International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

Interim Report **IR-12-018**

Influence of Structural Change in GHG Emissions on Total Uncertainty

Myroslava Lesiv (myroslava.lesiv@gmail.com)

Approved by

Michael Obersteiner
Leader, Ecosystems Services & Management Program

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CONTENTS

Abstract

It is important to understand the change in uncertainty in reporting greenhouse gas (GHG) emissions to improve the communication of uncertainty and to facilitate the setting of emission targets. Uncertainty in GHG emissions varies over time due to the effects of learning, as well as structural change. This report provides examples of change in uncertainty due to structural change in GHG emissions considering EU's "20-20-20" targets. We estimate uncertainty for the year 2020 for various scenarios of energy pathways assuming today's knowledge. We apply an emissions-change-uncertainty analysis technique (called Und&VT) developed in IIASA to calculate modified emission targets for the EU.

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About the Author

Myroslava Lesiv graduated from the Lviv Polytechnic National University in 2008, with a Master's degree in Applied Mathematics. At the time of her graduation, she was a first-year PhD student at the same university. This report is a product of Ms. Lesiv's participation in IIASA's Young Scientist Summer Program 2009. During this summer, Matthias Jonas, of IIASA's Forestry Program, supervised Myroslava Lesiv.

Influence of Structural Change In Emissions on Total Uncertainty

Myroslava Lesiv

1 Background and objectives

This report examines the influence of structural change in greenhouse gas (GHG) emissions on uncertainty.

GHG concentrations in the atmosphere have increased since the start of industrial era and are the main cause of the increases in average global temperatures. The Intergovernmental Panel on Climate Change (IPCC) assesses the best scientific work on climate change, its potential impact, and possible response strategies. One of the main policy tools is the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCC), which mandates reporting of GHG emissions at the level of countries and sets targets for the commitment year – 2012. The current goal of the UNFCC is to establish Post-Kyoto targets for the period from 2012.

The European Union (EU-27) is committed to reducing its GHG emissions by 20% (or 30% – see below) by 2020 compared to 1990 levels. The EU Member States claim in their annual inventory reports that between 1990 and 2008 GHG emissions decreased by 9%. As *Figure1* shows the EU-27 is off track compared with its linear target path for a 20% reduction by 2020, and even further off-track for a 30% reduction.

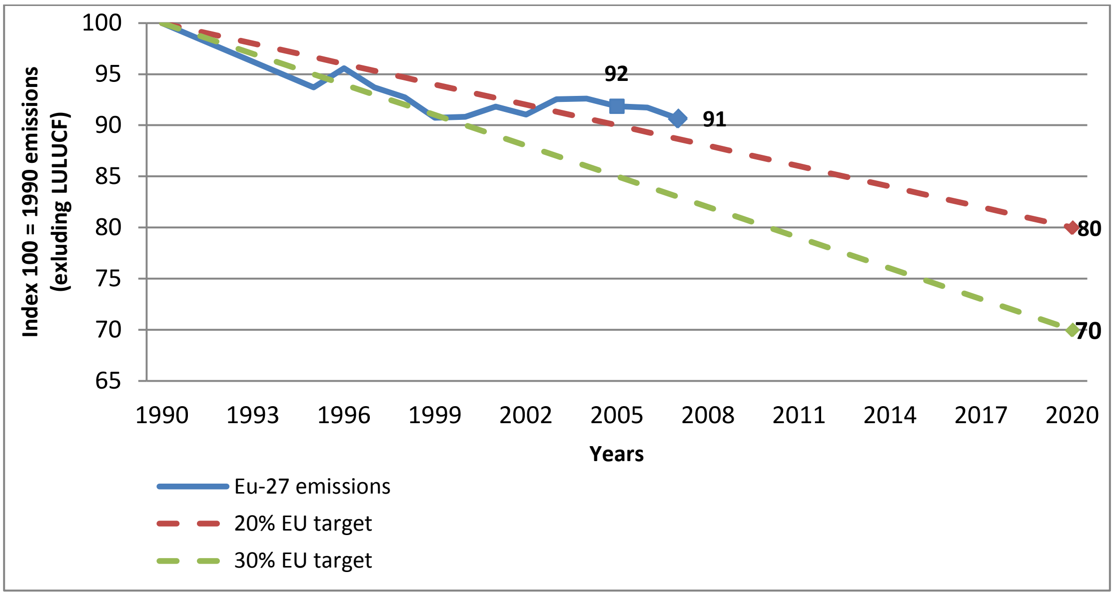

Figure1. GHG emissions trends and targets for the EU-27

The EU-27 GHG emissions are falling, but at a slower rate than desirable. If this trend continues through 2020, the 20% reduction target will not be achieved barring the implementation of additional measures, such as the EU Energy and Climate Change package. The EU needs to triple the impact of its energy efficiency policies (explained below) in order to reach the “20-20-20” targets.

The European Commission adopted the Climate Action and Renewable Energy package (2008) that is also referred to as the European “20-20-20” strategy. It was part of implementing the Integrated Energy and Climate Change package of 2007. The package underscores the objective of limiting the rise in global overage temperature to a maximum of two degrees Celsius above preindustrial levels. The Member States agreed to:

- Cut GHG emissions by at least 20% of 1990 levels (30% if other developed countries commit to comparable cuts), which equals a 14% reduction from 2005 levels;
- Cut energy consumption by 20% of projected 2020 levels – by improving energy efficiency;
- Increase use of renewables (wind, solar, biomass, etc) to 20% of final energy consumption.

The EU proposed the following targets:

- For power plants and energy-intensive industries – emissions are to be cut to 21 % below 2005 levels by the year 2020 (by granting fewer emission allowances under the EU Emissions Trading Scheme);
- For sectors not covered by the ETS (e.g. transport, except aviation, which will join ETS in 2012, farming, waste, households) – emissions are to be cut to 10% below 2005 levels by the year 2020 (through binding national targets);
- Renewables are to produce 20% of all the EU’s energy by 2020, and at least 10% of transport fuel in each country should be renewable (biofuels, hydrogen, ‘green’ electricity, etc). Biofuels must meet sustainability criteria);
- Promotion of safe use of carbon capture and geological storage (CCS) technologies in order to remove eventually most carbon emissions from fossil fuels used in power generation and industry.

Working together the 27 EU countries can have greater influence on the global fight against climate change than they could hope to have working separately.

In compliance with international obligations, it is very important to have guarantees that the reported GHG emissions are sufficiently accurate. However, all data that goes into GHG inventories are uncertain. Uncertainty in GHG emissions results from varied casual factors, including uncertainty regarding sources of emissions, absence of transparency in a process or an inventory, among others.

First-ever estimates of changes in uncertainty are presented in an IIASA report (Hamal, 2010). The author analysed changes in uncertainty over time that result from learning and structural change. The uncertainty reported in national inventory reports assume precision and do not consider errors of accuracy. Precision refers to the degree of reproducibility of repeated emissions (random errors). Accuracy is the difference between the reported emissions estimates (systematic errors). Hamal calculated combined relative uncertainties (for the EU-15), which consider both in accuracy and in precision. The results are plotted *(*see *Figure 2)* and fitted with a trend function that follows an exponential curve with a decrease of approximately 4.24% each year.

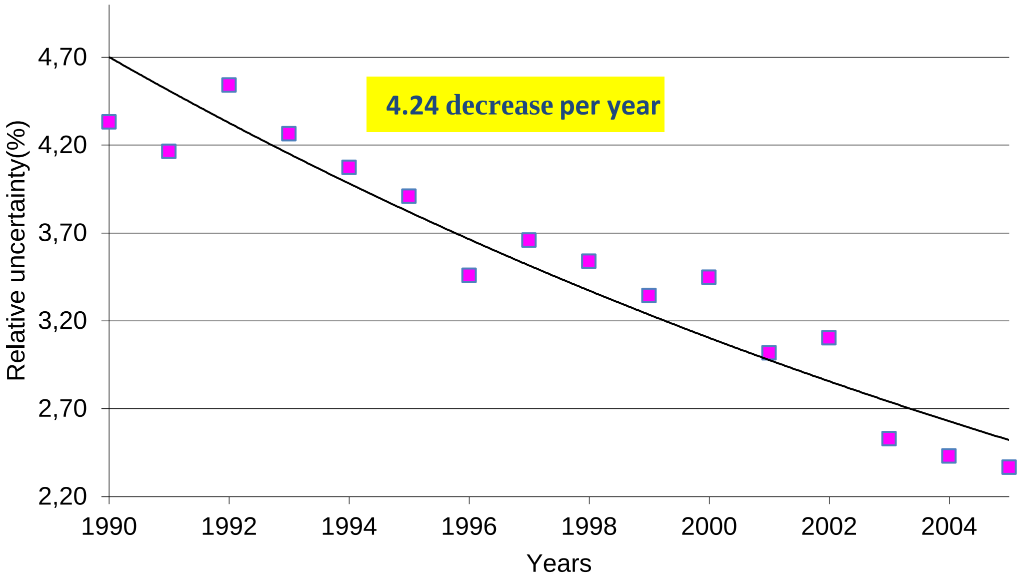

Figure 2. The EU-15: relative uncertainty ranges for the estimates of CO_2 emissions from fossil fuel burning and cement production. (Source: Hamal, 2010)

The decrease (*Figure 2*) in the past is thought to be almost exclusively caused by learning (95%) and only marginally by structural changes in fossil fuel technology (5%). However, structural change in emissions resulting from implementation of new energy measures can produce significant decreases or even increases in uncertainty. This can happen because uncertainty in emissions from different fuels is not the same (i.e., combustion of liquid and other fuels involves greater uncertainty than solid and gaseous fuels).

So far, we are able to estimate and distinguish between changes in uncertainty due to learning (1) and structural changes (2) in emitters, but only for a few countries with good emissions statistics and inventories; and we believe to know that the first effect currently outpaces the second. However, our knowledge is still poor and not yet robust.

This study focuses on estimating uncertainty under scenarios of structural change in GHG emissions considering new measures – the EU's "20-20-20" targets – using today's knowledge of emission generating activities and factors. This is a diagnostic exercise with one step forward. We calculate the total uncertainty that we will face at a specified time in the future using the diagnostic capabilities we have today.

In the report, we use data from National Inventory Reports (2009) and the Annual European Inventory Report to the UNFCC (2009):

- combined emissions (CO_2, N_2O, CH_4) in CO_2–equivalent by sector;
- CO_2 emissions from fossil fuel burning;
- relative uncertainties by gas and sector.

The report begins with a description of the methodology to estimate uncertainties and the Undershooting and Verification time (Und&VT) concept to calculate modified targets that involve uncertainty and the risk that GHG emissions in the commitment year exceed their official target. The next chapter presents the results:

- estimates of total uncertainty in GHG emissions under scenarios of change in emissions considering the EU's "20-20-20" targets for the EU-15 (relative uncertainties by sector are reported only for the EU-15);
- estimates of change in uncertainty in the energy sector assuming a New Energy policy for the EU-27 (relative uncertainties for the Energy sector were reported by all EU countries except Malta);
- calculation of modified targets for the commitment year (2020) taking into account uncertainty.

2 Mathematical background

2.1. Estimating uncertainty

Signatories to the United Nations Framework Convention on Climate Change (UNFCCC) annually report GHG emissions in accord with the standardized guidelines for national agencies developed by the IPCC. Countries are obliged to include in their reports direct or alternative estimates of uncertainty for estimates of GHG inventories. The estimates of CO_2 emissions from fossil fuel consumption are the most accurate to compare with other source categories (uncertainties for Tier1 method are estimated to lie in the range of ±5%).

In this report, we estimate uncertainty in CO_2 emissions from fossil fuel consumption at a point in time following these two steps:

- Calculating emissions from fossil fuel consumption using scenarios of future energy demand in the commitment year (i.e., 2020);
- Estimating total uncertainty by combining uncertainties in emissions from different fossil fuels and applying today's uncertainty expertise in emissions accounting.

CO_2 emissions are estimated from the amount of fuel burned, the carbon content of the fuel, and the efficiency of the combustion. As IPCC (2006) suggests, CO2 emissions are calculated from this equation:

$$Carbon\,emissions \;=\; AD * NCV * CC * COF, \tag{1}$$

where *AD* is activity data in physical units, Gg; *NCV* is net calorific value (energy per physical units), J/Gg; *CC* is the carbon content (mass of carbon per unit of energy on a net calorific value basis), Gg/J; *COF* is a carbon oxidation factor. It is assumed that 100% of the carbon in fuel (coal, oil and oils products, gas, peat) for electricity generation is fully oxidized, or, in mathematical language:

$$COF = 1.$$

In this study, total uncertainty in CO_2 emissions is estimated for future fuel consumption projected for the year 2020. We use our knowledge of uncertainty today in activity data and carbon content and keep relative uncertainty constant in both activity data and carbon content over the period projected.

We obtain all data (net calorific values, carbon content, and the carbon oxidation factor) for different fossil fuels from the IPCC Guidelines (IPCC, 2006); GHG emissions and their uncertainties by country and source we obtain from the 2009 National Inventory Reports to the UNFCCC and from the European Community GHG Inventory Report (EU, 2009).

To combine uncertainties approach 1 is implemented as described in the IPCC Guidelines, Chapter 3 (IPCC, 2006):

- Uncertain quantities combined by multiplication:

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \cdots + U_n^2}, \quad (2)$$

where U_{total} – combined uncertainty in relative terms; U_i - relative uncertainty associated with quantities.

- Uncertain quantities combined by addition and subtraction:

$$U_{total} = \frac{\sqrt{(U_1 * x_1)^2 + (U_2 * x_2)^2 + \cdots + (U_n * x_1)^2}}{|x_1 + x_2 + \cdots + x_n|}, \quad (3)$$

where U_{total} – total uncertainty in relative terms; $x_i$and U_i –emissions and the percentage uncertainties associated with them, respectively.

In calculating equations 2 and 3, correlation between years is disregarded, as we estimate total uncertainty at a single point in time. Emissions from fossil fuels are assumed to be uncorrelated, as we use overall consumption of individual fuels before combining uncertainties.

The GHG inventory is principally the sum of products of emission factors, activity data and other estimation parameters. Therefore, approach 1 can be applied repeatedly to estimate the uncertainty of the total inventory. We use equation 2 to combine uncertainties in activity data and the emission factor, and equation 3 to combine uncertainties from consumption of fossil fuels.

2.2. GHG emissions reduction targets with uncertainty considered

In this study, we use the Und&VT technique presented in IIASA Interim Report IR-04-024 (Jonas *et al.*, 2004) to calculate modified targets. The Und&VT technique applies undershooting and calculates a modified target to reduce the risk that the countries' true (but uncertain) emissions in the commitment year/period exceed committed levels. The Und&VT technique is described in online material at the IIASA web-site:

http://www.iiasa.ac.at/Research/FOR/uncertainty/MathBack_JONASetal.pdf.

The equation that calculates modified targets for the EU (Case 1in the aforementioned source):

$$\delta_{\text{mod}} = \delta + (1-\delta) \cdot \frac{(1-2\alpha)\rho}{1+(1-2\alpha)\rho}, \quad (4)$$

where δ_{mod} is the modified target; δ is the emission reduction/limitation target for the commitment year; ρ is the relative uncertainty in the commitment year; α $(0 < \alpha \leq 0.5)$ is the allowed risk that the true emissions in the commitment year exceed their target.

3. Calculations and results

3.1. Estimates of total uncertainty

Using the methodology described in Chapter 2 we estimate the uncertainty in GHG emissions for the commitment year 2020, taking into account the EU's "20-20-20" target. Calculations are for the EU-15. In this chapter, we work with the following assumptions for the period 2005-2020: energy demand is constant; emissions linearly approach the agreed targets; and relative uncertainty in source categories remains constant. To calculate average annual change in uncertainty we assume that total uncertainty changes linearly over time.

Figure 3 shows the uncertainty in emissions for the EU-15:

- Red curve: 30% cut of GHG emissions by reducing fossil fuel consumption(constant emissions from all other sources). Uncertainty increases by 2.8% per year. This is because other emission sectors such as Industry and LULUFC are more uncertain, and their values do not change over time.
- Blue curve: 20% cut of GHG emissions by reducing fossil fuel consumption, (constant emissions from other sectors). In this case, uncertainty increases by 1.6% per year for the same reason.
- Green curve: cut of GHG emissions in all sectors according to the EU's "20-20-20" targets. As result, uncertainty will increase by 0.2% per year. This value is very small compared to the two previous cases, because GHG emissions fall not only in the energy sector but also in all other sectors.

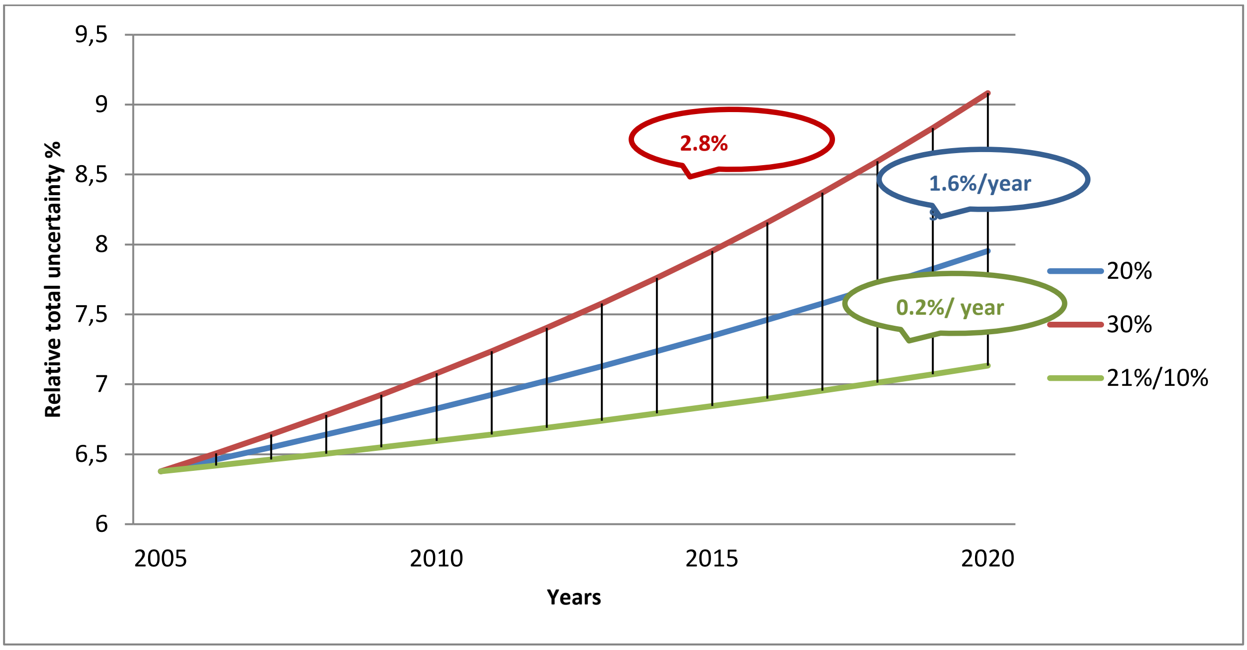

Figure 3. Estimates of uncertainty in GHG emissions considering step-by-step target mode for the EU-15

This is an example of possible changes in uncertainty due to structural change in emissions. However, the increase in uncertainty could be reduced by a "learning process" (see *Figure 2*).

3.2. Estimates of uncertainty in CO2 emissions in energy sector

Energy is the most important and best known sector, accounting for 80% of all EU emissions. GHG mitigation measures are set mainly in this sector.

This chapter focuses on EU-27 as a whole. We calculate uncertainty in CO_2 emissions of fossil fuel combustion under the three assumptions below.

(1) We use today's knowledge of activity data and emission factors (uncertainty in activity data and carbon content is the same in the commitment year as in the year 2005).
(2) During the projection period (2005-2020), GHG emissions approach the agreed targets ("20/20/20") linearly.
(3) GHG emissions, including CO_2 emissions from renewable energy sources, are assumed carbon-neutral. Increasing the share of renewables in the EU fuel mix will therefore result in significantly lower GHG emissions. The additional renewable energy deployment needed to achieve the 20% target will reduce the annual CO_2 emissions in the range of 600-900Mt in 2020 (COM 848, 2006). One important source of renewable energy is biomass. Amounts of biomass used as fuels are included in national energy consumption, but the corresponding CO_2 emissions are not included in the national total of emissions as it is assumed that biomass is produced in a sustainable manner and releases the carbon that it had soaked up before. If biomass is harvested at an unsustainable rate, net CO_2 emissions are generated as loss of biomass stocks in the Land-Use, Land-Use Change Forestry sector (EEA,2009).

All required data are available from the Member States' National Inventory Reports (NIR, 2003-2009) and the GHG Inventory Report (EEA, 2009). We calculate uncertainty for the EU (excluding Malta because it does not report uncertainty in its GHG inventories,).

In the previous Chapter, we assumed that energy consumption is constant. Here we allow for changes in energy demand. We use the two scenarios of future energy demand described in the Second Strategic Review (SEC 2871, 2008) of the EU to calculate emissions in the commitment year 2020:

- Baseline scenario reflecting current trends and policies;

- New Energy Policy scenario reflecting the EU targets on climate change mitigation, mainly a reduction of 20% of GHG emissions compared to 1990 due to the increase in the share of renewables in final energy demand by 2020, combined with a substantial improvement in energy efficiency.

Except for the policy assumptions, all other assumptions (with respect to technology, economic structure, demographic development, etc.) are the same for the Baseline scenario and the New Energy scenario. Both scenarios start from common projections, notably on economic growth (2.2 % on average up to 2020). The Baseline includes current trends and policies as implemented in Member States up to the end of 2006 (EC, 2008). The New Energy Policy scenario assumes vigorous implementation of policies to make substantial progress on energy efficiency and reach emission and climate targets. Implementing of the New Energy Policy scenario requires reduction of GHG emissions by 20%.

Both the Baseline and New Energy Policy scenarios give ranges for energy consumption depending on oil price environment. The moderate price means an oil price 61$ (2005)/barrel in 2020. The high price means an oil price 100 $ (2005)/barrel in 2020.

To facilitate the interpretation of results, we explain by referring to some examples of influence of structural change in fossil fuels consumption on relative uncertainty. Combustion of liquid and other fuels involves bigger uncertainty than solid and gaseous fuels, and each fuel has different emission factor *(Table 1)*. Replacing consumption of one fuel by another could result on increase or decrease in total uncertainty (*Figure 4*).

Table 1. CO_2 emission factors and uncertainty by fuel type

Fuel type	CO_2 emission factors (t/TJ)	Uncertainty in relative terms
Liquid Fuels	73.05	0.1000
Solid Fuels	97.30	0.04
Gaseous Fuels	56.59	0.02
Other Fuels	81.95	0.16

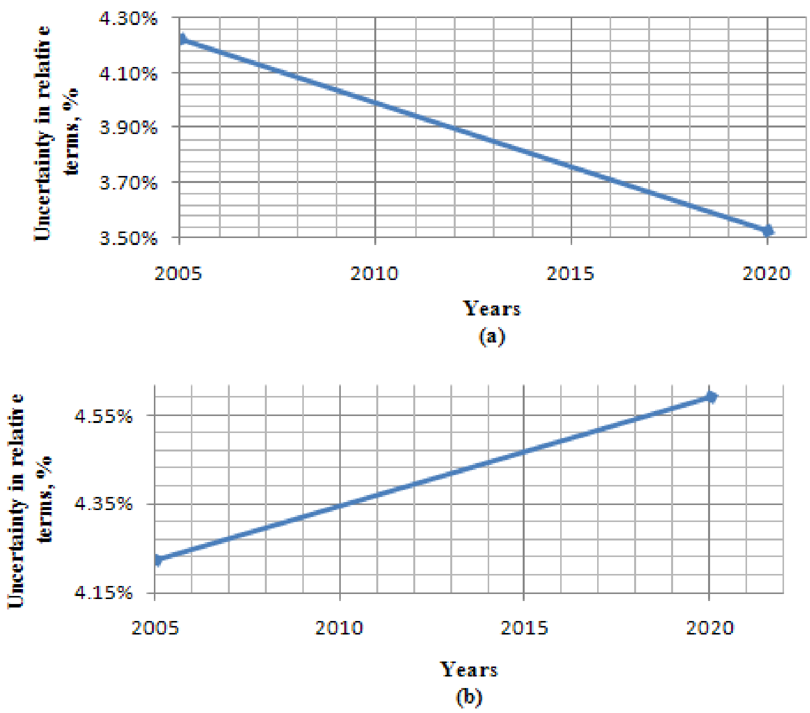

Figure 4. Examples of change in uncertainty due to replacement in fossil fuel consumption: a) liquid fuels by gaseous by 20%; b) solid fuels by liquid by 20%. We replace fuels in energy units (J)

Results

Estimates of total uncertainty under the energy scenarios (Baseline and New energy policy) are shown in the *Figure 5*:

- Baseline:
  a) Blue curve (moderate oil price) – uncertainty decreases by 0.13% per year because of using more gas in fossil fuel combustion that has lower uncertainty;
  b) Red curve (high oil price) – uncertainty decreases by 0.19% per year because of changes in fossil fuel combustion: less oil, and more solids, which have lower uncertainty;
- New Energy Policy:
  a) Green curve (moderate oil price) – uncertainty increases by 0.5% per year because of combination of reductions in combustion of all fuels (using more renewables);
  b) Purple curve (high oil price) – uncertainty increases by 0.27% per year because of reductions in combustion of all fuels, but greater than in case with moderate price.

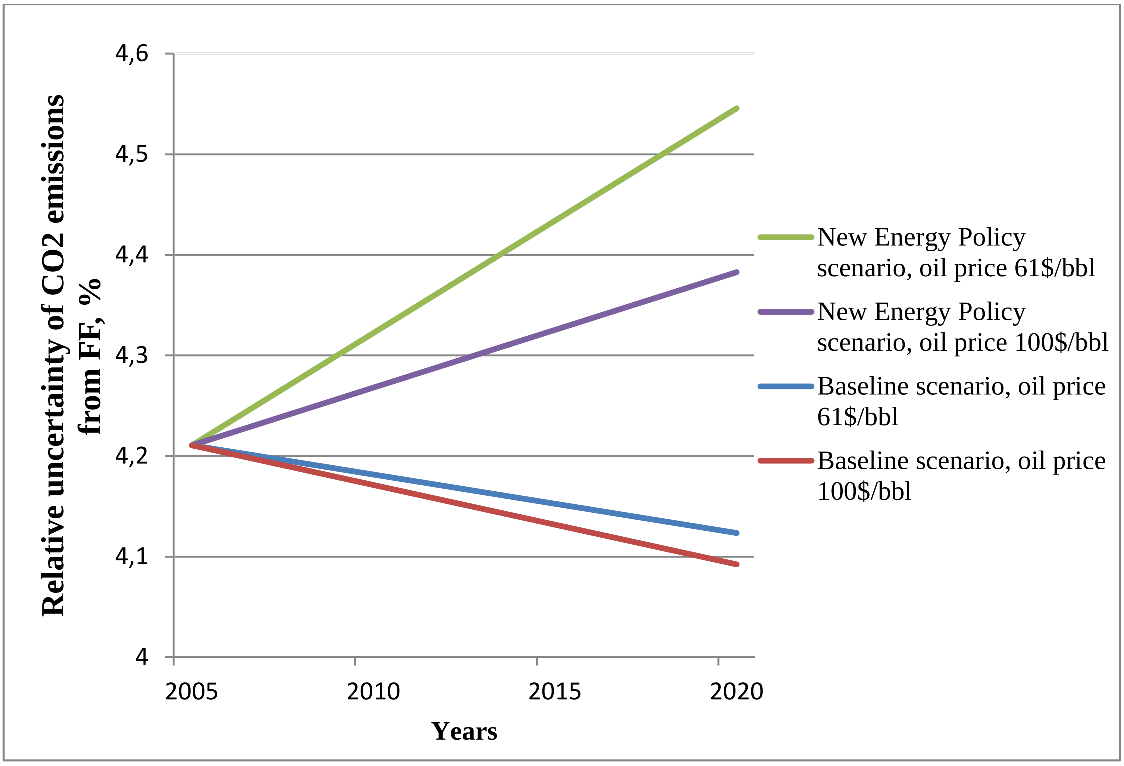

Figure 5. Uncertainty of CO_2 emissions of fossil fuels consumption consider future energy demand

In the case of the New Energy Policy, relative uncertainty in CO_2 emissions will increase due to structural change in fossil fuel combustion, but the change is very small and can be balanced by the other factor of change in uncertainty – "learning".

3.3. Calculation of new modified targets for EU

We calculate modified targets for the EU -15 considering uncertainty that change over time due to structural changes in emissions.

We use the Und&VT concept (described in Chapter 2.2) that helps to ensure that the change in emissions exceeds total uncertainty considering different levels of risk.

For experiments, total uncertainties of CO_2, N_2O, CH_4 emissions in CO_2 -equivalent (the EU-15) are used. They are calculated in Chapter 3.1 for the year 2020.

In *Figure 6* modified targets for different levels of risk are displayed, where α is the level of risk that the EU's true (but uncertain) emissions in the commitment period exceed its agreed emission targets.

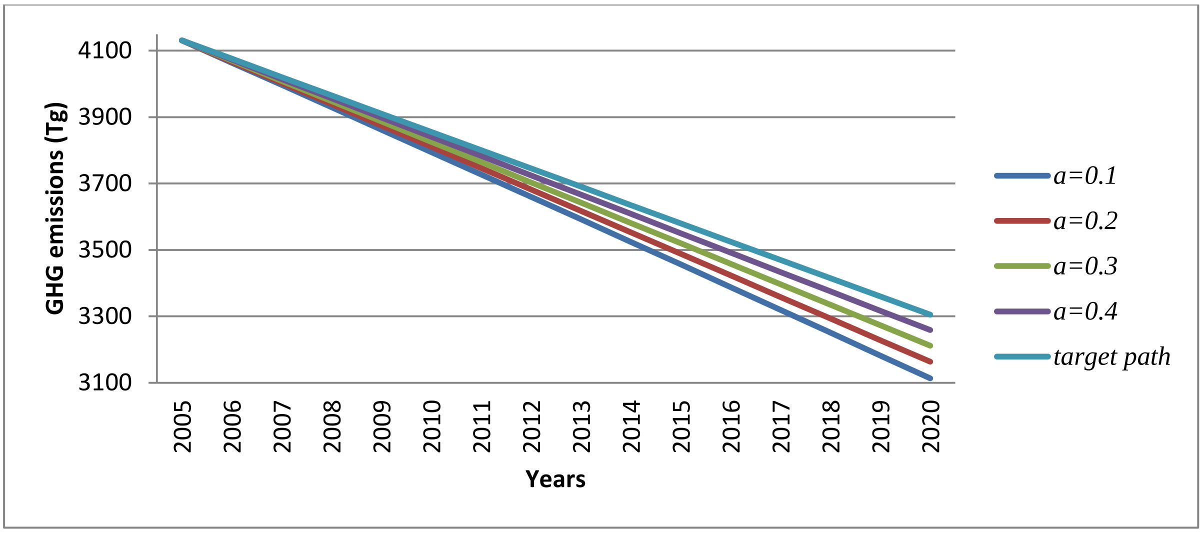

Figure 6. Calculated modified reduction targets CO_2, N_2O, CH_4 emissions in CO2-equivalent for the EU-15

The EU should undershoot its emissions even by an additional 6% to limit risk at a level of *0.1*.

Figure 7 compares modified targets for constant and changing uncertainty:

- Red curve: uncertainty is constant in time;
- Blue curve: uncertainty changes over time due to structural change in GHG emissions.

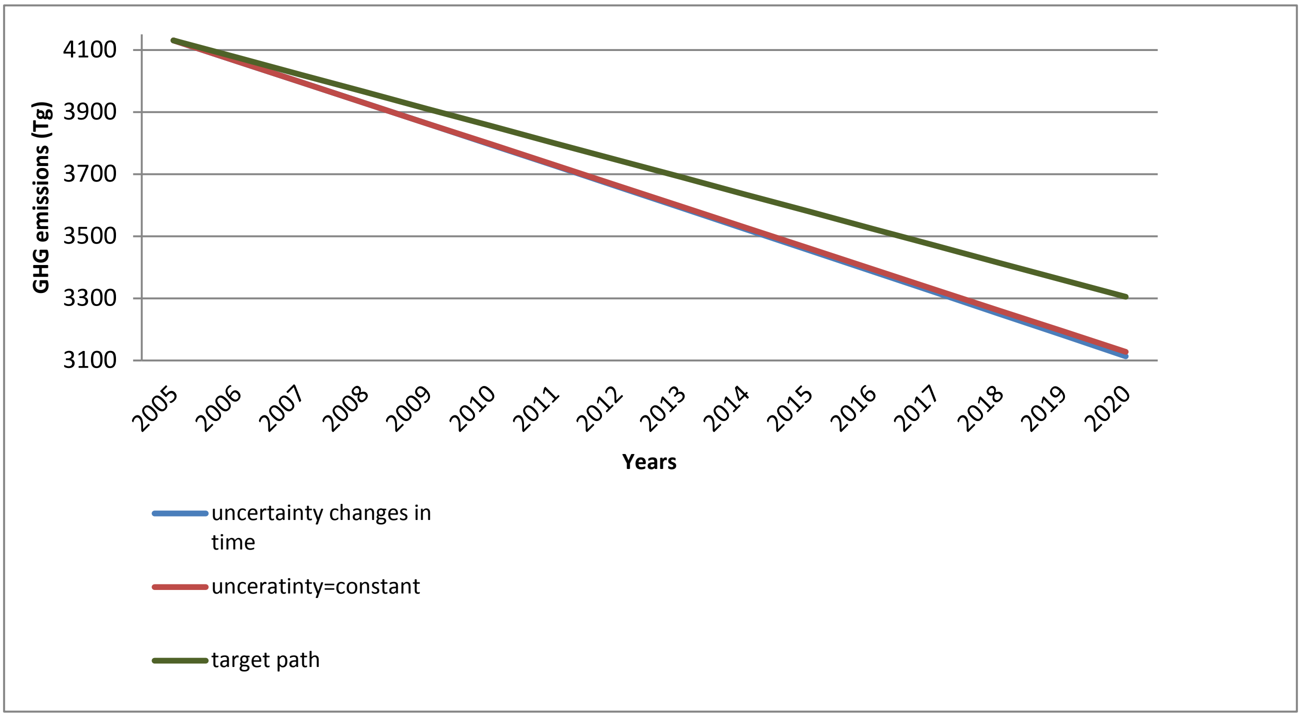

Figure 7. Comparison of modified targets for the EU-15 in two cases: (1) uncertainty changes over time, (2) uncertainty is constant.

Figure 7 shows that the difference between the two linear paths, when uncertainty is constant and when it changes due to structural change in GHG emissions, is very small. The change in uncertainty due to structural change in GHG emissions considering the EU's "20-20-20" are very small, so a greater effort should be put into increasing knowledge (learning).

Conclusions

In this report, we provide examples of future changes in uncertainty that result from emissions scenarios that are consistent with the EU's "20-20-20" strategy.

During the period 1990-2005, uncertainty of CO_2 emissions of fossil fuels consumption decreased by 4.6% per year (considering accuracy). An estimated 95% of the relative change in uncertainty was caused by learning and about 5% by structural change in consumption of fossil fuels.

We estimated total uncertainty in relative terms for the EU-15 considering EU's "20-20-20" targets for the year 2020. We calculated that uncertainty would increase by 0.2% per year. Estimates of future uncertainty in the Energy sector confirm that the percentage change in uncertainty due to structural change in GHG emissions is negligible. It varies from 0.27% to 0.5% per year. These numbers reflect the increase in total uncertainty in relative terms. Our calculations exclude emissions from LULUCF because they have greater uncertainty than emissions from fuel burning. Increased use of renewables in energy consumption can cause an increase in GHG emissions in other sectors that will increase total uncertainty.

Our results show that the structural change in GHG emissions causes only a small percentage change in relative uncertainty, so we suggest placing more effort on learning (increasing knowledge of inventory processes, improving methodology in estimating emissions and their uncertainties).

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