emission factor accounts for the assembly, operation and, in relevant cases, disposal emissions. In cases where banks occur, the equation for annual emissions is modified as follows:

$$\boldsymbol{Annual\ emissions = Net\ consuption \cdot Composite\ emission\ factor\ for\ first\ year + Total\ banked\ chemical \cdot Composite\ emission\ factor\ for\ bank} \qquad \textbf{Equation 30}$$

For the national inventory, the Czech Republic uses the default emission factors provided in IPCC (2006) for the Tier 1a approach. The Tier 2a approach requires country-specific data about the average chemical charges, average service life cycle, emission rates, recycling and disposal. Total emissions are estimated in the Tier 2a approach by the following equation:

$$\textbf{\textit{Total emissions}} = \textbf{\textit{Manufacturing emissions}} + \textbf{\textit{Operation emissions}} + \textbf{\textit{Disposal emissions}}$$

Equation 31

Manufacturing emissions occur when the product is manufactured or when new equipment is filled for the first time. Operational emissions occur as leaks or by diffusion during the use phase. Disposal emissions occur when the equipment reaches the end of its lifetime and is decommissioned or disposed.

The trend in emissions is depicted in Figure 16.

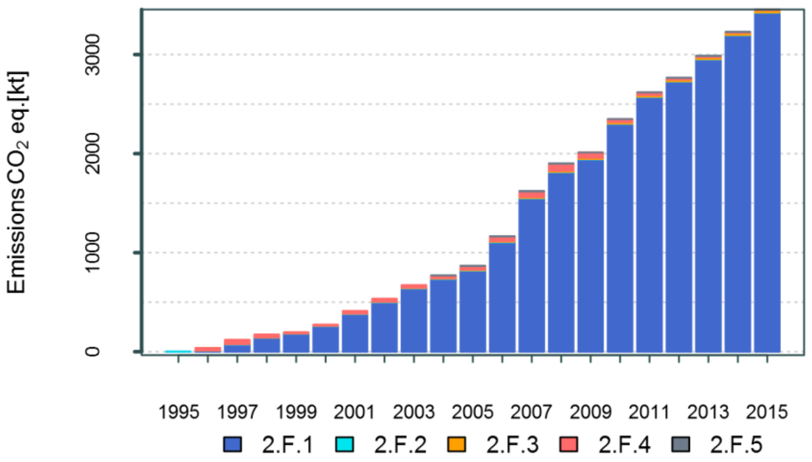

Figure 16 Trend of greenhouse gas emissions from category 2.F, CO_2 eq. [kt]

The major share of 99.05% in the range of actual emissions for 2015 corresponds to category 2.F.1 Refrigeration and Air Conditioning, which includes emissions of HFCs and PFCs. Emissions have exhibited an increasing trend since 1995, when emission estimates began. The increase in emissions is mainly driven by replacing HCFCs gases by HFCs. In 2015, emissions from Product Uses as Substitutes for Ozone Depleting Substances amounted to 3,456.60 kt CO_2 eq., which is 2.87% of total net emissions in the Czech Republic. Emissions increased by 6.95% compared to 2014 and were approximately 10,600 times higher than in 1995 (CHMI 2017).

4.1.2.2.5. Refrigeration and Air Conditioning (2.F.1)

Refrigeration and Air Conditioning Systems are divided into the following sub-applications for the national inventory: 2.F.1.a Commercial Refrigeration (e.g. vending machines, centralised refrigeration systems in supermarkets), 2.F.1.b Domestic Refrigeration, 2.F.1.c Industrial Refrigeration (e.g. chillers, cold storages), 2.F.1.d Transport Refrigeration (equipment used in trucks, containers, wagons etc.), 2.F.1.e Mobile Air Conditioning (used e.g. in passenger cars, trucks, buses, trains), 2.F.1.f Stationary Air Conditioning (e.g. air-to-air systems, heat pumps) (IPCC, 2006). Different F-gases are used throughout the described sub-applications of refrigeration and air conditioning systems, especially large amounts of blends composed of HFCs and/or PFCs. It follows that it is important to know the constituents of blends and percentage compositions for emission estimates. Data for emission estimates are prepared by the Czech sectoral expert, who verifies data obtained from ISPOP, the F-gas register and the Customs Administration of the Czech Republic. Unfortunately, there is a lack of information about specific uses of gas obtained from the mentioned sources and this lack cannot be remedied by a questionnaire. The calculation model for emission estimates uses expert judgement to estimate the relative share of each type of equipment, as shown in Table 13. The calculation model takes into account the phasing out or the phasing down of F-gases depending on the Montreal Protocol and national and regional regulation schedules, e.g. according to Regulation EU No 517/2014, the F-gas HFC-134a cannot be longer used in domestic refrigeration since 2015, which means that the relative share of HFC-134a has been considered to be 0% since 2015 (EU, 2014). The exact amount of HFC-134a in the 2.F.1.e subcategory is obtained from the questionnaire. Estimates for the charge, lifetime and emission factors are derived from default intervals from IPCC (2006), where the lower ranges are intended to indicate the status within the developed countries. Emissions from decommissioning are calculated using the Gaussian distribution model with the mean at the lifetime expectancy. The model takes into account different approaches for serviced equipment and newly filled equipment, assuming only half life-expectancy for the serviced equipment, resp. the amount of service-filled gas. Emissions from all the sub-applications are calculated as the sum of emissions from the use of a specific gas occurring under the sub-application multiplied by the appropriate GWP factor.

Table 13 Percentage share of HFCs and PFCs use by sub-application

F-gas	2.F.1.a Commercial Refrigeration	2.F.1.b Domestic Refrigeration	2.F.1.c Industrial Refrigeration	2.F.1.d Transport Refrigeration	2.F.1.f Stationary Air Conditioning
HFC-125	40%	x	15%	5%	40%
HFC-143a	60%	x	15%	5%	20%
HFC-23	100%	x	x	x	x
HFC-134a	60%	0%	15%	5%	20%
HFC-227ea	100%	x	x	x	x
HFC-32	40%	x	15%	5%	40%
HFC-152a	100%	x	x	x	x
C_6F_{14}	100%	x	x	x	x
C_3F_8	100%	x	x	x	x
C_2F_6	100%	x	x	x	x

In 2015, emissions from Refrigeration and Air Conditioning amounted to 3,423.82 kt CO_2 eq., which is 2.84% of total net emissions in the Czech Republic. Emissions of HFCs and PFCs increased by 7.07% compared to 2014 and were approximately 11,400 times higher than in 1995. The percentage shares of emissions in these subcategories are depicted in Figure 17. The major share 34.98% in the range of actual emissions for 2015 corresponds to the commercial refrigeration subcategory (CHMI, 2017).

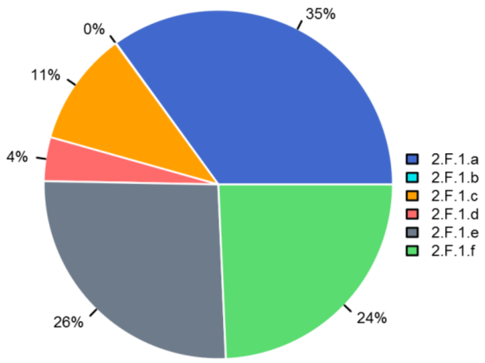

Figure 17 The share of individual subcategories under 2.F for CO_2 eq. emissions in year 2015

4.1.2.2.5.1. Methodology for emission estimates from refrigeration and air conditioning

Emission estimates for the annual national inventory must be in accordance with the IPCC methodology. Emission estimates for category 2.F.1 are prepared in accordance with the IPCC 2006 Guidelines, Vol. 3, Part 2 (IPCC, 2006). The methodology takes into account the national and regional regulations governing the use of F-gases, defines the emission factors for refrigerant charge, during operation, at servicing and at equipment end of life (IPCC, 2006).

4.1.2.2.5.2. Structure of the calculation model

The Phoenix calculation model was developed and implemented in Microsoft Excel, version 14.0.7184.5000. The structure of the Phoenix calculation model is depicted in Figure 18. The calculation model can be divided to four main parts: input, divider, emission estimates and output. For input, it is important to update the data on the consumption of F-gases, emission factors and legislative changes. The divider separates the input activity data into sub-applications, where division into the sub-applications is based on expert judgement. The emission estimates are fully automatic and calculate the emissions of refrigerant due to the charging process of new equipment, emissions during lifetime and emissions at the end of lifetime. The output provides information about total emissions under the sub-applications and overall emission trends. Each part of the calculation model is described in more detail in the following chapters.

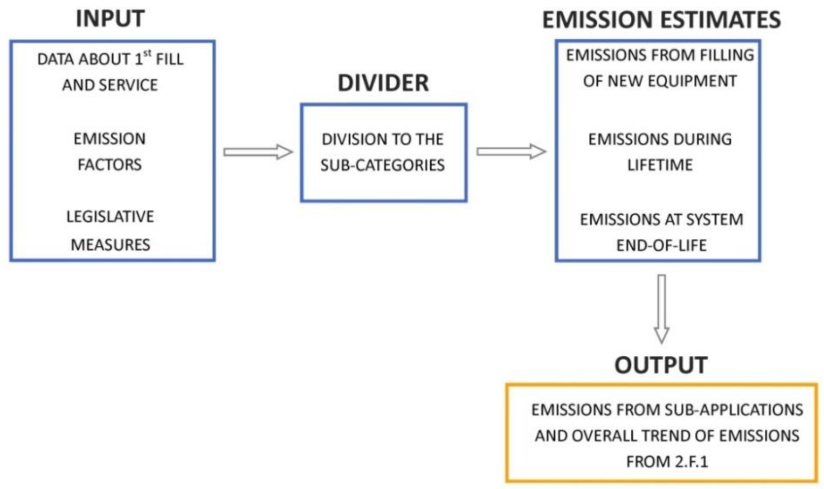

Figure 18 Structure of the Phoenix calculation model

Input

Input of the model consists of three parts – activity data, emission factors and legislative measures (see Figure 18). Activity data represent the annual data on consumption of F-gases for the initial charge of new equipment (1st fill) and for servicing equipment in use. Data about direct import/export, use and destruction are obtained from following sources:

- ISPOP ("Integrated system of reporting obligations"),
- The F-gas register (Questionnaire on production, import, export, feedstock use and destruction of the substances listed in Annexes I or II of the F-gas regulation (EU 2014)),
- The Customs Administration of the Czech Republic and a specific questionnaire prepared by the sectoral expert on F-gases (CHMI, 2017).

ISPOP provides data about import, export, regeneration, destruction and first placing on the market of F-gases considering the EU market. The threshold for submitting data to ISPOP by importers, exporters and users is 0.1 metric tonne of F-gases. The F-gas register provides data about the imported, exported and disposed amounts of F-gases and also contains information about the average specific charge of equipment, amount of imported, exported or disposed equipment and information about specific use of the equipment. Information in the F-gas register is related to the trade between EU countries and non-EU countries and the threshold for submitting data to the F-gas register is more than 1 metric tonne of F-gases. The threshold refers to the sum of F-gases, not each imported/exported gas separately. Customs data provides information about trading between the Czech Republic and the world market. These data provide information about imported/exported products and containers of fluorinated greenhouse gases; information is classified according to the combined nomenclature, which is regularly updated (CHMI, 2017). These data sources provide only information about the net amount of F-gases imported and exported to/from the Czech Republic and the amount of disposed F-gases and do not provide information about the amount of F-gases used for the 1st fill and for servicing of equipment. Therefore annually specific questionnaire on export and import of F-gases and questionnaire about additional information on the quantity, composition and use of F-gases was developed and is used. Verification is conducted by comparison of the data received from the mentioned sources (ISPOP, F-gas register, the Customs Administration of the Czech Republic and questionnaires). Data about the amount of F-gases used for the 1st fill and servicing of equipment represent the first input for the calculation model.

The second part of the input contains information on the emission factors used for emission estimates. Total emissions of refrigerant are calculated as the sum of the initial emissions (emissions occurring during the charging process of new equipment), operation emissions (including fugitive emissions, which represent leaks from fittings, joints etc. and servicing emissions) and emissions at the system end of lifetime (emissions at system disposal). Emission factors used for emission estimates are shown in Table 14.

Table 14 Emission factors used for emission estimates

Source sub-application	**Lifetime [years]**	**Emission Factors [% of initial charge/year]**		**End-of-Life emissions [%]**	
Factor in equation	**(d)**	**(k)**	**(x)**	**($\eta_{rec,d}$)**	**(p)**
		Initial Emissions	**Operation Emissions**	**Recovery Efficiency**	**Initial Charge Remaining**
2.F.1.a Commercial Refrigeration	10.50	1.00	13.00	55.00	70.00
2.F.1.b Domestic Refrigeration	13.50	0.50	0.25	55.00	70.00
2.F.1.c Industrial Refrigeration	17.00	1.00	11.00	55.00	70.00
2.F.1.d Transport Refrigeration	8.50	0.50	17.50	55.00	30.00
2.F.1.e Mobile Air Conditioning	13.50	0.50	12.50	10.00	30.00
2.F.1.f Stationary Air Conditioning	13.50	0.50	6.50	55.00	70.00

Initial emissions are calculated by using the emission factor for assembly losses of the HFC filled into new equipment. Operation emissions are calculated by using the annual emission rate of HFC for each sub-application bank during operation with accounting for average annual leakage and annual average emissions during servicing. Emissions at the end of lifetime are calculated by using the recovery efficiency at disposal, which represents the ratio of recovered HFC referred to HFC contained in systems and by using the residual charge in the equipment, which is being disposed (IPCC, 2006). Selection of emission factors should be based on the national information provided by manufacturers, service providers, disposal companies and other organizations. The emission factors are updated annually to ensure that the emission factors reflect more country-specific conditions. The emission factors are verified by comparison with the emission factors for neighbouring countries and for countries with similar status of refrigeration and air conditioning use.

National and regional measures are adopted worldwide to prevent a further increase in F-gases emissions and thus it is important to take into account legislative changes for emission estimates and implement these changes into the calculation model. The main legislative measures for the Czech Republic are the "MAC Directive" on air conditioning systems used in small motor vehicles (EU, 2006) and the "F-gas Regulation" which covers all other key applications in which F-gases are used. The calculation model takes into account the phasing out or the phasing down of F-gases depending on the Montreal Protocol and national and regional regulation schedules, e.g. according to Regulation EU No 517/2014, the F-gas HFC-134a cannot be longer used in domestic refrigeration since 2015, which means that the relative share of HFC-134a has been considered to be 0% since 2015 (EU, 2014).

Divider

According to the use of F-gases, refrigeration and air conditioning is divided into six sub-applications. F-gas register provides information about the specific use of F-gases but this information does not cover all the imported/exported equipment in the current year and, in some cases, the information is very general and cannot be linked with a specific sub-application.

This lack cannot be remedied by a questionnaire and thus the calculation model must divide input data into sub-applications by a divider. The divider is presented in Table 13. The percentage share of each gas in the relevant sub-application is currently based on sectoral expert judgement, which is based on long term experience in the use of F-gases and information from the F-gas register. The exact amount of HFC-134a in the sub-application is obtained from the questionnaire and thus sub-application is not included in the divider.

Emission estimates

The structure of the emission estimates of the model is depicted in Figure 19. Activity data about the 1st fill and consumption of F-gases are divided by a divider into the sub-applications according to the percentage share, based on expert judgement. Divided data are entered into the emission estimates of the model. The emission estimates consist of six parts; each part corresponds to the mentioned sub-applications. Each sub-application contains emission estimates for each individual F-gas reported under the sub-application on a single calculation sheet. The emission estimates are identical for all the F-gases and all sub-applications but the emissions factors are specific for the individual sub-applications (Table 14). The following description is concerned with emission estimates from F-gas use in specific sub-applications.

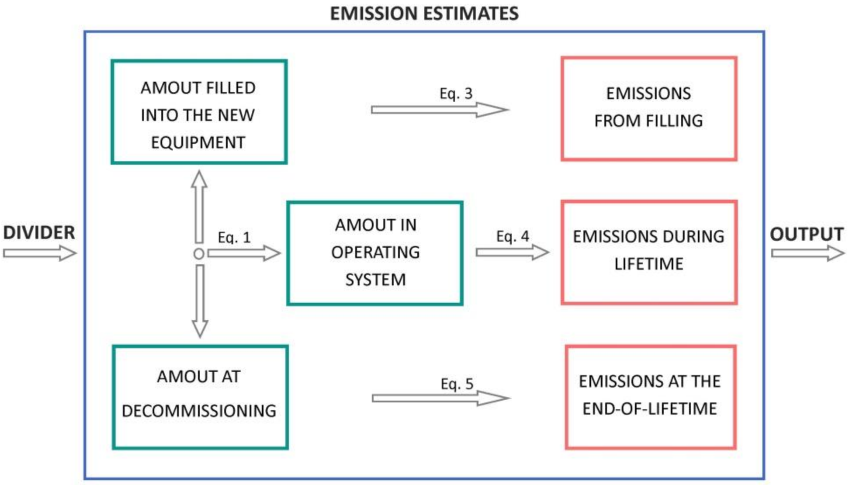

Figure 19 Detailed structure of emission estimates

Data from the input contain information about the amount of chemicals used for the 1st fill and for servicing. For emission estimates, the calculation model needs to contain information about the amount of chemical filled into a new manufactured product M_t, the amount of chemical banked in the operating system B_t and the amount of chemical remaining in the system at decommissioning H_t.

The amount of chemical filled into the new equipment M_t is known from the questionnaire (data about the 1st fill).

The total amount of chemical banked in the operating system (B_t) is calculated by the following equation

$$\boldsymbol{B_t = F_{banked,t} + B_{t-1} - E_{lifetime,t-1}}$$ **Equation 32**

where F_{banked} represents the amount of chemical banked in the operating systems and $E_{lifetime}$ represents emissions during the equipment lifetime. F_{banked} is calculated as

$$\boldsymbol{F_{banked,t} = S_t - E_{charge,t} - E_{end\ of\ life,t}}$$ **Equation 33**

where S_t is the amount of chemical charged into the equipment (1st fill and service), E_{charge}, represents emissions from filling of new equipment and $E_{end\ of\ life}$ represents emissions at the system end of life.

The amount of chemical remaining in the equipment at decommissioning H_t is calculated by using the Gaussian distribution model with mean at the lifetime expectancy for newly filled equipment and only half lifetime expectancy is assumed for serviced equipment. In addition, for calculation the amount of chemical remaining in the equipment at decommissioning H_t, model takes into account parameter p (Table 14), which represents the residual charge of HFC in the equipment being disposed and is expressed as a percentage share.

Total emissions for individual F-gas are calculated as the sum of emissions from filling of new equipment E_{charge}, emissions during the equipment lifetime $E_{lifetime}$ and emissions at the system end of life $E_{end\ of\ life}$. Emission factors set in the input of the calculation model represent indispensable parameters in emission estimates because each equation described below takes into account specific emission factors. Equations for emission calculation are in accordance with the equations described in the IPCC (2006).

The emissions from filling E_{charge} are calculated as

$$\boldsymbol{E_{charge,t} = M_t \cdot \frac{k}{100}}$$ **Equation 34**

where M_t is the amount of chemical used for the 1st fill and k is the emission factor for assembly losses charged into the new equipment (Table 14) (IPCC, 2006).

Emissions during the lifetime $E_{lifetime}$ consist of annual leaks e.g. from fittings, joints, shaft seals and ruptures, which led to partial or complete release of the refrigerant, and from emissions occurring during servicing. For example, servicing is performed every year or not at all during the lifetime of the equipment. Emissions during the lifetime $E_{lifetime}$ are calculated according to the equation

$$\boldsymbol{E_{lifetime,t} = B_t \cdot \frac{x}{100}} \qquad \textbf{Equation 35}$$

where B_t is the amount of chemical banked in the system and x represents the annual emission rate, which takes into account the average annual leakage and annual emissions during servicing (Table 14) (IPCC, 2006).

Emissions at the system end of life $E_{end\ of\ life}$ are calculated separately for newly filled equipment and for serviced equipment. The resultant amount of emissions at the system end of life is calculated as the sum of the emissions at the system end of life for newly filled equipment and serviced equipment. Emissions at the end of life $E_{end\ of\ life}$ are calculated as

$$\boldsymbol{E_{end\ of\ life,t} = \left(1 - \frac{\eta_{rec,d}}{100}\right) H_t} \qquad \textbf{Equation 36}$$

where $\eta_{rec,d}$ is the recovery efficiency at disposal (ratio of the recovered chemical referred to the chemical contained in the system) (see Table 3) and H_t is the amount of chemical remaining in the system at decommissioning, which is described above (IPCC, 2006).

To ensure proper submission of the national greenhouse gas inventory, it is necessary to separately report emissions from filling new equipment, emissions during equipment lifetime and emissions at system end of life for each sub-application and each individual gas.

Output

The output of the model represents an overview of F-gas emissions in sub-applications for the individual gases from 1995 to the latest year of the national inventory reporting and a total overview of emissions from refrigeration and air conditioning. Total emissions of F-gases from refrigeration and air conditioning are calculated as the sum of the emissions of the individual gases multiplied by the appropriate global warming potential (GWP) for time horizon 100 years.

4.1.2.2.6. Foam Blowing Agents (2.F.2)

The Foam Blowing Agents category includes reporting of F-gases which are used in foams and in insulation applications. Only HFCs are used for producing hard foam. Due to their relatively high cost, HFCs are being replaced by other hydrocarbons and thus the use of HFCs for foam blowing was not reported in 2015. However, emissions are still occurring, because emissions arise from banks of foam blowing agents. Emissions are calculated according to the default method described in IPCC (2006) called the Tier 1a method. The equation described above (36) is modified to take into account decommissioning losses and chemical destruction.

In 2015, emissions from Foam Blowing Agents amounted to 2.57 kt CO_2 eq., which is 0.002% of the total net emissions in the Czech Republic. Emissions of HFCs decreased by 2.56% compared to 2014 and were approximately 180 times higher compared to the base year of 1995 (CHMI, 2017).

4.1.2.2.7. Fire Protection (2.F.3)

In Fire Protection category, only HFCs are currently used in the Czech Republic. PFC (C_3F_8) was used only from 1995 to 1996, but emissions are still occurring in small amounts. HFCs and, during previous years, C_3F_8 were used as substitutes for halons, especially halon 1301. Old types of halons (prohibited before 2000) can no longer be manufactured but some of their mixtures can be reused after regeneration. A major part of new equipment employs HFC-227ea, while some installations are filled with HFC-236fa. Due to reuse of regenerated old halon mixtures, HFCs are being introduced rather slowly. Emissions are calculated according the Tier 1a approach described in IPCC (2006) with using default emission factors.

In 2015, emissions from Fire Protection amounted to 22.76 kt CO_2 eq., which is 0.02% of total net emissions in the Czech Republic. Emissions increased by 8.85% compared to 2014 and were approximately 2,500 times higher compared to the base year, which is 1995 for this sub-application (CHMI, 2017).

4.1.2.2.8. Aerosols (2.F.4)

Only HFC-134a, used in metered dose inhalers, is reported under the Aerosols category. Emissions from this category are considered to be prompt because the lifetime of the product is considered to be no more than two years and thus emissions occur during the first or second final year. Emissions are calculated according the Tier 1a method described in IPCC (2006) with a default emission factor of 50%. This means that half of the charge is considered to be emitted during the first year and the rest of the charge is considered to be emitted during the second year.

In 2015, emissions from Aerosols amounted to 6.66 kt CO_2 eq., which is 0.01% of total emissions in the Czech Republic. Emissions decreased by 17.81% compared to 2014 and were 4 times lower compared to 1996, when the use of HFC-134a occurred for the first time (CHMI, 2017).

4.1.2.2.9. Solvents (2.F.5)

Currently, only HCF-245fa, which is used as an aerosol solvent, is reported under the Solvents category. Emissions from this category are considered to be prompt. Emissions are calculated according the Tier 1a method with default emission factor of 50%. The methodology assumes total release of solvent within two years as in a case of Aerosols (IPCC, 2006).

In 2015, emissions from Solvents amounted to 0.78 kt CO_2 eq., which is 0.001% of total net emissions in the Czech Republic. Emissions decreased by 70.54% compared to 2014 and were 2 times lower compared to 2004, when the use of HFC-134a as a solvent began (CHMI, 2017).

4.1.2.2.10. Emissions from Other Product Manufacture and Use (2.G)

The Other Product Manufacture and Use category is divided into the following sub-applications, under which F-gases used in specific applications are reported for the national inventory: 2.G.1 Electrical Equipment and 2.G.2 SF_6 and PFCs from Other Product Manufacture and Use (IPCC, 2006).

The emissions trend is depicted in Fig. 4. Emissions from SF_6 use are reported under both sub-applications. Emissions have shown a stable trend since 1990, when estimates began for this category, with slight increase in 1996–2009, when the use of SF_6 for soundproof windows began to be included. In 2015, emissions from Other Product Manufacture and Use amounted to 74.31 kt CO_2 eq., which is 0.06% of total net emissions in the Czech Republic. Emissions decreased by 4.16% compared to 2014 and decreased by 11.65% compared to 1990 (CHMI, 2017).

4.1.2.2.11. Electrical Equipment (2.G.1)

Emissions from use of SF_6 for electrical insulation and current interruption used in the transmission and distribution of electricity are reported under this sub-application. The subcategory is divided into Medium Voltage (MV) Electrical equipment (< 52 kV) and High Voltage (HV) Electrical Equipment (> 52 kV) containing SF_6. The division into the two groups was based on data from two large and one smaller facility for energy transmission and distribution. According to the data almost 98.4% of the electrical equipment in the Czech Republic is attributed to HV Electrical Equipment and 1.6% to MV Electrical equipment. Data for emission estimates are obtained from a questionnaire conducted by the Czech sectoral expert. Emissions are calculated according the Tier 1 method described in IPCC (2006) with default emission factors for MV and HV electrical equipment. Emissions from the use of a specific gas are calculated as the sum of manufacturing emissions, equipment installation emissions, emissions occurring during use of equipment and disposal emissions.

In 2015, emissions from Electrical Equipment amounted to 71.08 kt CO_2 eq., which is 0.06% of total net emissions in the Czech Republic. Emissions decreased by 4.30% compared to 2014 and 15.48% compared to 1990, which is the base year for this subcategory (CHMI, 2017).

4.1.2.2.12. SF_6 and PFCs from Other Product Manufacture and Use (2.G.2)

This subcategory contains the use of SF_6 for manufacturing of double-glazed sound-proof windows during 1996–2009. The lifetime of windows filled with SF_6 is assumed to be 25 years, which means that emissions from stocks are still occurring. SF_6 was replaced by argon and nitrogen. Emissions are estimated according IPCC (2006) by using the default method for double glazed sound proof windows.

In 2015, emissions from double-glazed sound-proof windows amounted to 3.22 kt CO_2 eq., which is 0.003% of total net emissions in the Czech Republic. Emissions decreased by 1.01% compared to 2014 and 64.29% compared to 1996 (CHMI, 2017).

4.2. Scenarios and assumption for the emission projections

4.2.1. Energy sector

Under Energy sector is necessary to consider scenarios of trends in global prices of fuel and energy. Petroleum, natural gas and black coal are commonly traded energy commodities on the global market. Price trend scenarios are also regularly prepared for these three basic energy commodities. Recently, electrical energy has been increasingly traded; however, because of the regional character of trade, no scenarios have been published for price trends. European commission usually publish document with recommended parameters of the global prices.

It is crucial to consider domestic scenarios of trends in domestic prices and availability of fuel and energy. Solid fuels are expected to be a main domestic primary energy source by 2020. However, availability of domestic coal in future is depending on territorial environmental limits. The environmental limits can restrict surface mining of the brown coal (lignite). Also economic situation of the coal mining companies has also to be considered while creating relevant scenarios. Good example can be OKD, a. s. which is recently going through financial problems, some of the mines were already closed, and the future of the company is not sure.

The purchase prices of electricity from renewable energy sources and from sources with combined heat and electricity production were stipulated by a Decree of the Energy Regulation Authority. The Energy Regulatory Office could reduce these prices by up to 5% annually compared to the previous year.

Further, scenario of energy production is relevant. The Czech Republic has State Energy Policy, which presents possible evaluation of energy market in the Czech Republic. Expectation about nuclear power stations are included.

Also all relevant policies and measures would have different impact on the emission levels. In order to reach goal of emissions decrease relevant policies have to be establish and measures would be applied. These considers mainly energy taxation policy, eco-design directive and further policies usually formulated by European Union. Member states are then applying their own measures or related policies to maintain to goals. List of relevant policies and measures relevant for the Energy sector is very broad and is out of the scope of this work.

4.2.2. Industrial Processes and Other Product Use sector

General assumption for the IPPU sector is assumption of the lifetime of the installations, as well as availability of the input materials. Development of GDP is the major driver. While expecting construction of the nuclear units, increase production of clinker is expected. Also, due to decrease of use of coal, decreasing trend in lime productions is expected, since huge desulphurization is not going to be needed.

Related policies include Regulation on fluorinated greenhouse gases, which is actually restricting usage of some the F-gases. Future development of F-gases emissions is clearly related to the obligations provided by this regulation. Also, Directive 2010/75/EU on industrial emissions is applied.

5) Discussion

As was already mentioned, currently available models for projections of emission estimates are not using detailed data which are used for emissions estimation in the official reporting of greenhouse gas inventories. Usually, the first step in the model is final data from the official inventory submission. One of the goals of this research was to include primary data in the projection calculation. To this date, the data of expected different type of fuels were used only in relation to the impact of specific policies. However, no emission computations were provided. These calculations were included in this research.

Additionally, relevant structure of the official reporting of projections for the European Commission was developed. The structure follows logical structure of sectors, from which emissions are arising. The Policies and measures are reported separately for each sector, as well as projections. The structure of the reporting is presented in Annex 3.

5.1. Energy

Interconnected model with emission calculations was developed. Details of the model can be seen in the Figure 3. The starting point is official data reported by the Czech Statistical Office in the official energy balance. The data in the official energy balance are reported in kilotons of each fuel in specific sector of use. The data from the energy balance are automatically transferred to the next step of the model, where for each fuel and each sector of use (as it is reported in the energy balance) are added also relevant subcategories from the official reporting of greenhouse gas emission inventories. Further, the data are summed up for the specific categories and data are recalculated to the energy units, joules. Further, data for each fuel are transferred to the specific sectors. For every sector, every fuel in every year in the whole time series is then set up emission factor and oxidation factor for CO_2, emission factors for CH_4 and N_2O. Next, the emissions are calculated still on the very detail of each subcategory, fuel and year. In the final step the data are summed up in the requested group of fuels – solid fuels, liquid fuels, gaseous fuels, biomass, other fuels – for each subcategory. This is the structure requested by UNFCCC for the official reporting of greenhouse gas emissions inventories. In this structure, the data are transferred to the official reporting tool (CRF Reporter).

For the projections part were in the second step included expected amounts of the fuels used in the further years. Since the calculation is automatically set up, the emission calculation in future years is then done in the same way as in the calculation model for the inventory. For the case of projections, the final step is including the final projected emissions on the official template for the emission projections for the European Commission. Figure 20 and Figure 21 are representing projected consumption of fuels till 2035, as well as projections of emissions on CO_2 equivalent.

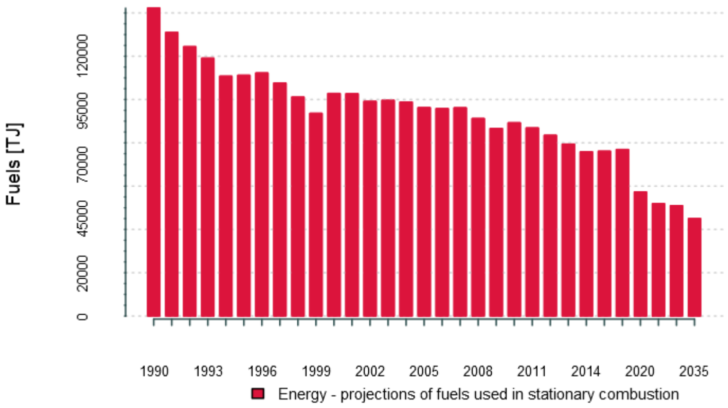

Figure 20 Projected consumption of fuels in stationary combustion

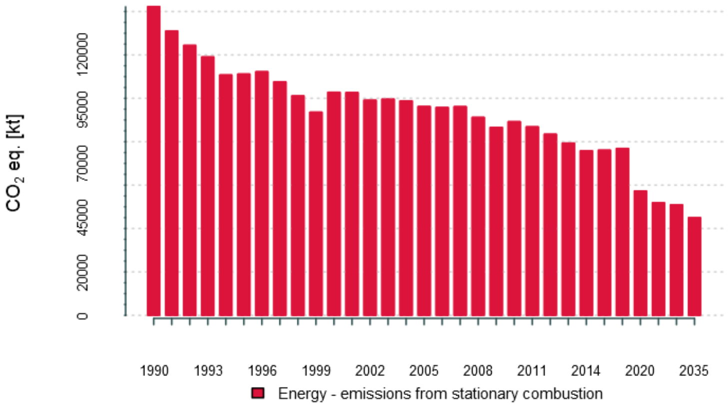

Figure 21 Projected CO_2 emissions from stationary fuel combustion

Verification of the result for projections from the model can be compared to the results of the official reporting of projections, in which model MESSAGE was used, and to the model calculations provided by EFOM/ENV. Since MESSAGE and EFOM/ENV are not using the detailed data for reporting, some differences are expected. However, major trend in the emissions projections should follow similar development. Table 15 provides comparison of emission results provided by the model build in this research and the MESSAGE model. It is crucial to point out, that available estimates from the MESSAGE model are two years old, while the model was built with the currently available data. From that reason, the difference in the original data is already apparent. Further, the results from the MESSAGE model are not significantly different for two scenarios: with existing measures, with additional measures (Table 16 and Table 17). Also it is important to note, that in the computational model developed in this research, detailed projected emissions factors for each fuel were applied. Since MESSAGE model is not working with the data on the very detailed level, this assumption couldn’t be included in the results from the MESSAGE model. Results from this thesis research are used for the verification purposes of MESSAGE outputs.

Following the description in chapters 4.1.1 and 4.2 the difference between these two scenarios is expected to be more significant, than MESSAGE model shows. The data estimated in the model developed in this research are already including all expected additional measures including all known data. Overall the results from the calculation model is generally more optimistic in the expected trend decrease. However, during the preparation of the inventory, the calculation is proved to be working and the additional measures are better reflected in that model.

Table 15 Comparison of results given by MESSAGE model and model build

2020–1990 decrease	**MESSAGE**	**research**
SUM CO_2 eq.	40.31	59.74
2025–1990 decrease		
SUM CO_2 eq.	45.76	63.54
2030–1990 decrease		
SUM CO_2 eq.	48.13	64.21
2035–1990 decrease		
SUM CO_2 eq.	51.96	68.38

Table 16 Projected emissions by MESSAGE model in Energy sector for scenario with existing measures

[Mt CO_2eq]	1990	2015	2020	2025	2030	2035	1990 – 2020(%)	1990 – 2030(%)
CO_2	144,74	90,47	88,69	80,64	77,04	71,65	–38.72	–46.78
CH_4	11,75	4,45	4,31	4,77	3,69	3,20	–63.28	–68.60
N_2O	0,78	1,06	1,20	1,23	1,18	1,04	53.82	51.71
Total	157,27	95,98	94,20	85,64	81,90	75,88	–40.10	–47.92

Table 17 Projected emissions by MESSAGE model in Energy sector for scenario with additional measures

[Mt CO_2eq]	1990	2020	2025	2030	2035	1990 – 2020(%)	1990 – 2030(%)
CO_2	144,74	88.4	80.3	76.7	71.3	–38.94	–47.01
CH_4	11,75	4.31	3.77	3.69	3.20	–63.28	–68.60
N_2O	0,78	1.20	1.23	1.18	1.04	53.82	51.71
Total	157,27	93.88	85.31	81.57	75.55	–40.30	–48.13

MESSAGE model and the calculation model developed in this research agree on the level of the main subcategories in the trend. The category with the major share of the emissions is 1.A.1 Public electricity and heat production, where the consumption of the fuels can be converted mainly from the solid fuels toward use of natural gas. Further, the boilers for the natural gas are more efficient, than the boilers for solid fuels, thus this brings more apparent decrease in emissions of CO_2 next to the lower CO_2 emission factor. Further, biofuels and Natural Gas increased use is expected in the 1.A.4 Other sector.

This was proven also while using EFOM ENV model, where the fuels differentiation between different sectors is more apparent. From the Table 18 is apparent comparison between results in projected fuels based on EFOM ENV model and based on the development from this research. EFOM ENV expects much higher share of biofuels in future years. However, this fact does not correlate with the expected consumption of solid, liquid and gaseous fuels. For the 2020 it is apparent, that the expectations for solid and liquid fuels are very similar in these two models. Higher use of natural gas is expected in the model developed in our research. Almost double increase is expected in EFON ENV for biofuels. In relation to the rest of the fuels, this share would not be possible with current establishment of the power sector. Similar situation is apparent also for projected amount of fuels in 2025, 2030 and 2035. While solid and liquid fuels expect similar trend, the gaseous fuels in the model developed in our research is increasing more significantly, than in

EFOM ENV. Further, in all years the biomass share does not reflect amount of all fuels in total. In total figures, EFON ENV is expected similar amount of consumed solid, liquid and gaseous fuels. However, it is expecting almost double consumption of biofuel, than our research. This would lead to the very high amount of electricity and heat produced. The model developed in our research is reflecting the request by National Renewable Energy Action Plan enough. Such high increase of biofuels used should be investigated by the EFON ENV is suspicious.

Table 18 Comparison of results given by EFOM ENV model and model build in this research

	Decrease [%]		Fuels consumed [TJ]	
2020–1990	**EFOM ENV**	**research**	**EFOM ENV**	**research**
solid fuels	47.19	49.41	746,340	596,593
liquid fuels	86.02	83.64	25,590	33,013
gaseous fuels	–21.46	–37.49	374,720	282,318
biomass	–303.80	–165.35	178,210	152,816
2025–1990				
solid fuels	55.54	67.69	628,340	380,994
liquid fuels	85.13	82.81	27,210	34,682
gaseous fuels	–22.29	–45.48	377,270	298,713
biomass	–367.00	–186.57	206,100	165,037
2030–1990				
solid fuels	57.52	72.92	600,380	319,305
liquid fuels	86.99	82.85	23,800	34,607
gaseous fuels	–19.17	–49.06	367,650	306,072
biomass	–434.75	–211.48	236,000	179,383
2035–1990				
solid fuels	60.75	74.27	554,670	303,437
liquid fuels	87.77	82.84	22,380	34,621
gaseous fuels	–9.82	–53.18	338,810	314,533
biomass	–492.55	–238.88	261,510	195,162

As it was presented, there are different options how to achieve emission reduction in the energy sector. However, after application of possible measures, there are no further political instruments to manage further emission reductions. Recently, carbon capture and storage started to be investigated in different research projects. Currently, there is no such processes occurring in the Czech Republic and so there are no such emissions reported in the Czech Republic inventory or projections. For instance, application of the carbonate loop in the Czech industry and power sector was investigated. The method consists of high temperature carbonate loop method of carbon dioxide sorption from flue gas. Sorption properties of the natural limestones are defined, since this raw material is preferentially estimated for application in the Czech Republic, where this mineral is quarried. The studies concerned with the issue of hydrocalcites and their modifications, likewise the experiments with zirconates were investigated. Further, possibilities of the employment of the CO_2 sorption in the Czech industry and power sector were investigated. Technical background as well as details of the application can be seen in Staf et al. 2016. Because the power industry represents actually the main source of the emissions of this greenhouse gas a presumed evolution of this sector within several future decades is outlined, based on the Czech Republic´s Energy Concept.

5.2. Industrial Processes and Other Product use sector

Calculation model for emissions arising from the Industrial Processes and Other Product Use sector was also developed. The model reflects specific calculation procedures in different subsectors. In the industrial processes the most decrease can be expected mostly only due to decrease in production of the specific product. Such decrease in not expected, however different processes might gain further importance and influent emission levels. As it was explained in chapters 4.1.2 and 4.2.2 the biggest share on the emissions from IPPU is from Iron and Steel production. The calculation of CO_2 emissions from Iron and Steel Production is based on the carbon balance of the process. The main input for the calculation is amount of coke oven coke used in blast furnaces. Since coke oven coke is a fuel reported in the official energy balance and there is expectation about its production, these data were used for the emission estimation. Further, small amount of bituminous coal is also used in blast furnaces. Figure 22 presents trend in CO_2 emissions from iron and steel production based on the projected use of coke oven coke and bituminous coal.

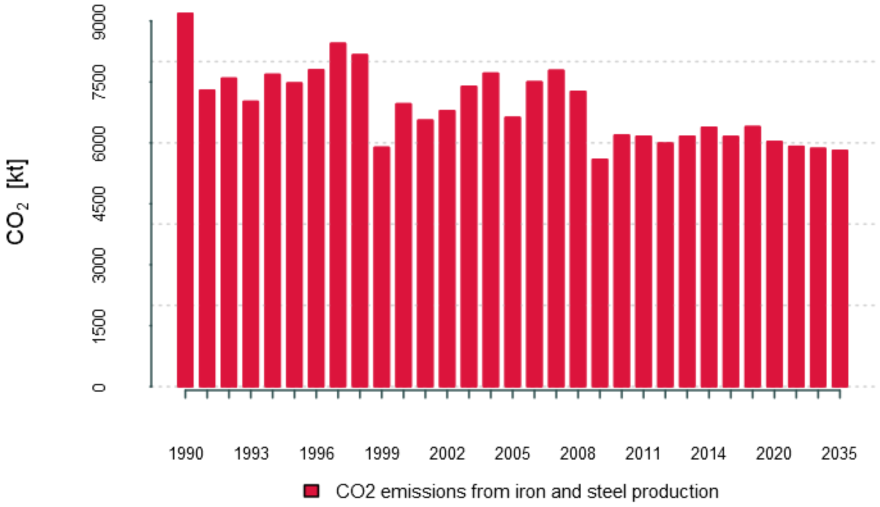

Figure 22 CO_2 emissions from iron and steel production

Neither MESSAGE nor EFOM ENV are models with detailed background in the Industrial Processes. Both of these models are focusing on the energy sector. The reflection of industrial processes is in these models done under energy sector, where combustion of fuels is necessary for industrial production. However, these emissions are then reported under energy sector, specifically under 1.A.2 Manufacturing industries and construction. However, the general expectations and scenarios for projections in IPPU are similar in all presented models. The crucial driver is economic situation of the respected country. The emissions in IPPU generally reflect any economic crisis. This can be also observed on the Figure 22 for 2008, when due to the economic recession the production of iron and steel dropped significantly. However, in future years is not expected any changes in the production, which is also apparent from the Figure 22.

In the chemical industry major decrease was already observed, mainly in the nitric acid production. Emissions from nitric acid production have decreased by 79.37% compared to 1990; the substantial decrease in recent years has been a consequence of the gradual introduction of mitigation technology and improving its effectiveness. All the nitric acid production processes in the Czech Republic are equipped with technologies for removal of nitrogen oxides, NO_X, based on selective or non-selective catalytic reduction. Non-selective catalytic reduction also makes a substantial contribution to removal of N_2O. Since 2004, the technology to reduce

N_2O emissions, based on catalytic decomposition of this oxide, has been gradually introduced at units working at elevated pressure. It has been possible to substantially improve the effectiveness of this process in recent years. No further decrease is expected in the subcategory.

Generally, emissions in the IPPU processes depend on the amount of production. In the recent years was observed couple of accidents in Czech refineries, which are having effect on the total emission levels. For the future levels it is expected to reopen these parts of the process and thus the emission will rise in comparison to the recent emission inventories.

Emissions from non-energy use of fuels are also reported under the IPPU sector. Reporting details of this category are presented in Krtková et. al., 2018 (under review). For the projection purposes is in this case also used official energy balance published by the Czech Statistical Office. The energy balance includes also fuels, which are used for non-energy purposes. Thus, calculation model developed for the inventory is used for the projections as well. For the future years activity data are extrapolated and the emissions are calculated using the same process as in the inventory. The emissions from this category are in comparison to the CO_2 emission from iron and steel production and F-gases minor.

Crucial part of the emission reporting, and thus also projections of emissions from industrial processes consist of emission of fluorinated gases. As it was explained in Ondrušová, Krtková 2017 and 2018, specific model was developed for emission estimation of these substances. This model also decreases uncertainty of the estimated F-gases emissions. Uncertainty analysis is provided as combined uncertainty (uncertainty of the activity data (input data for emission estimates) and uncertainty of the emission factors) and uncertainty of the trend. The uncertainty is calculated using the error propagation equation (IPCC, 2006). The combined uncertainty of the activity data and emission factors for category 2.F.1 was approximately 44% in 2015. The high value of the combined uncertainty is caused by the high uncertainty of the activity data, which are obtained from various sources, and with the high uncertainty of the employed emission factors, which are based on expert judgement and IPCC (2006). The uncertainty introduced into the trend in total national emissions from 2.F.1 was approximately 1% (CHMI, 2017). The Phoenix calculation model was introduced for the first time in 2017. Until 2017, the Czech Republic estimated emissions using the old calculation model, which had major deficiencies. The major deficiency was the absence of a divider and thus the Czech Republic reported emissions from all F-gases used in refrigeration and air conditioning systems under sub-application 2.F.1.a Commercial Refrigeration and 2.F.1.f Mobile Air Conditioning. After implementation of the divider, emissions can be calculated for all the sub-applications under 2.F.1 using the revised emission factors. In addition, the new calculation model takes into account legislative changes, which are important mainly for control procedures and dividers. Comparison between the total amount of emissions calculated by the old calculation model and the total amount of emissions calculated by the new Phoenix model is depicted in Figure 23. Implementation of the new calculation model led to an increase in emissions compared to the amount of emissions calculated by the old calculation model.

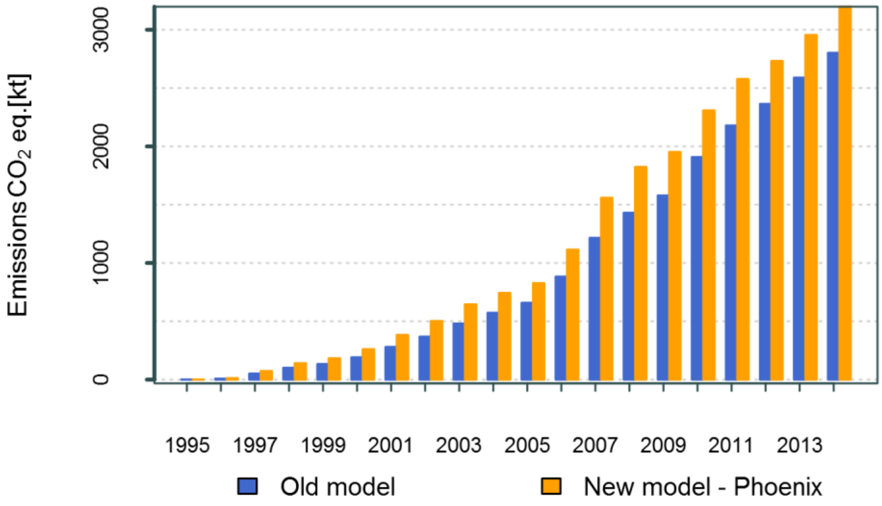

Figure 23 Comparison of emission levels calculated by the old calculation model and new Phoenix calculation model

6) Conclusions

As a Party on United Nations Convention on Climate Change and Kyoto Protocol, as well as s member state of European Union, the Czech Republic has obligations to report each year reporting of greenhouse gas emissions and removals, and each two year reporting of projections, policies and measures. By these reportings, the Czech Republic is presenting, that the reduction goal agreed under the Kyoto Protocol and further specified in the European Union, is met. These obligations are undergoing several quality control procedures from the authority of European Union, or UNFCCC.

It is crucial to manage the reporting on the accurate, transparent, consistent, comparable and complete way. For that, IPCC developed methodologies for emission estimation. However, this default methodology is valid overall in the whole world, thus it is apparent, that the emissions calculated using it, are going to have high uncertainty. The countries are recommended to develop own country specific methodologies for the reporting of greenhouse gas emissions.

In this thesis, development of different country specific emission and oxidation factors were carried out. The CO_2 emission factor was developed for Natural Gas, Liquefied Petroleum Gas, Refinery Gas, Coking Coal, Bituminous Coal and Brown Coal were developed. Also, oxidation factors for Bituminous Coal, Brown Coal and Brown Coal Briquettes were evaluated. These specific values are increasing accuracy of the reporting and are also part of the developed calculation models.

Further, development considering reporting on non-energy use of fuels was analysed. It is important the relate reporting of fuels not used for energy purposes to the total picture of the energy related emissions to avoid double counting of the emissions.

Computational model for emission estimation was developed. The model interconnects primary data with detailed calculation of emissions. In the final step calculated emissions are summed up in the required structure for the reporting under the UNFCCC. This model was also used for estimation of emission projections in the future years. Amount of fuels used and mined is available. The data was inserted into the developed calculation model and emissions were estimated using the same approach as it is used in the annual emission inventories. It is necessary to point out, that such detailed calculations are not provided by any of the available models. Recently available models are using for the projections estimation only summed data from the final figures in the emission inventory reporting.

In the industrial processes the main driver is production of the relevant product. The processes are usually depended on the economic situation. Extrapolation of the production was applied in cases where no reduction of production is expected. In the part of non-energy use of fuels amount of fuels expected to be used in this process was used and applied to the annual inventory calculation. Respective processes are published in Krtková et. al., 2018 (under review). Also, main driver of CO_2 emissions from iron and steel production is coke oven coke used in blast furnaces.

Important part of the inventory in the industrial processes are emissions of F-gases. Detailed model for emissions of F-gases was also developed. The new calculation model was introduced in 2017 and was used for the first time for emission estimates in the 1990–2015 time series. Emissions are estimated for each gas individually under the sub-applications by using specific emission factors, which are defined in the input. The model is used for the projections estimates.

Further, possible additional measures of emission decline were discussed (Staf et al., 2016).

The thesis brings computational model of emission arising from stationary combustion and for the industrial processes. The model was already used in practice for inventory reporting submitted to the UNFCCC in 2018. The projection model will be used during preparation of the official projections reporting in 2019.

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Annexes

Annex 1a Structure of Energy sector (Category 1A Fuel Consumption Activities)

1.A Fuel Consumption Activities	1.A.1 Energy industries	1.A.1a Main activity electricity and heat production	1.A.1ai Electricity generation
			1.A.1aii Combined heat and power generation
			1.A.1aiii Heat plants
		1A.1b Petroleum refining	
		1.A.1c Manufacture of solid fuels and other energy industries	1.A.1ci Manufacture of solid fuels
			1.A.1cii Other energy industries
	1.A.2 Manufacturing industries and construction	1.A.2a Iron and steel	
		1.A.2b Non-ferrous metals	
		1.A.2c Chemicals	
		1.A.2d Pulp, paper and print	
		1.A.2e Food processing, beverages and tobacco	
		1.A.2f Non-metallic minerals	
		1.A.2g Transport equipment	
		1.A.2h Machinery	
		1.A.2i Mining (excluding fuels) and quarrying	
		1.A.2j Wood and wood products	
		1.A.2k Construction	
		1.A.2l Textile and leather	
		1.A.2m Non-specified industry	
	1.A.3 Transport	1.A.3a Civil aviation	1.A.3ai International aviation
			1.A.3aii Domestic aviation
		1.A.3b Road transportation	1.A.3bi Cars
			1.A.3bii Light-duty trucks
			1.A.3biii Heavy-duty trucks
			1.A.3biv Motorcycles
			1.A.3bv Evaporative emissions from vehicles
			1.A.3bvi Urea-based catalysts
		1.A.3c Railways	
		1.A.3d Water-borne navigation	1.A.3di International water-borne navigation (International bunkers)
			1.A.3 dii Domestic water-borne navigation
		1.A.3e Other transportation	1.3.. ei Pipeline transport
			1.A.3eii Off-road
	1.A.4 Other sector	1.A.4a Commercial/Industrial	
		1.A.4b Residential	
		1.A.4c Agriculture/forestry/fishing/fish farms	1.A.4ci Stationary
			1.A.4cii Off-road vehicles and other machinery

			1.A.4ciii Fishing (mobile combustion)
	1.A.5 Non-specified	1.A.5a Stationary	
		1.A.5b Mobile	1.A.5bi Mobile (aviation component)
			1.A.5bii Mobile (water-borne component)
			1.A.5biii Mobile (other)
		1.A.5c Multilateral operations	

Annex 1b Structure of Industrial Processes and Product Use sector (Category 1A Fuel Consumption Activities)

2 Industrial Processes and Product Use	2.A Mineral industry	2.A.1 Cement production	
		2.A.2 Lime production	
		2.A.3 Glass production	
		2.A.4 Other process uses of carbonates	2.A.4a Ceramics
			2.A.4b Other uses of soda ash
			2.A.4c Non metallurgical magnesia production
			2.A.4d Other
		2.A.5 Other	
	2.B Chemical industry	2.B.1 Ammonia production	
		2.B.2 Nitric acid production	
		2.B.3 Adipic acid production	
		2.B.4 Caprolactam, glyoxal and glyoxylic acid production	
		2.B.5 Carbide production	
		2.B.6 Titanium dioxide production	
		2.B.7 Soda ash production	
		2.B.8 Petrochemical and carbon black production	2.B.8a Methanol
			2.B.8b Ethylene
			2.B.8c Ethylene dichloride and vinyl chloride monomer
			2.B.8d Ethylene Oxide
			2.B.8e Acrylonitrile
			2.B.8f Carbon black
		2.B.9 Flourochemical production	2.B.9a By-product emissions
			2.B.9b Fugitive emissions
		2.B.10 Other	
	2.C Metal industry	2.C.1 Iron and steel production	
		2.C.2 Ferroalloys production	
		2.C.3 Aluminium production	
		2.C.4 Magnesium production	
		2.C.5 Lead production	
		2.C.6 Zinc production	
		2.C.7 Other	
	2.D Non-energy products from fuels and solvent use	2.D.1 Lubricant use	
		2.D.2 Paraffin wax use	
		2.D.3 Solvent use	
		2.D.4 Other	
	2.E Electronics industry	2.E.1 Integrated circuit or semiconductor	
		2.E.2 TFT flat panel display	
		2.E.3 Photovoltaics	
		2.E.4 Heat transfer fluid	

		2.E.5 Other	
	2.F Product use as substitutes for ozone depleting substances	2.F.1 Refrigeration and air conditioning	2.F.1a Refrigeration and stationary air conditioning
			2.F.1b Mobile air conditioning
		2.F.2 Foam blowing agents	
		2.F.3 Fire protection	
		2.F.4 Aerosols	
		2.F.5 Solvents	
		2.F.6 Other applications	
	2.G Other product manufacture and use	2.G.1 Electrical equipment	2.G.1a Manufacture of electrical equipment
			2.G.1b Use of electrical equipment
			2.G.1c Disposal of electrical equipment
		2.G.2 SF6 and PFCs from other product uses	2.G.2a Military applications
			2.G.2b Accelerators
			2.G.2c Other
		2.G.3 N_2O from product uses	2.G.3a Medical applications
			2.G.3b Propellant for pressure and aerosol products
			2.G.3c Other
		2.G.4 Other	
	2.H Other	2.H.1 Pulp and paper industry	
		2.H.2 Food and beverage industry	
		2.H.3 Other	

Annex 2a Emission factors for different kinds of fuels used in last reported submission (Energy sector)

	1A1a	1A1b	1A1c	1A2	1A4
Refinery Gas1)	55.08	55.08	55.08	55.08	55.08
LPG1)	65.86	65.86	65.86	65.86	65.86
Naphtha)	73.30	73.30	73.30	73.30	73.30
Gasoline	69.30	69.30	69.30	69.30	69.30
Kerosene Jet Fuel	71.50	71.50	71.50	71.50	71.50
Other kerosene	71.90	71.90	71.90	71.90	71.90
Diesel Oil	74.10	74.10	74.10	74.10	74.10
Heating and Other Gasoil	74.10	74.10	74.10	74.10	74.10
Fuel Oil – Low Sulphur	77.40	77.40	77.40	77.40	77.40
Fuel Oil – High Sulphur	77.40	77.40	77.40	77.40	77.40
Residual Oil	77.40	77.40	77.40	77.40	77.40
Lubricants	73.30	73.30	73.30	73.30	73.30
Other Oil	73.30	73.30	73.30	73.30	73.30
Anthracite	98.30	98.30	98.30	98.30	98.30
Coking Coal1)	93.56	93.56	93.56	93.56	93.56
Other Bituminous Coal1)	95.00	95.00	95.00	94.03	93.95
Brown Coal + Lignite1)	100.31	100.31	100.31	100.38	99.85
Coke	107.00	107.00	107.00	107.00	107.00
Coal Tars	80.70	80.70	80.70	80.70	80.70
Brown Coal Briquettes	97.50	97.50	97.50	97.50	97.50
Gas Works Gas1)	100.38	100.38	100.38	100.38	100.19
Coke Oven Gas	44.40	44.40	44.40	44.40	44.40
Natural Gas1)	55.30	55.30	55.30	55.30	55.20
Waste – fossil fraction	91.70	112.00	112.00	112.00	112.00
Waste – biomass fraction	100.00	54.60	54.60	54.60	54.60
Wood/Wood Waste	112.00	112.00	112.00	112.00	112.00
Gaseous Biomass	54.60				
Charcoal	112.00				

1)*country specific emission factors*

Annex 2b Emissions factors used for emission estimate in Industrial Processes and Product Use sector

type of product		unit
cement production	0.538706	t CO_2/ t sinter
lime production	0.757545	t CO_2/ t CaO
glass production	0.2	t CO_2/t glass
other carbonates		
roof tiles	0.028	t CO_2 / t roofing tiles
brick unit	0.09	t CO_2 / brick unit
ammonia production	3.273	kt CO_2/kt NH_3
nitric acid production	1.380746	kg N_2O/ t HNO_3
caprolactam production	5.7	kg N_2O/ t CL
Ethylene	1.90	kg CO_2/t C_2H_4
Ethylene dichloride and vinyl chloride monomer	0.294	t CO_2/t VCM
lead production	0.52	t CO_2/t lead production
zinc production	1.72	t CO_2/t zinc production

Annex 3

Policies and measures

Cross-cutting policies and measures

Policies and measures in Energy sector

Policies and measures in 1.A.1

Policies and measures in 1.A.2

Policies and measures in 1.A.3

Policies and measures in 1.A.4

Policies and measures in Industrial Processes and Product Use sector

Policies and measures in Agriculture sector

Policies and measures in Land use, land use change and forestry sector

Policies and measures in Waste sector

Projected greenhouse gas emissions by gas and source

Background information, methodologies and key assumptions

Inventory of greenhouse gas emissions

Base year and cross-cutting period of the projections

Cross-cutting assumptions and scenarios

Projected greenhouse gas emissions aggregated

Projected greenhouse gas emissions ‘With measures (WEM) scenario’

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’

Energy (sector 1)

Methodological issues

Projected greenhouse gas emissions for 1.A.1 Energy industries

Projected greenhouse gas emissions ‘With measures (WEM) scenario’

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’

Projected greenhouse gas emissions for 1.A.2 Manufacturing industries and construction

Projected greenhouse gas emissions ‘With measures (WEM) scenario’

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’

Projected greenhouse gas emissions for 1.A.3 Transport

Projected greenhouse gas emissions ‘With measures (WEM) scenario’

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’

Projected greenhouse gas emissions for 1.A.4 Other sectors

Projected greenhouse gas emissions ‘With measures (WEM) scenario’

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’

Projected greenhouse gas emissions for 1.B Fugitive emissions

Projected greenhouse gas emissions ‘With measures (WEM) scenario’

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’

Sensitivity analysis

Industrial processes and other product use (sector 2)

Methodological issues

Projected greenhouse gas emissions ‘With measures (WEM) scenario’

Projected greenhouse gas emissions ‘With measures (WEM) scenario’ for IPPU overall

Projected greenhouse gas emissions ‘With measures (WEM) scenario’ for F-gases

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’ for IPPU overall

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’ for F-gases

Sensitivity analysis

Agriculture (sector 3)

Methodological issues

Projected greenhouse gas emissions ‘With measures (WEM) scenario’

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’

Sensitivity analysis

Land Use, Land-Use Change and Forestry (sector 4)

Methodological issues

Projected greenhouse gas emissions ‘With measures (WEM) scenario’

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’

Sensitivity analysis

Waste (sector 5)

Methodological issues

Projected greenhouse gas emissions ‘With measures (WEM) scenario’

Projected greenhouse gas emissions ‘With additional measures (WAM) scenario’

Sensitivity analysis