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Integrated Approach to Climate Change Mitigation and Air
Quality Protection

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Prohlášení

Prohlašuji, že jsem předkládanou práci zpracoval samostatně a použil jen uvedené prameny a literaturu.

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ABSTRAKT

Tato bakalářská práce je zaměřena na kvantifikaci úspory nákladů na ochranu ovzduší a klimatu v České republice za předpokladu, že jsou nástroje k dosažení cílů v těchto oblastech koncipovány na společné bázi. V práci jsou nejprve stručně vysvětleny oba pojmy, následně je popsána evropská legislativa zaměřená na ovzduší a klima. Druhá kapitola je věnována historickému vývoji obou oblastí v České republice. K ověření teze je užit model GAINS, ve třetí kapitole jsou vysvětleny jeho matematické základy a popsány scénáře budoucího vývoje v obou oblastech. V závěrečné kapitole jsou prezentovány výsledky analýzy popsaných scénářů, se zvláštní pozorností věnovanou pravděpodobnému budoucímu vývoji a popisu dopadů snížení emisí na lidské zdraví a ekosystémy.

ABSTRACT

This bachelor thesis is aimed at quantification of cost reduction of integrated approach to climate change and air pollution in the Czech Republic. Firstly, the terms of air pollution and climate change are explained and the relevant EU legislation is described. The second chapter is dedicated to historical development in the both fields in the Czech Republic. The main assumption of the thesis is examined using the GAINS model. In the third chapter is provided introduction to the mathematical foundations of the model as well as description of scenarios of possible future development in both of the fields. Finally, the results of the analysis are presented, with special care dedicated to the most likely scenarios and impacts of emissions reduction on human health and ecosystems.

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1. Introduction

The introductory part of this work includes a description of the issues connected to the climate change and air quality as well as a list of relevant legislation and market based instruments of climate change mitigation and air pollution reduction.

1.1 The Problem Description

We live in the blissful ages. The second half of the 20th century meant an economical growth of western societies in extent never seen before. The quality of human life improved fundamentally, letting us live our lives under the best circumstances ever. However, this rapid growth had some less appealing consequences.

Ever since the Great Smog of London that killed several thousand people over a few days, both policy makers and public started to care about the environment and the ways we continue to spoil it. We finally began to pay the price inseparably linked to progression of our society. The reeking chimney and the fiery locomotive are not the signs of success anymore.

With that in mind, the society and its representatives began to put pressure on the environmental topics. The more we know about the ways we jeopardize the sustainable growth of our society, the higher the pressure on some kind of solution. There indeed are many legislation pieces and regulations that aim at reverting our way to the environmental collapse, and the European Union is the indisputable leader in this field.

This work describes the currently adopted approach to the climate change and air quality. Rather than solving the health and ecosystem hazards resulting from the air pollution and the change of the face of the world stemming from the greenhouse effect as two separate issues, these two problems need to be considered as one. As demonstrated on results of IIASA GAINS model, this way will save the resources that are invested into the climate and air quality, letting us do more for less. Ability to face the issues in the most effective way is then crucial, as there are a number of countries that are on the same fast track to success that we rode a few decades ago. If they repeat our environmental mistakes, the world will definitely change to worse.

The question is, whether the cost difference stemming from combined approach to climate change mitigation and air quality protection really matters, if the co-benefits of combined approach are large enough to be compared with some 80 bn. Euros that are each year spent on the air quality alone. Or from the other way around, if the same funding was invested in the co-benefit approach rather than the traditional one, will that mean some substantial improvements? This work tries to answer these questions from both economic and environmental points of view.

This thesis is focused on the cost-benefit analysis of integrated approach to climate change mitigation and air quality management at the macro-level and the GAINS model has been chosen as the best available instrument to do this.

1.2 A short introduction into the air quality and climate change

Global climate change is understood as a critical issue of sustainable development worldwide and therefore has become a substantial topic of environmental policies. Greenhouse gasses (GHGs) in atmosphere, above all carbon dioxide CO₂, nitrous oxide N₂O, methane CH₄ (but also certain fluorinated gases, “black carbon” and ground-level ozone O₃) are blocking the solar energy reflected from earth surface, effectively capturing it in the atmosphere and rising temperature of the earth. There are numerous issues related to the rising GHG concentration, from the melting of polar icecaps and dilatation of water resulting in rise of the ocean level to changes in ecosystems and heat waves during summer.

Air pollution is in present recognised as one of major environmental problems in most of countries. Above all, suspended particulate matter (PM)¹, ground-level ozone (O₃), sulphur dioxide (SO₂), nitrogen oxides (NO_x), volatile organic compounds (VOCs) and ammonia (NH₃) but also other pollutants such as heavy metals (HMs) or persistent organic pollutants (POPs) adversely affect both human health and the environment.

While the majority of air pollutants is emitted directly, suspended particulates might be either emitted directly (primary particles) or created in the atmosphere by physical processes or chemical reactions of their gaseous precursors – sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia (secondary particles). Ground-level ozone is not emitted directly at all but is formed by photochemical reactions of its precursors - NO_x and VOCs.

The most severe impacts of the air pollutants are those on human health. The results of local air pollution account for roughly 320 thousands of premature deaths a year [1]. Even a short-term exposition to ambient air with elevated PM concentration may cause reduced lung capacity, asthmatic symptoms or other health affecting problems. Serious health problems and even premature deaths may also be attributed to exposition to elevated concentrations of ground-level ozone.

Impacts of air pollution on the environment involve acidification² and eutrophication³ caused by directly emitted pollutants such as SO₂, NO_x and NH₃ alter the properties and further development of ecosystems and damage to crops and vegetation caused by ground-level ozone.

Box 1: Acidification

„Acidification is causing damage to freshwater systems, forest soils and natural ecosystems in large areas of Europe. The effects of acidification have been evident in various different ways, including defoliation and reduced vitality of trees, declining fish stocks and decreased diversity in acid-sensitive lakes, rivers and streams and changes in soil chemistry.“

Source: EEA [2]

¹ PM₁₀ and PM_{2,5}, particles with diameter less than 10 and 2,5 µm respectively

² pH decrease

³ Rise of NO_x and NH₃ concentration

Box 2: Eutrophication

“The major consequence of eutrophication concerns the availability of oxygen. Plants, through photosynthesis, produce oxygen in daylight. On the contrary, in darkness all animals and plants, as well as aerobic microorganisms and decomposing dead organisms, respire and consume oxygen. These two competitive processes are dependent on the development of the biomass. In the case of severe biomass accumulation, the process of oxidation of the organic matter that has formed into sediment at the bottom of the water body will consume all the available oxygen. Even the oxygen contained in sulphates will be used by some specific bacteria. This will lead to the release of sulphur that will immediately capture the free oxygen still present in the upper layers. Thus, the water body will lose all its oxygen and all life will disappear.”

Source: WHO [3]

Box 3: Particulate matter

„Exposure to PM in ambient air has been linked to a number of different health outcomes, ranging from modest transient changes in the respiratory tract and impaired pulmonary function, through increased risk of symptoms requiring emergency room or hospital treatment, to increased risk of death from cardiovascular and respiratory diseases or lung cancer. (...) Health effects are observed at all levels of exposure, indicating that within any large population there is a wide range of susceptibility and that some people are at risk even at the lowest end of the observed concentration range. People with pre-existing heart and lung disease, asthmatics, socially disadvantaged and poorly educated people and children belong to the more vulnerable groups.”

Source: WHO [4]

Box 4: Ground-level ozone

“The adverse effects of ozone on the respiratory tract, from the nasal passages to the gas-exchange areas, are unequivocal. Although there are considerable variations in response between species and between individuals, acute ozone exposure causes reduced pulmonary function, pulmonary inflammation, increased airway permeability and heightened hyperreactivity. These effects and ensuing tissue injury in the small airways and the gas exchange region, depending on exposure concentration and duration as well as individual susceptibility, may lead to irreversible changes in the airways and worsen lung disease.”

Source: WHO [5]

Due to that, the air quality has been in the forefront of environmental policies in the developed world since the mid-20th century. The air quality issues rise on importance also in developing world, particularly the fast-growing Asian and South American economies, as their welfare growth is connected with rise in energy demand or car usage and hence the decrease in urban air quality.

Importance of climate change, though it is a major environmental problem worldwide, was not recognised until late 1980s. Whereas local air pollution is a clearly observable issue, our knowledge of global climate change is based mainly on scientific conclusions. Moreover, the GHGs are rather long-lived, which gives them enough time to disperse in the atmosphere. Emissions from one particular place therefore influence the world in global. While the growing concentrations of GHGs in atmosphere are observed since the mid-18th century and the beginning of industrial revolution, above mentioned issues gained on importance only recently. As most of GHGs are long-lived, the concentrations rose steadily and the accompanied effects became more severe.

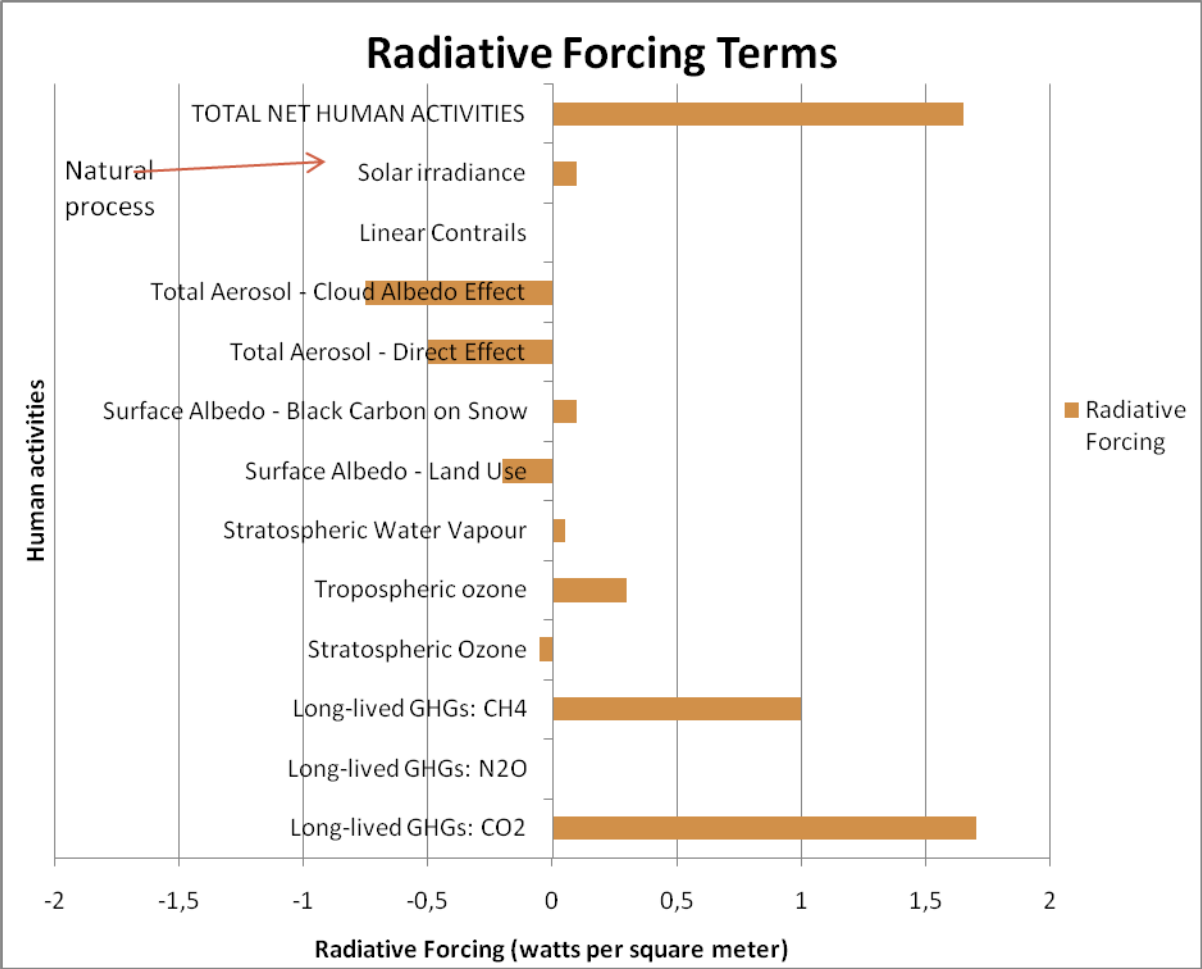
Box 5: Threats of the climate change

There is a number of impacts linked to the climate change. Among the most severe are:

- There will be more deaths from malnutrition and heat stress, diseases such as malaria and dengue fever will spread
- Decline of crop yields and hunger
- Rising sea levels, increase of flood risk, reduction of freshwater reservoirs
- Ecosystems under great risk, 15% to 40% of species facing extinction
- Change in weather patterns such as monsoons rains. More severe impacts of hurricanes, stronger heat waves
- **Impacts linked with the climate change are comparable with those of the Great Depression or post-world war II situation.**

Source: Stern Review [6]

Figure 1: Factors of radiative forcing



Source: IPCC [7]

Furthermore, it has been found that air pollutants may also affect the climate. While sulphur dioxide or aerosols have negative radiative forcing and therefore a cooling effect on climate, ground-level (tropospheric) ozone and black carbon have directly positive radiative forcing and therefore a heating effect on climate. In addition, chemical reactions among certain air pollutants and greenhouse gases may occur. The radiative effects of GHGs and air pollutants and potential interactions among air pollutants are presented in Figure 1.

Table 1: Potential interactions among air pollutants and GHGs (X for interaction)

	PM	SO ₂	NO _x	VOC	NH ₃	CO ₂	CH ₄	N ₂ O	Fgases
Health impacts									
Particulate matter (PM)	X	X	X	X	X				
Ozone (O ₃)			X	X			X		
Impacts on ecosystems and vegetation									
Ozone			X	X			X		
Acidification		X	X		X				
Eutrophication			X		X				
Radiative forcing									
Direct						X	X	X	X
Via aerosols	X	X	X	X	X				
Via OH radicals			X	X			X		

Source: IIASA [8]

The most important GHG – carbon dioxide CO₂ - is in most cases emitted from same or similar sources as the air pollutants, above all from the energy sector (combustion of fossil fuels in stationary as well as mobile sources). Therefore, majority of measures applied in order to reduce the emissions of air pollutants therefore affects GHG emissions as well, and vice versa.

It is clear that the final outcome of a measure in one field can have positive, neutral or negative impact in the other one, selected strategy can bring either win-win or trade-off effect. For example, increase in efficiency of energy generation from fossil fuels will lower emissions of both air pollutants and GHG pollutants. On the other hand, flue gas desulphurization resulting in lower SO₂ emissions from power generation has negative impact on effectiveness, rising the CO₂ emissions.

Close relations and interactions between air pollutants and greenhouse gasses might be an important driving force for current approaches to climate change. With possible co-benefits and trade-offs in mind, current environmental goals can be achieved with substantially lower costs. For instance, under current legislation, the CO₂ emissions reduction of 10% in 2020 would also lead to approximately 5% drop in PM_{2,5} and similar reductions in emissions of other air pollutants [9].

Both air quality and climate change are covered by international legally binding instruments, the Kyoto protocol and the Gothenburg protocol.

1.3 Air pollution policies – Gothenburg Protocol to UNECE CLRTAP and its reflection in the EU

Gothenburg Protocol to the United Nations Economic Commission for Europe Convention on Long-range Transboundary Air Pollution (UNECE CLRTAP) was adopted in November 1999 (as the 8th protocol to this Convention) in order to abate acidification, eutrophication and ground-level ozone. Similarly to the Kyoto Protocol (see subchapter 1.4), the main aim of the Gothenburg Protocol is to cut emissions of four pollutants – sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia - by 2010 in compare with year 1990. Parties to the protocol are supposed to cut SO₂ emissions by 63%, NO_x emissions by 41%, VOC emissions by 40% and ammonia emissions by 17%. The Protocol offers numerous measures of emission abatement including economic instruments.

Directive 2001/81/EC implements goals of the Gothenburg protocol into European Community legislation by setting emission ceilings (“upper bounds”) for each of the four pollutants. Member states can choose which measures to take in order to comply with the goals. At present, Directive 2001/81/EC is being updated to introduce more stringent national emission ceilings until 2020 and to add a brand new emission ceilings for suspended particulate matter PM_{2.5}.

Obligations from the Kyoto and Gothenburg protocols are implemented and further specified in EU environmental and climate policies. The **6th Environment Action Programme of the European Community** (Environment 2010: Our future, our hope; the 6th EAP) is a framework for the environmental policy making in 2002-12 that specifies seven Thematic Strategies for better environment, among all also air quality and climate.

The Clean Air For Europe (CAFE) initiative has laid down a background for future activities in the field of air quality assessment and management. Afterwards, **Thematic Strategy on Air Quality** has appeared to specify numerous air quality-related tasks and suitable measures to fulfil them. In this work, four main goals of the Thematic Strategy are considered to be these: 74% decline in forest area receiving critical loads of acidifying substances, 43% decline in forest area receiving critical loads of eutrophication substances, 47% cut in years of life lost caused by PM_{2.5} and 10% decline in premature deaths caused by ozone.

Finally, new **Air Quality Framework Directive** (Directive 2008/50/EC on ambient air quality and cleaner air for Europe) has been adopted which sets major ambient air quality standards (PM, sulphur dioxide, nitrogen dioxide and nitrogen oxides, carbon monoxide, benzene, lead and ozone). This framework directive is accompanied by the Directive 2004/107/EC which sets air quality limit values for heavy metals and polycyclic aromatic hydrocarbons. On the “emission side”, the major role is played by Directive 2001/81/EC (national emission ceilings), Directive 2001/80/EC (large combustion plants), Directive 1999/13/EC (VOCs from the use of organic solvents) and Directive 2008/1/EC (IPPC – Integrated Pollution Prevention and Control).

Along with air quality related issues, tackling of climate change is also a part of the 6th EAP. The **European Climate Change Programme** (ECCP) has been launched in June 2000 in order to keep pace with the Kyoto Protocol requirements. The main policy designs during the First ECCP (2001-03) were the baselines for EU ETS programme, one of most powerful tools for tackling of the climate change. The member states agreed on system that “(...) must be environmentally effective and economically

efficient, simple and transparent” and that “(...) should endeavour to share effort equitably between all sectors of society and emitters” [10]. First ECCP then also proposed the exact framework of EU ETS. Along with the emission trading (directive 2003/87/EC), other legislation was introduced, such as Directive on the promotion of biofuels (directive 2003/30/EC) or Directive to promote combined heat and power generation (directive 2004/8/EC). Second ECCP is then aimed mostly at the further development of tackling of climate change.

1.4 Climate change policies – the Kyoto Protocol to the UN FCCC

United Nations Framework Convention on Climate Change (UN FCCC) is an international instrument that sets a framework for governments of 192 countries to join powers in tackling of the climate change. The main goal of the states that have ratified the UN FCCC is to share the scientific findings on the climate change and pursue common mitigation and adaptation policies. The UN FCCC entered into force in March 1994.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change, adopted in December 1997, contains emission targets for developed countries for the post-2000 period. The goal of the Kyoto Protocol is to prevent dangerous anthropogenic interference with the climate system by cutting the annual emissions of the main GHGs, carbon dioxide, methane, nitrous oxide and fluorinated gases by at least 5% by the period 2008-2012, measured against the base year of 1990. While emissions in many of the EU countries rose after 1990, the actual percentage of emissions to be cut is well over the 5%.

Besides the national measures that are the primary tools of GHGs reduction in order to meet the Kyoto target, there are also three market-based **Kyoto mechanisms** included in the Kyoto Protocol. The projects and investments carried out as the Kyoto mechanism are a way in which the developed countries converge to their targets by removing the emissions in the developing countries in a cost-effective way. First measure, **Emission trading**, is based on a possibility of trading the “allowed emissions”. If a country does better in emission reduction and therefore emits less GHGs than the expected amount, the rest could be sold to countries that need to cut down their emissions in order to meet their goal. Second measure, the **Clean Development Mechanism**, and third measure, **Joint Implementation**, allow the countries that ratified the Kyoto Protocol to invest in emission reducing projects in other countries. While an investment under the JI takes place in an annex B country (country that ratified the Kyoto Protocol), the CDM could be executed in any other country.

While it is not a policy, it is still important to mention the **Stern Review on the economics of climate change**. It is a comprehensive review of the climate change development, containing description of active policies as well as recommendations on new legislative designs, along with costs of the recommended measures and expected outcomes of the climate change under different legislative, economic and environmental circumstances. After the publication in 2006, the Review became one of driving forces behind the climate-related legislative processes in the EU.

There are a few measures applied in order to reach the goals of the Kyoto protocol and the UN FCCC. **European Union Greenhouse Gas Emission Trading Scheme (EU ETS)** is based on trade in CO₂

allowances, allocated to each relevant source of GHGs. Along with other measures (energy efficiency, energy savings, support to renewable energy sources), it is supposed to help keep the climate change to 2 degrees Celsius, in accordance with the EC January 2007 agreement.

The **Linking Directive** (2004/101/EC) amends the connection among EU ETS and the Kyoto Mechanisms. The number of the ways how to attain desired emissions is further extended by the directive, letting the subjects included in the EU ETS to cut down the emissions in more effective manner.

This effort was deepened in the January 2008 by the **Climate and Energy Package** (C&E Package) of the European Commission waiting for its final adoption recently. The GHGs emissions should decline further on, the aim is 20% cut in GHGs emissions in year 2020 in compare to year 1990. What is more, share of renewable energy sources should rise to 20% by the same time. Recently, negotiations are in progress to achieve a kind of global agreement on the GHGs emission reduction for the “post-Kyoto period” to be adopted at the UN Climate Change Convention in Copenhagen before the end of 2009.

The package contains a number of directives that are designed to achieve the 20 20 20 goal. The main three legislative measures are the **amended EU ETS** (amendment of directive 2003/87/EC), **promotion of usage of energy from renewable sources** and directive on **geological storage of CO₂**, these are to be accompanied by a number of supportive directives (concerning biofuels or transport emissions).

It is important to say that along the mitigation efforts, there are also adaptation measures. Many of the current effects of the climate change are irreversible and even fulfilling of the climate and air quality goals will not offset or reverse certain impacts of GHGs on ecosystems, hence the need to find out how to adapt on these impacts.

2. Air quality and GHGs emissions in the Czech Republic

This part of the work is aimed at the Czech Republic, the emissions of the relevant pollutants and GHGs, related costs and legislative.

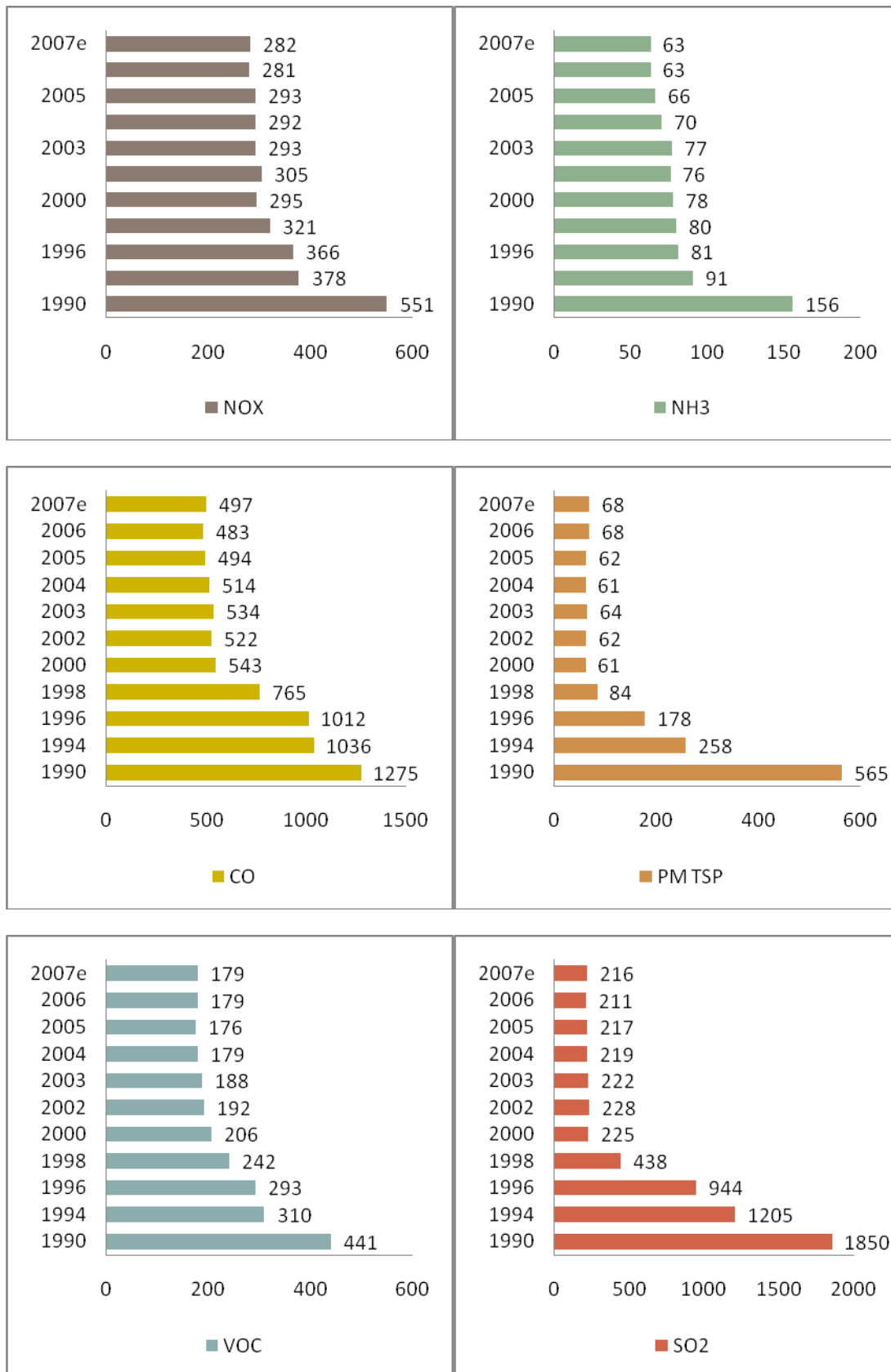
While air quality and other environment-related issues gained on weight in the most western countries since the 1950s, these topics were largely disregarded in the Czech Republic which was due to the structure of its economy one of the most polluted parts of Europe. After the Velvet Revolution in the end of the 1980s, the whole national economy (especially the energy sector and manufacturing industry) underwent a rapid change and many of the sources of GHGs and air pollutants simply ceased to exist. As a by-product of these changes in national economy, emissions of both GHGs and air pollutants had decreased dramatically. In addition, modern environmental legislation had been adopted after 1990 focused on the improvement of air quality as soon as possible. As a result, all major power stations and heat stations had introduced technical measures to abate emissions of dust, sulphur dioxide and nitrogen oxides and to comply with stringent emission limit values before 1998. Newly built infrastructure had allowed several hundred thousands of households to switch their heating from coal to natural gas.

The Czech Republic was among the Parties to both the Kyoto Protocol and the Gothenburg Protocol and took part in every important air quality and climate change mitigation action since. Since the 2004 access to the EU, CR also fulfils the requirements of the policies of the European Union.

2.1 Developments – GHGs emissions and air pollution

As a result of various policies, the emissions of air pollutants were on a gradual decline since 1990 with stabilization in past years (see Figure 2).

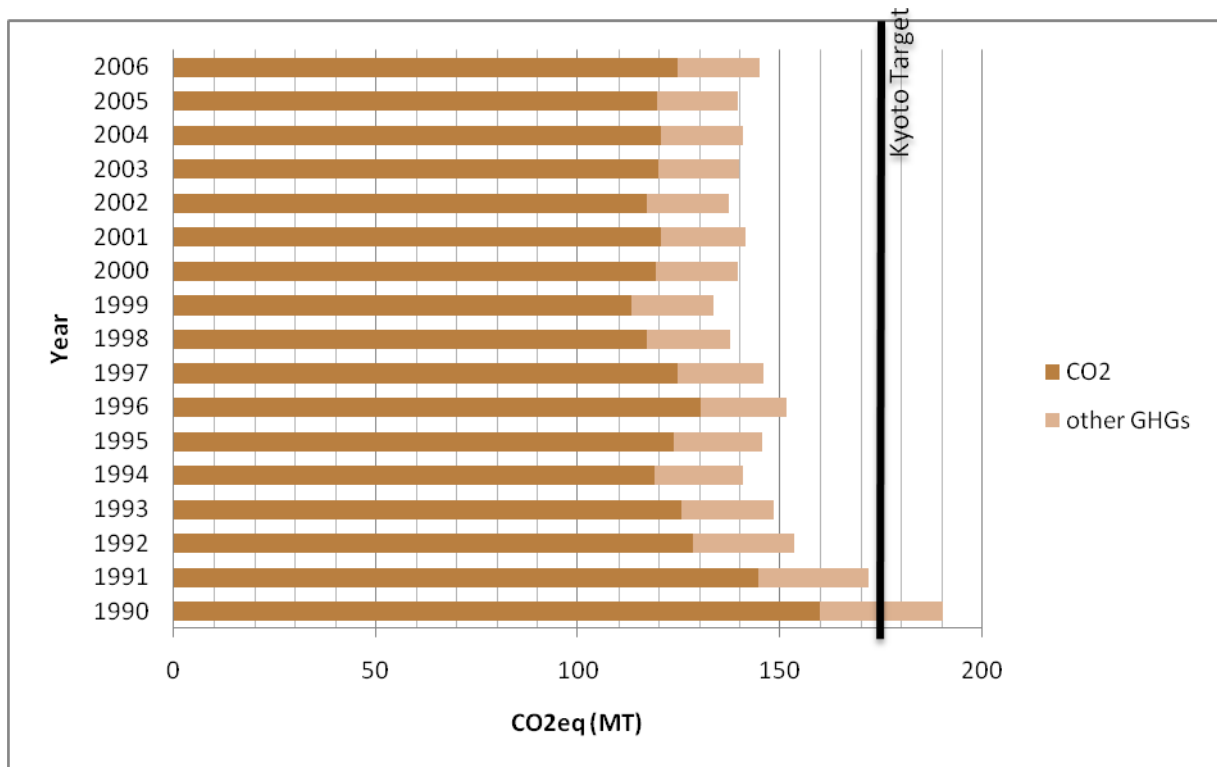
Figure 2: Historical values of air pollution in the Czech Republic, in kt.



Source: CHMI [11]

Also GHGs emissions have fallen in the past years, by 23,7% in year 2006 against year 1990. The largest decline occurred in years before 1994, to great extent due to restructuring of industry. Since then, the decline is slow, in some years the emissions even grew. However, Czech Republic still fulfils the Kyoto target (see Figure 3).

Figure 3: Historical emissions of GHGs in the Czech Republic



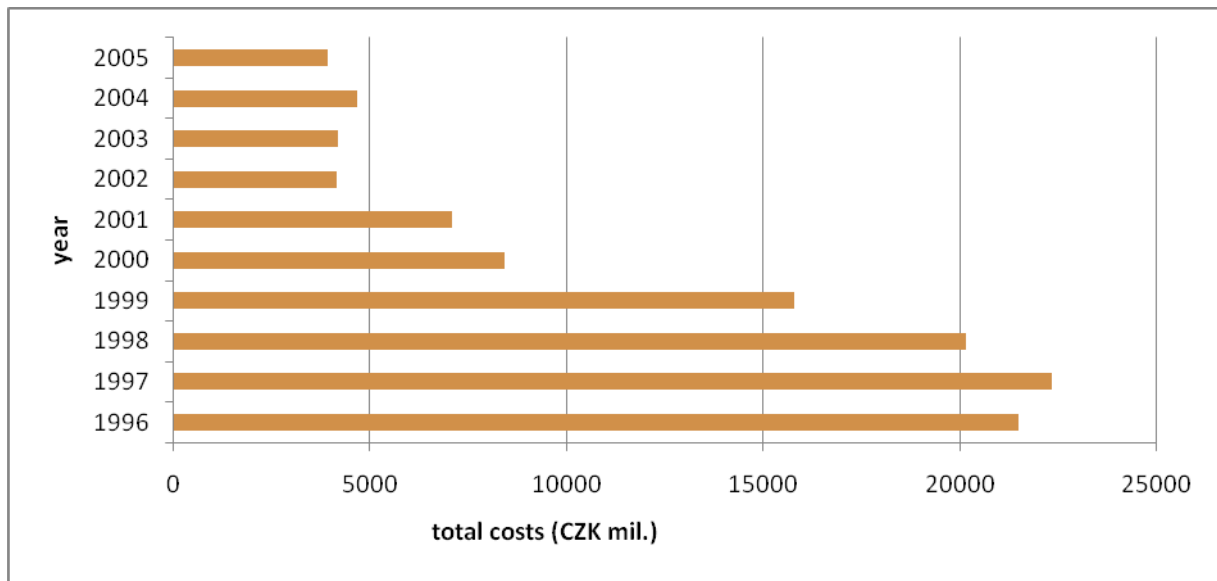
Source: ISSAR [12]

The largest source of air pollutants among stationary sources is the energy sector (80% SO₂ emissions and 45% NO_x emissions in year 2007) along with household heating (30% of PM₁₀ and 23% of PM_{2.5}), agriculture (95% of NH₃) and others. Also mobile sources (transport and non-road mobile machinery) affect the air quality to a great extent with 45% of NO_x emissions and 51% of PM_{2.5} emissions.

As for the emissions of GHGs, combustion of fossil fuels in stationary sources in the energy sector generates 65 % of national emissions of CO₂, the transport sector then generates 13% of CO₂ emissions (MŽP [13]).

The costs of air protection have met the highest absolute values in the first half of the 1990s, due to the necessity to resolve a number of air quality-related issues that were left out in the previous decade. Since then, the investments into air quality were on decline, following the steep slump of emissions of the six main pollutants.

Figure 4: Costs of air and climate protection in the Czech Republic, mil. CZK



Source: ČSU [14], [15]

An analysis of unit costs of emission reduction was recently developed by Ščasný and Pavel (Jílková et al., [16]). Marginal costs of the pollutant are the minimal unit costs that guarantee compliance with national emission ceilings. According to the study, the marginal price of ton of pollutant should be somewhere around 16000 CZK for SO₂, 32000 CZK for NO_x and 97000 CZK for PM_{TSP}, assuming efficient implementation of Climate and Energy package of the EC. These numbers are relatively low in compare to the marginal costs in other EU countries.

2.2 Current Czech policies and legislation

State Environmental Policy of the Czech Republic 2004-10 is the local implementation of the 6th EAP framework. Similarly to the EAP, it contains policies concerning a number of topics related to environment and its protection. National Programme To Abate the Climate Change Impacts in the Czech Republic is the cornerstone of Czech approach to climate change, containing data on current emissions of GHGs and projections of the future values as well as proposals for future mitigation measures and adaptation on the climate changes. According to the 2007 review of the Programme, remarkable achievements have been made over the last few years. Furthermore, alternative sources share in energy generation grew greatly. However, GHGs emissions are still well above the EU average, both per capita and per unit of GDP. Further steps will be taken in order to comply with the obligations to the EU. The National Emission Reduction Programme of the Czech Republic, adopted in 2007, is then an implementation of air quality-related policies of the EU.

The demands of above policies might have serious impacts on Czech industry. According to a report by McKinsey and co. [17], because of a high share of industry on GDP and large values of exports of

both goods and electricity, complying with the Environmental Policy will mean rather huge investments into measures of GHGs emissions reduction.

3. Integrated Approach to Climate Change Mitigation and Air Quality Management and its Methodology

Beside the introduction into the integrated approach, this chapter is dedicated to the GAINS model that was selected to prove or disprove the thesis of this work. Description of the used scenarios as well as in-depth look into the mathematical foundations of the model is provided too.

3.1 Introduction to the integrated approach

Short time ago, both climate change mitigation and air quality management were considered as independent issues and were thus being solved separately both at the level of strategies and policies and at the level of instruments and measures. Recently, a new trend of integrated (co-benefit) approach to climate change mitigation and air quality management is emerging at global (UN), regional (EU) and national (UK, USA, Japan, China, India) levels which is based on robust scientific background as well as on the economic analysis.

The rationale behind the integrated approach is rather clear: Firstly, both air pollutants and GHGs are often generated by same sources, mainly the combustion processes in energy sector or transport. Secondly, some of the air pollutants such as particulate matter or ground level ozone may also affect the climate

Efforts in this field are visible at two levels. On the macro-level, there are complex mathematical models describing costs and benefits of the integrated approach within the standard DPSIR framework (driving force- pressure – state – impact – response). On the micro level, particular models are used for development and application of integrated environmental methodologies to solve concrete problems.

3.2 A short review of relevant papers

The topic of integrated approach was already explored in the past by various authors. This chapter describes the outcome of their works.

Baker and Rosendahl [18] used the E3ME model to value the SO₂, NO_x and PM₁₀ emission reduction stemming from meeting the Kyoto protocol in 19 Western European regions. Using three scenarios (carbon permits, carbon taxes and combination of both) and ExternE methodology of valuation of air pollution impact on human health and ecosystems, they assumed the ancillary benefits to be about 9 bn. year 1990 Euro a year in 2008-12 period, which is 138 Euro per ton reduction of carbon.

However, the results might not be entirely correct, as some the critical assumptions of this forecast (carbon permit price over 135 year 2000 Euros) are not fulfilled. The assumption that if oil prices overstep 40\$ per barrel, no further mitigation policies will be needed and there will be no ancillary benefits, was also broken, with substantially different results.

Vuuren et al. [19] further argues for an integrated approach and for need of proper climate policies design that generates the highest ancillary benefits. According to an analysis based on RAINS, TIMER and FAIR 2.0 models, meeting the Kyoto goals would bring 4% to 15% reduction for SO₂ emissions, 2% to 6% reductions in NO_x and PM₁₀ and 1% to 2% reduction in VOC. Further on, almost 50% of the costs of meeting the Kyoto target could be considered “saved”, as they lower the air control costs by the same amount, suppose a proper climate policy design.

Interestingly, the ancillary benefits are higher in case of unlimited emission trading and joint implementation. The CO₂ emissions would then be cut down in the Central and Eastern Europe regions as a part of emission reduction of Western European countries. However, the air quality benefits would be felt in the Western Europe as well, because of the trans-boundary character of the air pollutants.

The discussion was extended in a report of European Environmental Agency [20]. The results of this analysis are even more favourable for the integrated approach, in terms of both lower costs for air quality and climate change mitigation and climate-related policy-driven air pollutant emissions reduction. If properly designed, the climate policies would bring 17% decline in SO₂ emissions, 10% NO_x emissions reduction and 8% to 10% reduction in particulate matter in year 2030 compared to case of no climate policy. The savings for the air quality emission controls of each of the pollutants would then be 12%, 20% and 14% respectively. Important to mention, these co-benefits are powerful enough only in a limited number of sectors, namely energy or transport.

These benefits of integrated approach would lead, among others, to fall of premature deaths from particulate matter and ozone by 20000 by the year 2030. Furthermore, the costs of the air quality measures would fall by 10bn Euro a year, avoided health costs would then vary between 16 and 46 bn. Euro a year. However, the current legislation will not be enough to maintain the air quality goals, even when the co-benefits are taken into account. To attain the goals, new legislation is needed in the fields that are currently not regulated, such as shipping.

3.3 Detailed description and methodology of the IIASA GAINS model

As stated above, many measures to reduce GHG emissions may lead to the reduction of air pollutant emissions and vice versa (co-benefit measures). On the other hand, certain measures to reduce GHG emissions may lead to the increase of air pollutant emissions (trade-off measures). To prepare environmentally effective and cost-efficient mix of measures (with maximized use of co-benefit measures and minimized use of trade-offs), the tool to assess and forecast the impact of potential policies and measures is necessary.

The Greenhouse Gas and Air Pollution Interactions and Synergies model developed by International Institute of Applied Systems Analysis model (IIASA GAINS) is one of answers to the growing pressure

on improvement of the forecasts of measures and policies impact. It is an online-based model with modules for Europe and Asia, there is also a North American version that will be finalized soon.

GAINS is an extension of previous Regional Air Pollution Information and Simulation model (RAINS) that has been developed by IIASA in the 1990s. 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.

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 GHGs and 6 air pollutants, are considered in the model: NH₃, CO₂, CH₄, NO_x, N₂O, particulate matter (TSP, PM₁₀ and PM_{2,5}), SO₂, VOC, CO and the F-Gases. The data on historical emissions, economic development drivers and other data used in analysis are taken from national inventories or existing registers such as the register of CH₄ emission sources of the IPCC. 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.

There are a few possible sources of uncertainty that could lessen the relevance of the model to the case of the Czech Republic. Firstly, the results of modelled situations are understandably subject to various errors in measurement of input data stemming from aggregation, imperfect measurement, worse 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. 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.

Unlike 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.

The structure of GAINS is following: 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 GHGs 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.

The GAINS model is then capable of drafting the spatial distribution of the pollutants in the atmosphere as well as resulting acidification, eutrophication or tropospheric ozone impact caused by the pollutants dispersed in the atmosphere. The health and environmental impacts of the pollution are then also quantified, in case of health effects as loss in statistical life expectancy or lost lives attributable to the ground-level ozone exposure. These impacts can be confronted with environmental targets of active and proposed policies.

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 CO₂ 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 CH₄ 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 N₂O 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.

Beside the GHG emission reduction measures, there are also approximately 1500 measures of reduction of air pollutants, taken from the RAINS model.

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, CO₂ 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.

The PRIMES model is used to quantify the implications of economic driving forces on national energy systems. Macroeconomic development and international energy prices are a base for energy consumption, another driving force in each scenario. Forecast of these factors for 2020 is based on year 2000 data and in all the scenarios described below (with exception of the NEC baseline scenario that has been designed as a non-C&E scenario) assumes compliance with Climate and Energy (C&E) package of the EC. The indicators are calculated for fuel consumption in each country and fuel consumption in each sector.

The resulting data on energy sector are then translated into CO₂ emissions projection using the PRIMES model. There are a few constraints applied, in cases below (with exception of NEC baseline) compliance with C&E package and price of carbon allowances in EU ETS system of 30 Euro per one ton of carbon dioxide. Historical values for years 1990 and 2005 and forecast for year 2020 are then again used in energy sector forecast. This means that CO₂ emission projections are calculated outside the model and imported as exogenous data to GAINS.

Agricultural activities are treated in a similar way. Data on agriculture in year 2000 are a base for 2020 projections. These projections are provided by the EU-27 countries and should reflect national agricultural policies and comply with the Kyoto targets for GHGs for year 2012. It is assumed that the 2020 level of emissions from agriculture is at least the same as the 2012 level. For states that have not provided data on agriculture (Bulgaria, Cyprus, Greece, Lithuania, Luxembourg, Romania and Slovakia), the values are taken from the CAPRI and EFMA agricultural and fertilizer projections or, when unavailable, from the Food and Agricultural Organization projections.

Impacts of emissions of air pollutants could be perceived in tens or hundreds of kilometres from their sources. Environment in the EU countries is therefore affected by emissions from surrounding countries. In order to exactly describe the state of air quality in the Union in the future, GAINS contains data on development of air pollution in nearby countries and adds them into the analysis when relevant.

Constitution of GAINS is such that the decisions of policymakers and technical issues following their decisions could be completely separated. Decisions about environmental targets, levels of acceptable risk for inhabitants and ecosystems and willingness to pay for better quality of environment are dependent solely on what is agreed on by the concerned parties, the ways of fulfilling the resulting decisions are then only technical issues. Rather complicated mix of measures for different EU countries with differing industries, pollution levels or environmental features is then based only on demanded outcomes.

3.4 Inside the black box – mathematical foundations of the GAINS model

In order to be a tool usable for policymakers as well as experts, GAINS is conceived as a “black box” model. That means that the proceeding of the analysis is not explicitly stated and only the outputs (“answer”) are presented, dependent on the input data (“question”). Following pages describe the way in which GAINS handles the input data. *Please note that this part of the paper should be only an outline made in order to understand what is happening inside the model, rather than an in-depth*

description. For more information on this topic, please review the sources – Klaassen et al [21], Wagner et al. [22].

3.4.1 Notation

Fashion in which GAINS chooses a combination of control measures that minimizes the costs for attaining certain environmental goals is defined by the *Objective Function*. In order to describe the function, mathematical framework is presented first.

Let $i \in I$ denote a country from a group of emitting countries (land-based regions) and $k \in K$ denote a country from a group of emission receptor countries. This allows for tasks such as evaluation of impact of pollution from sources in one country on other country.

Data in GAINS are structured by sector-activity combinations: for each sector $s \in S$ there is a number of different activities $f \in F$ (for example usage of different types of coal, gas and other fuels in energy sector). Not every activity occurs in every sector, furthermore, the combinations are different among the countries. One of control measures employed in the model is substitution of certain sector-activity combination by other, $(s, f) \rightarrow (s', f')$. Set of all combinations that can replace given combination is then denoted as $A_{i,s,f}$ and is dependent also on the country.

The set of pollutants $p \in P$ contains air pollutants as well as GHGs. The emission control technologies are aggregated into the set of emission control technologies $t \in T$, but not every technology is usable to control every pollutant, therefore there is a subset of technologies that control certain pollutant, $T_p \subset T$. $T_{s,f}$ is then a subset of technologies that controls certain sector-activity combination and $T_{s,f,p}$ is a subset that controls certain pollutant in some sector-activity combination. Conversely, there is also a subset of pollutants that can be controlled by certain technology, $P_t \subset P$, and a set of pollutants associated with certain sector-activity combination, $P_{s,f}$.

Among the control technologies is also included NOC_p , which stands for no control applied. This “technology” is included in order to simplify the equations below.

Finally, $P_t \subset P$ are emissions of certain pollutant from all the sectors and activities controlled by certain control technologies. In this case, the activities f denote fuels used in energy sector or fuels used in transportation.

The first decision variable used in GAINS is *Technology-specific activity variable*, which describes level of activity f in sector s and country i that is controlled by technology t :

$$0 \leq x_{i,s,f,t}, \quad i \in I, s \in S, f \in F_{i,s}, t \in T_{i,s,f}$$

Equation 1

The second decision variable used in GAINS is *Activity substitution variable*, which describes substitution of activity (fuel):

$$0 \leq y_{i,s,f,s',f'}, \quad i \in I, s \in S, f \in F_{i,s}, (s, f) \in A_{i,s,f}$$

Equation 2

Where $A_{i,s,f}$ is a set of allowed substitutions, $(s, f) \rightarrow (s', f')$.

In order to formulate total level of activity (total fuel consumption) in some sector, we need to sum up the Technology-specific activity variables of all the technologies used in this particular sector, including the “no control” technology. Total level of activity is then:

$$xp_{i,s,f} = \sum_{t \in T_{s,f,p}} x_{i,s,f,t}$$

Equation 3

Furthermore, consistency of the equation is ensured by the “no control” parameter, hence the total activity level in particular sector can be computed as a sum over technology controlling any pollutant, the total level of activity will still be the same:

$$xa_{i,s,f} = xp_{i,s,f} \quad p \in P_{s,f}, i \in I, s \in S, f \in F_{i,s}$$

Equation 4

Application rate for certain technology then could be computed as:

$$q_{i,s,f,t} = \frac{x_{i,s,f,t}}{xa_{i,s,f}} \quad i \in I, s \in S, f \in F_{i,s}, t \in T_{s,f}$$

Equation 5

so that $0 \leq q_{i,s,f,t} \leq 1$. This concludes description of the notation. The above framework is used in the next few pages to describe approach of the model to emission and cost calculation and quantification of environmental impacts.

3.4.2 Emission calculation

One of functions of the GAINS model is forecast of emissions of a pollutant in a country under various control measures. This is done by applying control measures to forecasted emissions. The final level of emissions is then obtained by summing the abated emissions over sector, activity and technology.

$$E_{i,p} = \sum_{s,f,t} Ef_{i,s,f,p} (1 - Eff_{i,s,f,t,p}) X_{i,s,f,t} + const_{i,p}$$

Equation 6

Where $E_{i,p}$ are total emissions of some pollutant in a country, $E_{i,s,f,p}^f$ are unabated (uncontrolled) emissions of some pollutant in a sector-activity combination and country, $Eff_{i,s,f,t,p}^f$ is efficiency of abatement technology (including the “no control” technology) and $X_{i,s,f,t}$ is actual level of implementation for this technology. Emissions from sectors that are not controlled by any control measure in GAINS are then denoted $const_{i,p}$ and held constant.

3.4.3 Unit Cost calculation

In order to compute minimal costs for control strategy (combination of emission control measures) that would achieve desired emission level, the unit costs for each measure and each pollutant is computed and plugged into the *Objective Function*.

Unit costs (cost per unit of abated pollutant) are computed on production level in year 2000 Euros. Free market is assumed, without any distortions such as mark-ups of produced goods, transfers, taxes or subventions, hence the capital investments into abatement measures are independent on the country. However, country-specific parameters such as boiler sizes, vehicle utility rates or emission factors are taken into account.

Final unit costs are composed of expenditures on investment, fixed costs and variable costs. Furthermore, the unit costs are computed separately for stationary combustion, industrial processes and mobile sources, as the composition of expenditures varies among these categories.

Parameters that compose the final costs are either mutual among the considered countries or country-specific. To the first group of common parameters belong technology-specific data, unit investment costs, fixed costs and parameters used for variable costs calculation such as extra demand for labour, energy or materials stemming from the investments into emission control measures. The second group of country-specific parameters is composed by average size of installations in a given sector, operating hours, fuel consumption, vehicle mileage, price of labour, fuel and electricity or cost of waste disposal.

Unit Cost Calculation - Stationary Combustion

The first considered category is stationary combustion. The investment costs composed by delivery of installation, engineering and consulting or land and capital acquisition are computed as follows.

$$I = (ci^f + \frac{ci^v}{bs})v(1+r)$$

Equation 7

The first of right-hand terms describes cost of investment to installation ci , either for hard coal (coefficient f) or for other fuels that generate different volumes of flue gas (coefficient v). Size of

investment is also dependent of boiler size bs . Additional costs generated by retrofitting an existing boiler are taken into account by parameter r .

The cost of investment is then annualized over its lifetime.

$$I^{an} = I \frac{(1+q)^{lt} q}{(1+q)^{lt} - 1}$$

Equation 8

Where lt is lifetime of the particular investment and q is real interest rate.

Fixed operating costs are composed of cost of repairs, maintenance or related administrative, they are not immediately tied to the actual use of the plant.

$$OM^{fix} = fI$$

Equation 9

Where f is some standard percentage of I .

Variable operating costs are related to actual operation of the plant, additional demand for labour, change in demand for energy used to operate the device or waste disposal.

$$OM^{var} = \lambda^l c^l + \lambda^e c^e + ef\eta\lambda^d c^d$$

Equation 10

Where λ^l , λ^e and λ^d are changes of demand for work, energy and waste disposal and c^l , c^e and c^d are the respective prices. Unabated emissions are then denoted $ef = Eff_{i,s,f,p}$, emission removal efficiency is denoted $\eta = Eff_{i,s,f,t,p}$.

Finally the unit reduction costs are computed and related either to one unit of fuel input (in PJ), where pf is number of operating hours per year, or to unit of emission abated (ton).

$$c_{PJ} = \frac{I^{an} + OM^{fix}}{pf} + OM^{var}$$

Equation 11

$$c_p = \frac{c_{PJ}}{ef\eta}$$

Equation 12

The latter term will be used in the objective function.

Unit Cost Calculation - Industrial Processes

Unit costs in this category are computed in a way that is similar to stationary combustion. The investment costs are given per ton produced or per ton of raw oil input in case of refineries and annualized. Please note that even some unrelated sectors such as agriculture are computed in this fashion.

Investments:

$$I = ci^f (1+r)$$

Equation 13

$$I^{an} = I \frac{(1+q)^t q}{(1+q)^t - 1}$$

Equation 14

Operating costs are then the same as in case of stationary combustion.

$$OM^{fix} = fI$$

Equation 15

$$OM^{var} = \lambda^l c^l + \lambda^e c^e + ef\eta\lambda^d c^d$$

Equation 16

Finally, unit costs for industrial processes are computed as follows per ton of product and per ton of pollutant.

$$c_{ton} = I^{an} + OM^{fix} + OM^{var}$$

Equation 17

$$c_p = \frac{c_{ton}}{ef\eta}$$

Equation 18

Unit Cost Calculation - Mobile Sources

The investment cost for mobile sources $I_{f,t}$ in Euros per vehicle are available separately for each category of vehicles and abatement technology. They include additional investment costs, increase in maintenance costs or change in fuel cost resulting from inclusion of emission control. The annualised investment is computed as follows:

$$I_{i,f}^{an} = I_{i,f} \frac{(1+q)^{lt_{i,f,t}} q}{(1+q)^{lt_{i,f,t}} - 1}$$

Equation 19

Where $lt_{i,f,t}$ is lifetime of particular control equipment.

While fixed costs are computed similarly to above categories, variable costs are specific for the vehicle category, accounting for change in demand for fuel caused by control measures or by change in fuel quality. The variable costs are also time-dependent.

$$OM_{i,f,t}^{fix} = I_{i,f,t} f$$

Equation 20

$$OM_{i,f,t}^e(t) = \Delta c_f^e + \lambda_{f,t}^e (c_{i,f}^e + \Delta c_f^e)$$

Equation 21

Where $\lambda_{f,t}^e$ is extent to which is fuel consumption of vehicle type f changed because of implementation of control measure t , fuel consumption net tax in the base year is denoted $c_{i,f}^e$ and Δc_f^e is change in fuel cost caused by improved quality.

Unit cost for mobile sources is expressed either per unit of fuel input or per unit of abated emission.

$$ce_{i,f} = \frac{I_{i,f}^{an} + OM_{i,f}^{fix}}{fuel_{i,f}(t)} + OM_{i,f}^e(t)$$

Equation 22

$$cn_{i,f} = \frac{ce_{i,f}(t)}{ef_{i,f}\eta}$$

Equation 23

3.4.4 Unit cost of substitution and increased efficiency

Beside the end-of-pipe (EoP) measures, there are also other ways of reducing the emissions, above all increases in fuel efficiency (ability to generate the same energy from less resources) and substitution from more polluting to less polluting fuel. While the increases in fuel efficiency are taken from literature and are used in the model as constants that are not a part of the optimization, the substitution is quantified in a way similar to EoP measures.

The optimization of substitution among the fuels is based on national energy models of each relevant country, where are provided the substitution potentials of national energy systems. As stated above,

unit cost of substitution that is used in the optimization is computed in a way similar to the unit costs of end-of-pipe measures discussed above, however, the way the model approaches substitution differs among different pollutants and GHGs. Following is the way in which substitution is accounted for in case of CO₂. *For substitution quantification in case of other pollutants and GHGs, please review the references [23], [24], [25], [26], [27] and [28].*

Fuel efficiency and unit cost of substitution in power generation sector

In the model, there is a possibility to replace energy generation from coal, oil and natural gas by natural gas, nuclear energy and other forms of clean energy and renewables. These fuel swaps are modelled as country-specific measures. Beside the costs, also efficiencies of such changes are accounted for: a fuel in some sector that generates one petajoule of electricity is compared to another fuel and sector that generates the same electricity output, the efficiencies are then used in order to find optimal way to lesser emissions.

The fuel substitution is implemented in a way similar to end-of pipe measures. Once again, the costs are divided into investment, fixed expenditures and variable operating costs.

$$I^{an} = I \frac{(1+q)^{lt} q}{(1+q)^{lt} - 1}$$

Equation 24

$$OM^{fix} = I f$$

Equation 25

$$OM^{var} = c^f (3.6 / 1000) \frac{100}{\eta^e} pf$$

Equation 26

Where c^f is unit price of GJ of fuel, pf denotes operating hours of the appliance per year and η^e is electricity generation efficiency.

The final cost per unit of abated pollutant or GHG is then expressed as

$$\Delta E = \frac{\eta_r^e \left(\frac{I_a^{an} + OM_a^{fix} + OM_a^{var}}{pf} - \frac{I_r^{an} + OM_r^{fix} + OM_r^{var}}{pf} \right)}{(e_{ffr} - e_{ffa}) \frac{\eta_r}{\eta_a}}$$

Equation 27

Where r denotes the replaced plant and a denotes the replacing plant, and where

$$Ce = \frac{I_a^{an} + OM_a^{fix} + OM_a^{var}}{pf}$$

Equation 28

is unit cost per kWh and η_r^e is electricity generation efficiency of the replaced fuel.

Unlikely fuel substitution, fuel efficiency improvement unit costs are implemented from literature and not counted by the model itself. Beside gradual efficiency improvement of currently used technologies such as is the cogeneration of heat and electricity, also new measures such as carbon capture and storage are accounted for.

Fuel efficiency and unit cost of substitution in transport sector

The construction of this part of the optimization problem is similar to the case of power generation sector: There are again a number of technologies to be substituted (gasoline, diesel) and technologies to substitute with (bio-diesel, ethanol, compressed gas, hydrogen...), and the substitution can be applied to some extent only, depending on substitution potential. The investment-fixed costs-variable costs combination is in this case expressed for one car rather than peta joule:

$$I_{i,j,t}^{an} = I_{j,t} \frac{(1+q)^{lt_{i,j,t}} q}{(1+q)^{lt_{i,j,t}} - 1}$$

Equation 29

$$OM_{i,j,t}^{fix} = I_{i,j,t} f_t$$

Equation 30

$$OM_{i,j,t}^{var_e}(t) = fuel_{i,j,a} c_{i,j,a}^f - fuel_{i,j,r} c_{i,j,r}^f$$

Equation 31

Where a denotes the “alternative” car, r denotes the “reference” car, $fuel$ denotes fuel consumption and c is fuel price. This could be converted into cost of abatement per unit of pollutant.

$$cn_{i,j,t}(t) = \frac{I_{i,j,a}^{an} + OM_{i,j,a}^{fix} + OM_{i,j,t}^e(t)}{ef_{i,j,r} fuel_{i,j,r} - ef_{i,j,a} fuel_{i,j,a}}$$

Equation 32

Where the denominator is unit cost of abatement per car.

Costs of fuel efficiency improvements are in this case calculated by GAINS for a number for transport sector categories (mainly passenger cars, light duty vehicles, heavy-duty vehicles). Various versions of

fuel-saving efficiency improvements are aggregated into technology packages and used in optimization.

3.4.5 Objective function

Objective Function is the core component of GAINS. It is minimized in order to find the least-cost control strategy for attaining the desired environmental goals. Each of its components is basically an aggregation of data for sector-activity combinations.

$$OF = EoP_cost + FSW_cost + Ceq_revenues$$

Equation 33

EoP _ cost is cost of end-of-pipe measures that reduce emissions and do not change the activities (however there might be a change in activity that follows introduction of some EoP measure, see variable cost of mobile source emission reduction).

$$EoP_cost = \sum_{i,s,f,t} uc_{i,s,f,t} x_{i,s,f,t}$$

Equation 34

Where $uc_{i,s,f,t}$ is unit price of particular abatement technology in sector-fuel combination and country and $x_{i,s,f,t}$ is an extent to which is this technology applied (activity variable). Please note that in order to prevent the double-count, the costs are not summed up over the pollutant.

FSW _ cost is cost of fuel substitution.

$$FSW_cost = \sum_{i,s,f,(s',f')} ucy_{i,s,f,s',f'} y_{i,s,f,s',f'}$$

Equation 35

Where (s', f') is a fuel-sector combination that is being substituted by, $ucy_{i,s,f,s',f'}$ is unit price of substitution and $y_{i,s,f,s',f'}$ is activity substitution variable. Construction of this variable is similar to the activity variable, but it is different for each pollutant and sector-fuel combination.

Ceq _ revenues is a climate penalty term, describing the costs for the EU ETS or any similar emission trading scheme. It is computed rather straight-forwardly as follows.

$$Ceq_revenues = CO2eq_price.GHG_emissions$$

Equation 36

Where the *CO2eq* _ price is price of ton of carbon equivalent that is set exogenously, either from some other model that forecasts situation on the emission market or from official forecasts, in our case expectations about the carbon price from the EC. *GHG* _ emissions are then emissions of the GHGs and could be capped at certain level for each country in order to reflect current legislation,

$GHG_emissions_i \leq GHG_emissions_cap_i$. The climate penalty term could be extended to include other measures such as joint implementation.

$GHG_emissions_i$ parameter could be further disaggregated as follows.

$$GHG_emissions = \sum_{i,p} GWP(p).emissions_{i,p}$$

Equation 37

Where $GWP(p)$ is global warming potential of pollutant p and $emissions_{i,p}$ are emissions of this pollutant in country i .

Rather than absolute value of the OF, cost results are presented as difference between baseline aggregated costs and costs of concerned policy, describing increase of costs in this case.

$$\Delta_{OF} = OF - OF^{BL}$$

Equation 38

3.4.6 Constraints of the model

There is a number of constraints implemented into the model in order to keep it consistent, to quantify technological constraints or to keep the emissions under the legislatively-imposed ceilings.

Balance equations

Balance equations ensure consistency between an activity $xa_{i,s,f}$ and a fuel substitution variable $y_{i,s,f,s',f'}$. In other words, both activity that is being replaced and activity that is used as a replacement, $(s, f) \rightarrow (s', f')$, are accounted for. There are two constraints because of cogeneration or other processes that generate both electricity and heat.

$$xa_{i,s,f} - \sum_{(s',f') \in A_{i,s,f}} y_{i,s',f',s,f} \chi_{i,s',f',s,f}^{ELECTRICITY} + \sum_{(s',f') \in A_{i,s,f}} y_{i,s',f',s,f} = xa_{i,s,f}^0$$

Equation 39

$$xa_{i,s,f} - \sum_{(s',f') \in A_{i,s,f}} y_{i,s',f',s,f} \chi_{i,s',f',s,f}^{HEAT} + \sum_{(s',f') \in A_{i,s,f}} y_{i,s',f',s,f} = xa_{i,s,f}^0$$

Equation 40

Where $xa_{i,s,f}^0$ is the pre-optimization value of the activity and $\chi_{i,s',f',s,f}^{ELECTRICITY}$, $\chi_{i,s',f',s,f}^{HEAT}$ are substitution factors that measure efficiency changes after the replacement of the activities $(s, f) \rightarrow (s', f')$.

Technological constraints – Applicability of technologies

Some technologies are applicable only to a limited extent. This is quantified as

$$q_{i,s,f,t} \leq q_{i,s,f,t}^{MAX}$$

Equation 41

Where $q_{i,s,f,t}$ is application rate of technology t in sector s on activity f and $q_{i,s,f,t}^{MAX}$ is maximal applicability of this technology in this particular case. There also are some modifications for applicability of technologies for NH₃ from livestock, where the above equation is comparing maximal application value to a basket of technologies rather than to only one technology.

Technological constraints – Emission standards

Emissions in each sector-activity can only stay the same or decrease. This is formalized as follows:

$$\sum_{t \in T_{s,f,p}} E f_{i,s,f,t,p}^{abated} x_{i,s,f,t} \leq \sum_{t \in T_{s,f,p}} E f_{i,s,f,t,p}^{abated} x_{i,s,f,t}^0 \frac{x a_{i,s,f}}{x a_{i,s,f}^0}$$

Equation 42

There are a few exceptions for abatement technologies that increase emissions of other pollutants.

Technological constraints – Technology standards

The “older” control technologies such as EURO II and such cannot increase their share in the scenarios. This is also used in case of the NOC_p no-control technology, that should not increase its share as well.

$$x_{i,s,f,t}^{old-t} \leq q_{i,s,f,t}^0 x a_{i,s,f}$$

Equation 43

Where $x_{i,s,f,t}^{old-t}$ is level of activity controlled by certain “older” technology and $q_{i,s,f,t}^0$ is pre-optimization application rate of this particular technology.

Technological constraints – Technology potentials

In some cases, the level of controlled activity needs to be constrained in order to disallow premature scrapping of recently installed equipment and other economically irrational behaviour.

$$x_{i,s,f,t}^{\min} \leq x_{i,s,f,t} \leq x_{i,s,f,t}^{\max}$$

Equation 44

Activity constraints

Similarly to the last equation, also all the activity levels in certain sectors are constrained, as there are some minimal levels of activities that need to be maintained (lower limit) as well as maximal levels that ensure there will be no overly growth in activities.

$$x a_{i,s,f}^{\min} \leq x a_{i,s,f} \leq x a_{i,s,f}^{\max}$$

Equation 45

For similar reasons, fuel (activity) substitutions are also constrained, because of limited stocks of available renewable energy resources and others reasons.

$$y_{i,s,f,s',f'} \leq y_{i,s,f,s',f'}^{\max}$$

Equation 46

Aggregations

Some of technologies or fuels (activities) are disaggregated in the model in order to capture certain differences. For example, power plant activity levels are aggregated from values that are specific for the heat/electricity types of the power plants as well as the approach to the waste heat (IGCC/non-IGCC power plants). Boiler types or solid fuel types are treated similarly. The respective equations are simple aggregations, hence they are not explicitly stated out here.

Environmental Targets

Environmental constraints for the impacts of air pollution are implemented for the Thematic Strategy indicators (acidification, eutrophication, years of life lost due to high particulate matter concentration and ozone). In this way, consistency with the relevant policies is ensured.

$$YOLL_k \leq YOLL_ceiling_k$$

Equation 47

3.4.7 Environmental impacts

Assessing the environmental impacts of the air pollutants to the pollution level is another function of the model.

Years of life lost YOLL is the quantification of loss to life expectancy. It is represented as a sum of two terms for population above 30 years of age.

$$YOLL^{tot}(K) = \sum_k YOLL_k + \sum_k YOLL_k^{CD}$$

Equation 48

The first right-hand side term is general value for each country, second term is modified to account for higher concentrations of pollutants in cities.

Both terms can be further disaggregated.

$$YOLL_k = C_k POP30_k PM\ 2.5_{k,pop-w}$$

Equation 49

$$YOLL_k^{CD} = C_k POP30_k^U PM\ 2.5_k^{CD}$$

Equation 50

Where C_k is country-specific parameter that describes changes in life expectancy for each cohort (group of people affected by pollution) and can be derived from the Cox Proportional Hazards Model⁴ $POP30$ parameter describes either population in country ($POP30_k$) or in cities in country ($POP30_k^U$). Finally, $PM_{2.5}$ are emissions of either primary or secondary $PM_{2.5}$, again either in country or city modification.

Acidification, eutrophication and ground level ozone are incorporated in same fashion as the YOLL parameter, as linear functions with corresponding variables: emissions of NO_x , NH_3 and SO_2 for acidification, NO_x and NH_3 for eutrophication and NO_x and VOC for ground level ozone. These are calibrated and minimized in order to receive average accumulated exceedance or maximum ozone concentration.

3.5 Overall description of the scenarios in the GAINS model

Aside from possibility to create own scenarios, there is number of predefined scenarios that are based on recent policies and possible future developments. Scenarios described in this work are based on the National Emission Ceilings Scenario Analysis Report Nr. 6 for revision of the NEC directive (Amman et al. [29]). The projections under the NEC 6th have a few common assumptions.

Activity projections for year 2020 are consistent with the January 2008 proposal of the EC on the C&E package. The quantitative targets for emission sources involved in EU ETS are set down, along with GHGs reduction targets for non-ETS sectors for each EU-27 country. The carbon prices in the EU ETS system are limited to 30 Euro per ton of carbon. National targets for shares of renewables for each state are determined to be 20%, and full trade in renewables among the EU-27 states is possible in order to reach the 20% share of renewables in energy production sector. Clean Development Mechanism and Joint Implementation are available in fashion stated in the Kyoto protocol, making it possible for the non-ETS sectors to meet the target values.

Along with C&E package, objectives of the Thematic Strategy on Air Pollution (TSAP) are also implemented in the selected range of NEC 6th scenarios. The TSAP contains environmental objectives for improvements in selected air pollutants in year 2020 compared with the year 2000. Environmental targets used for the analysis are as follows: 47% decline in million year of life lost due to particulate matter pollution, 43% reduction of unprotected ecosystem area suffering of eutrophication, 74% reduction in areas with acid deposition exceeding critical loads and 10% cut in cases of premature deaths attributable to ground-level ozone.

The two most relevant scenarios are based on current policy and current legislation. The first scenario used in this paper is the **C&E package and Current policy scenario** (*denoted as Current Policy in the following tables*). The forecasts in this scenario are constrained not only by all the current emission control legislation that is laid down in EU-27 national laws, but also by the proposal

⁴ A survival model based on development of hazard over time and on parameters describing links among the hazard and other factors.

of the EC on the revision of the IPPC directive for large stationary sources⁵ and EURO-VI directive for heavy duty vehicles⁶. Compliance with the NEC directive is also assumed. On the other hand, neither the Nitrates directive (91/676/EEC) nor Air Quality directive (96/62/EC) is considered, because while it is clear how will the legislation look like, it is not sure how it will be implemented in the national law.

The second considered scenario is **C&E package and Current legislation scenario** (*Current Legislation*). Contrary to the Current policy scenario, the Current legislation scenario does not contain Euro-VI or IPPC revision. The rest is mutual with the Current policy scenario, which means full implementation of legislation that was put out before mid-2006. Additional existing international legislation that is not put into national legislations of EU-27 member states is not considered.

The third scenario is **Least cost implementation of C&E package scenario** (*OPTV*). Content of the scenario is same as in case of current policy scenario, but the measures are selected in a way that minimizes the consequential costs. This scenario will be used further on as a benchmark.

The fourth scenario, **C&E package and Maximum Technically Feasible Emission Reduction** (*MTFR scenario*), shows potential for further emission reductions that could be achieved by full application of the most advanced technical emission control measures. The scenario is limited to the technologies, no respect is paid to possible fuel substitution in transportation or household sectors, neither energy efficiency improvements nor premature scrapping of existing, less-effective capital are expected. What is more, behavioural changes such as consumer turn to smaller cars or more savvy approach to household warming are hard to forecast and quantify and therefore are not included.

The fifth scenario, **NEC2007 baseline and current policy** (*BASELINE*), is the only one that does not meet the objectives of the C&E package. It is basically a business-as-usual scenario with no further climate or air quality measures. Current version of the EU ETS is assumed with carbon price limited to 22 Euro per ton of carbon. What is more, GDP of the EU-27 is expected to rise between 2000 and 2020 by 57% on average, along with 17% energy consumption growth.

Finally, the sixth and last scenario, **C&E package and the EP proposal scenario** (*EP Proposal*), reflects pressure of the EP (European Parliament) on further tightening of the emission caps. According to the EP, the ambitions in emissions reduction should be higher in order to attain the targets of 6th EAP. Environmental targets are tightened to a limited extent: decline of 50% in million year of life lost due to particulate matter pollution (47% in current policy scenario), 46% reduction of unprotected ecosystem area suffering of eutrophication (43% in current policy), 79% reduction in areas with acid deposition exceeding critical loads (74% in current policy) and 16% cut in cases of premature deaths

⁵ "The aim of the current proposal is to revise and merge seven separate existing Directives related to industrial emissions into a single Directive. (...) Furthermore, the proposal will strengthen or add certain provisions to ensure better implementation and enforcement of the legislation by national authorities with the aim of achieving a high level of environmental protection, while simplifying legislation and at the same time reducing unnecessary administrative burdens. Clearer provisions will allow better monitoring and enforcement of the legislation through Community actions." EC [35]

⁶ "The objective of the proposal is to lay down harmonised rules on the construction of motor vehicles with a view to ensuring the functioning of the internal market while at the same time providing for a high level of environmental protection regarding atmospheric emissions." EC [36]

attributable to ground-level ozone (10% in current policy). This would further gross up the costs and apparently cause decline in emissions in compare with the Current policy scenario.

Note that while Current Policy, Current Legislation and NEC2007 baseline scenarios are not optimized and hence they do not consider co-benefits and trade-offs, the MTFR and EP proposal are based on the optimized *Least-cost of Current Policy (OPTV)* scenario and therefore are optimized.

4. Analysis of the Predefined Scenarios

Following pages are dedicated to an analysis of the six scenarios for the Czech Republic. Similar analysis was carried out for the whole EU-27 and its results are used here as a reference. For deeper insight into the future EU costs and emissions, please see the annex.

Each of the six scenarios is based on a set of input data (*economic activity pathways*) and emission control options. This part of the work describes the final results of the scenario analysis as well as input data that are used in the analysis for the Czech Republic. Special care will then be dedicated to the two most relevant scenarios.

Important to mention, the value of the analysis is not in the concrete numbers. Input data on economic as well as industrial or agricultural development are forecasted by other models and therefore are subject to a great number of uncertainties. These uncertainties are translated into the results of GAINS analysis. Because of that, the results might but need not to be close to the reality. However, the outputs of analysis of each scenario are comparable, as the possible errors stemming from input data are similar for each of them. **The real substance of analysis is therefore not the exactly quantified forecast of the future development, but the possibility to compare outcomes of different scenarios.**

Another thing worth noticing is that GAINS is a model aimed on the larger groups of countries rather than on one individual country. However, as the model is designed to be used by the policy makers, it is quite interesting to see how it performs under circumstances it was not designed for.

4.1 Economic activity pathways – General Macroeconomic Drivers of the Czech Republic

5. First set of inputs are macroeconomic drivers that describe future development of Czech economy. The set of data is common for all the scenarios.

Table 2: General Macroeconomic drivers of the Czech Republic

	2000	2005	2010	2015	2020
GDP, bn. Euro	166.82	199.47	249.1	296.98	356.38
Value added - total, bn. Euro	149.34	178.9	222.97	265.18	316.75
Value added - tertiary sector, bn. Euro	89.88	105.72	130.61	156.71	189.83
Value added - industry, bn. Euro	44.01	57.21	73.99	87.31	102.72
Total population, millions	10.3	N/A	10.1	N/A	9.9

Source: GAINS [30]

The data on macroeconomic drivers are implemented to GAINS from the PRIMES model. The GDP growth forecast might look slightly overestimated, however, as these numbers are the same for all the scenarios, it does not cause any substantial harm to the analysis.

It is expected that GDP of the Czech Republic will rise relatively faster in compare with the rest of the EU-27, growing more than two-fold between 2000 and 2020. The largest share of the rise will be due to the tertiary sector. Besides that, the population number is expected to shirk slightly.

5.1 Economic activity pathways – Activity Data of the Czech Republic

As well as in previous case, the source of the data is the PRIMES model. The reference year 2000 is in this case included in three versions. “CaE package scenarios” are year 2000 data used in analysis of all the scenarios with except of the Baseline, “nec2007 Baseline” is then used in the Baseline scenario analysis. Most recent data on year 2000 from Eurostat are added as a reference.

Table 3: Energy data aggregated by activity, the Czech Republic, in PJ

ENERGY: DATA AGGREGATED BY ACTIVITY (PJ)					
source	EUROS TAT	CaE package scenarios	NEC2007 baseline	CaE package scenarios	NEC2007 baseline
year	2000	2000	2000	2020	2020
Coal	904	823	906	489	673
Heavy fuel oil		58		99	101
Medium distillates (diesel, light fuel oil; includes biofuels)		147		250	251
Gasoline and LPG		112		228	232
Oil	336	317	326	577	585
Natural gas (incl, other gases)	314	385	314	412.06	400
Nuclear	147	147	147	0	0
Biomass and waste		28		259	152
Other renewables		6		318	299
Renewables	25	34	30	577	452
Electricity (import)	-38	-38	-36	0	0
Sum		1668	1688	2055	2109

Source: GAINS [30], CaE package scenarios: data for year 2000 from Amman et al. [29], NEC2007 Baseline scenario: data from Capros et al. [31], converted using IAEA [32], EUROSTAT 2000: data from Eurostat webpage [33]

Expected development in activities is much more rapid in case of the Czech Republic than in the whole EU-27 case. There will be **steep decline in coal usage**, as the percentage of energy generated from fossil fuels is currently well above European average. On the other hand, **fuel oil consumption will rise nearly twofold, as well as consumption of diesel and gasoline** that will follow growth of transport sector. The **decline in coal will be offset by rise in oil and natural gas**. Controversially, the **nuclear energy production is expected to cease completely after 2020, as it is expected that there will be no new nuclear plants after end of lifetime of Temelin and Dukovany nuclear power plants, and even these two plants are expected to shut down earlier than expected**. This might be one of the errors that are omitted in current version of the model and that will need to be solved in the future versions of the model. Finally, similarly to other new EU countries, **usage of renewables in power generation is currently on a low level, this sector will hence rise rapidly in the future** in order to assess the environmental goals.

Table 4: Energy data aggregated by sector, the Czech Republic, in PJ

ENERGY: DATA AGGREGATED BY SECTOR		
source	CaE package scenarios	NEC2007 baseline
year	2020	2020
Conversion	187	182
Residential, commercial, services, agriculture, etc,	502	491
Industry	435	435
Non-energy use of fuels	149	150
Power sector	382	445
Transport	400	405
Sum	2055	2109

Source: GAINS [30]

As apparent from this table, the only major difference between the C&E package scenarios and the **BASELINE** scenario is the energy consumption of the power sector, which is higher for the Baseline scenario.

Table 5: Agriculture data for the Czech Republic

AGRICULTURE: LIVESTOCK NUMBERS (1000 heads)		
year	2000	2020
Cattle and fur animals	1 609	5 200
Pigs	3 315	12 500
Chicken and poultry	32 043	23 994
Sheep and goats	118	28
Horses	26	12 136
AGRICULTURE: MINERAL FERTILIZERS PROD AND CONS (kilotons of N)		
year	2000	2020
N - fertilizer consumption	213	230
N - fertilizer production	306	310

Source: GAINS [30], data for year 2000 from Amman et al. [29]

The CAPRI model used to generate agricultural forecast missed out in case of livestock numbers, as especially the skyrocketing of horse population is hardly rational or even achievable. However, this should not have any significant impact on the analysis. **The fertilizer production and consumption follow the pattern of European development in this field.**

5.2 Analysis – emissions and costs for the Czech Republic

Table 6: Emissions, the Czech Republic

EMISSIONS, sorted by cost									
scenario		EUROSTAT	6th EAP	BASELINE	current legislation	current policy	OPTV	EP proposal	MTFR
year		2000	2000	2020	2020	2020	2020	2020	2020
CO ₂	mt/year	127	N/A	126	107	107	107	107	107
N ₂ O	kt/year	25	N/A	32	36	36	36	36	36
CH ₄	kt/year	575	N/A	373	340	366	611	607	599
F-GAS	mt/yr	N/A	N/A	2	1	2	2	2	2
NH ₃	kt/year	N/A	84	77	77	77	69	64	56
NO _x	kt/year	396	315	187	207	181	156	149	139
PM _{2.5}	kt/year	N/A	57	38	42	40	37	34	17
PM ₁₀	kt/year	N/A	63	51	57	53	49	47	27
PM _{TSP}	kt/year	N/A	98	88	95	89	85	82	58
SO ₂	kt/year	264	252	90	119	81	65	59	52
VOC	kt/year	244	234	169	182	181	181	160	78

Source: GAINS [30], data for year 2000 from Amman et al. [29] and Eurostat [33]

The above table shows estimated future emissions of all the major air pollutants and GHGs. Along with the future data, values for year 2000 are provided as a reference. While the historical emission levels are not explicitly stated for all the pollutants and GHGs in the GAINS model, the values from the 6th NEC Report (exact values used in the model) are accompanied with most recent values from Eurostat.

Unlike the other emissions, the future values of CO₂ emissions are predicted by the PRIMES model for both CaE and baseline scenarios, with carbon prices limited to 30 Euro and 22 Euro carbon prices respectively. Because of that, the **CO₂ emissions are fixed at the 107 megatons a year for the CaE scenarios and at 126 megatons for baseline**. These are very strong assumptions that might differ from the real future values, however, the inter-comparability of the results stays unharmed. The **CH₄ emissions will rise for the C&E-based optimised scenarios** (least cost of CP, MTFR, EP proposal), **which will be offset by improvements in air pollutants**. The F-Gas emissions are on a low level and will further fall.

There is a clearly visible tendency that divides optimized scenarios (*OPTV, MTFR, EP proposal*) and non-optimized scenarios (*Current Policy, Current Legislation*) that include CaE package. The optimized scenarios assume larger emissions of GHGs (N_2O , CH_4 , F-GAS) in comparison with the non-optimized scenarios. On the other hand, the emissions of air pollutants are significantly lower for the optimized scenarios. This is a rational approach, as the volumes of emissions of GHGs other than CO_2 are relatively very low in compare with CO_2 emissions volumes and therefore have a lesser impact, even in terms of CO_2 equivalent. Furthermore, the MTFR scenario assumes the maximal feasible reduction for the air pollutants only. The higher reduction in air pollutants is then, conversely, a substantial improvement for ecosystems and human health. **Emissions are expected to drop for all the air pollutants in the future, and this decline is most apparent in case of the optimized scenarios.**

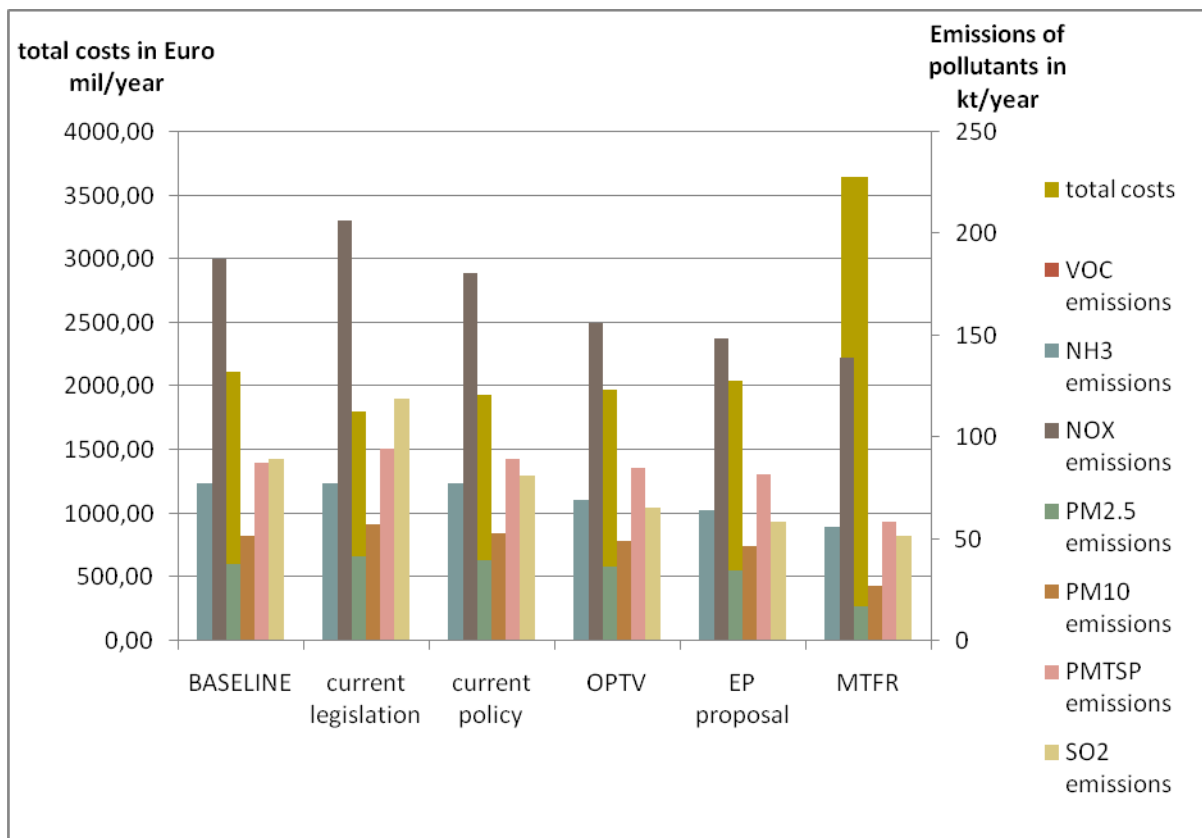
The Table 7 describes costs of air protection and GHGs mitigation in the year 2020 under the six scenarios.

Table 7: Costs, the Czech Republic

COSTS in year 2020, total in yr 2000 million Euros, sorted by cost						
	BASELINE	current legislation	current policy	OPTV	EP proposal	MTFR
N_2O	0	0	0	N/A	N/A	N/A
CH_4	506	411	384	N/A	N/A	N/A
F-GAS	N/A	31	N/A	N/A	N/A	N/A
NH_3	88	88	88	98	113	180
NO_x	1002	888	971	989	1013	1098
PM_{TSP}	395	339	342	345	365	1089
SO_2	600	461	507	516	527	606
VOC	32	31	31	28	29	670
All Air Pollutants	2116	1807	1939	1977	2048	3643
All GHGs	506	442	384	N/A	N/A	N/A

Source: GAINS [30]

Figure 5: Air pollution and its costs in the Czech Republic



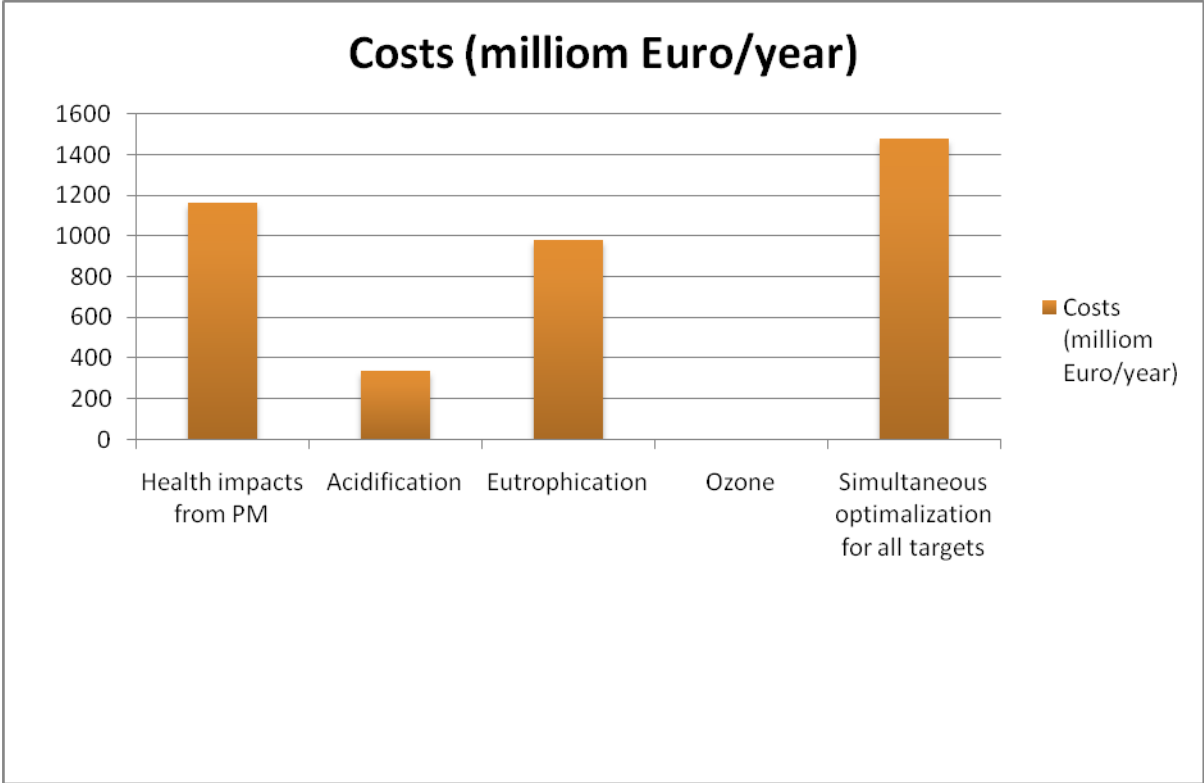
Source: GAINS [30]

Costs of CO₂ mitigation are held constant and are not included into the cost analysis for both CaE and baseline scenarios. The *OPTV*, *EP proposal* and *MTRF* scenarios are optimised to consider only the air pollutants, hence no GHGs costs.

In case of the Czech Republic, the results are fully consistent with how the analysis looks like for the EU-27. According to European Environmental Agency [20], the costs of air quality control were 906 million Euro in year 2000. The costs of additional air quality measures will then be twice or more this value in 2020. **The *OPTV* scenario is slightly more expensive than the current policy scenario, but this increase in cost is well compensated by the air quality improvements. Once again it is clear that maximal feasible emission reduction would be accompanied with extremely high costs.** Similarly to the EU-27 results, the Climate and Energy package means lower costs, which is evident from the *BASELINE* scenario costs.

The cost improvements between the current policy scenario and its optimized version are not apparent on the first sight from the figure 5, as the final levels of air pollutants and GHGs emitted under the scenarios differ. However, according to the literature (Amman et. al [29]), while the Thematic Strategy goals are achieved in both cases, costs of the optimized scenario are significantly lower than in the non-optimized one. **The additional costs over the cost of *Current Legislation* scenario needed to achieve the TSAP targets for the whole EU are 2,65 billion Euro a year in case of non-optimized scenario, while the additional costs for the optimized scenario are only 1,49 billion Euro a year.** This is illustrated in the figure 6.

Figure 6: Co-benefits for the optimized scenario for the whole EU-27



Source: Amman et al. [29]

The costs for the baseline scenario for the Czech Republic (figure 5) are surprisingly high in compare with the *Current Policy* scenario, taking into consideration that the emissions resulting from *BASELINE* scenario are the same or even higher than those from *Current Policy* scenario. According to Capros et al [31] and 6th NEC report (Amman et. al [29]), this mixture of rather high emissions and high costs is caused by lower decline in coal activity that means higher SO₂ emissions and higher costs for their abatement as well as more strict NO_x ceilings. From this point of view, **the Climate and Energy Package actually lowers the aggregated costs for air pollution reduction measures in the whole EU-27 by some 6 billion Euro a year.**

5.3 Analysis – impacts on the Czech Republic

Following tables and figures capture relative improvements in each of the four goals of the Thematic Strategy under considered scenarios. Generally speaking, the extent to which one of the four indicators grows between the *Current Policy* and the *OPTV* scenario (marginal utility of the measure) is much higher than the growth of the costs connected with the indicator (marginal cost). **In this context the combined approach is indeed an effective one.**

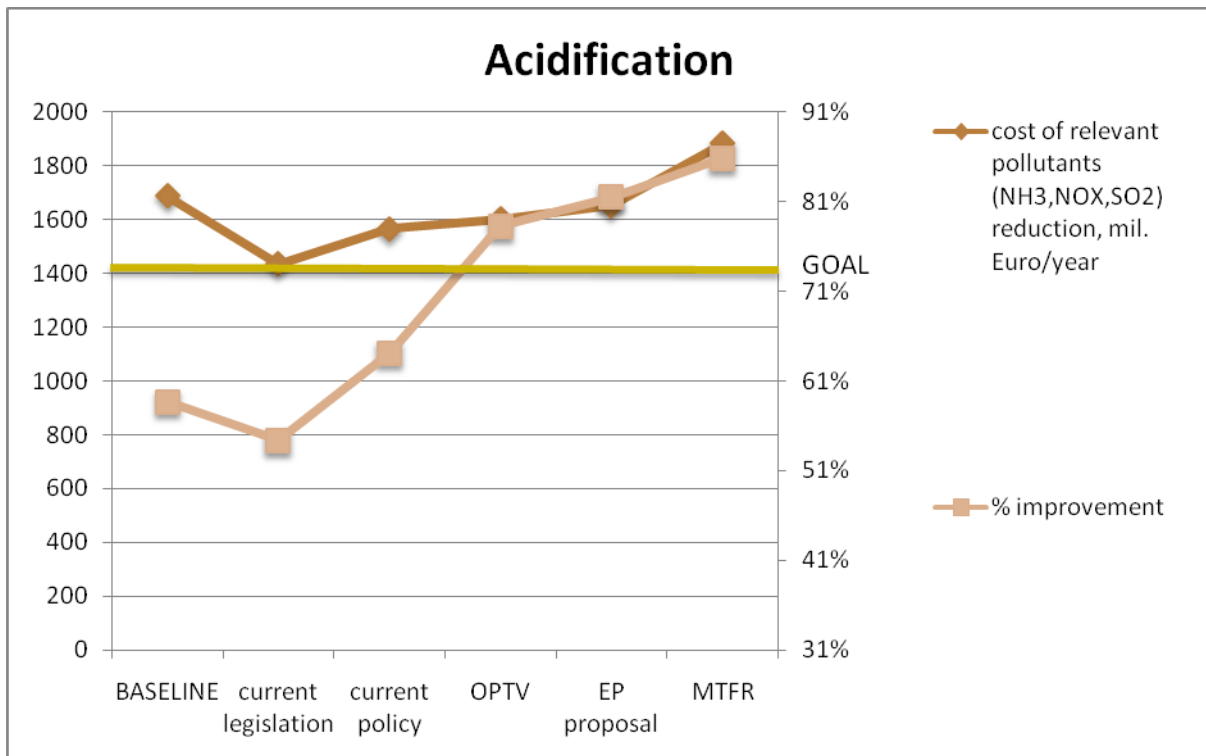
The goal values of the Thematic Strategy are to be met for the whole EU-27, however, these are still included into the analysis as a benchmark.

Table 8: Acidification in the Czech Republic

ACIDIFICATION	forest area receiving deposition in excess of critical loads, 1000km ²					
goal:74%	BASELINE	current legislation	current policy	OPTV	EP proposal	MTFR
2000	2020					
9.2	3.8	4.2	3.3	2	1.7	1.3
% improvement	59%	54%	64%	78%	82%	86%

Source: GAINS [30]

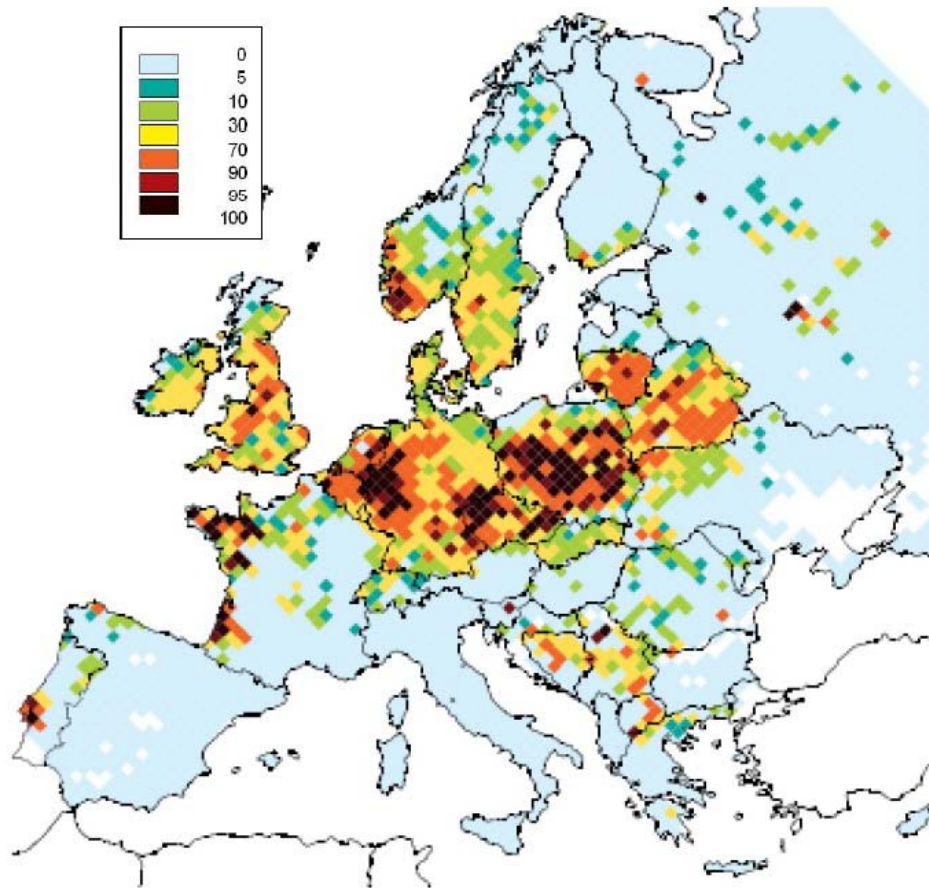
Figure 7: Acidification in the Czech Republic



Source: GAINS [30]

Every additional Euro invested into the NH₃, NO_x and SO₂ reduction causes a steep improvement in terms of acidification. However, this holds true only for the “cheaper” scenarios: while a modest rise of investments into emission control has a great impact on acidification for the optimised scenario, further investment of comparable size brings much lesser improvements. **The optimised scenario is indeed the best-performing one.** The situation is very similar in case of the EU-27, with exception that the whole EU will overstep the goal value with a lesser margin. The steep decline in volume of spatially distributed acidifying pollutants will be followed by improvements in most of the forest ecosystems. Only the north and north-west that have not yet recuperated from the pre-1990s era will continue to suffer excessively from acidification.

Figure 8: Percentage of forest area where acid deposition exceeds the critical loads for acidification in the year 2000, EU-27



Source: Amman et al. [29]

Figure 9: Percentage of forest area where acid deposition exceeds the critical loads for acidification in the year 2020, the Current Policy and OPTV scenarios



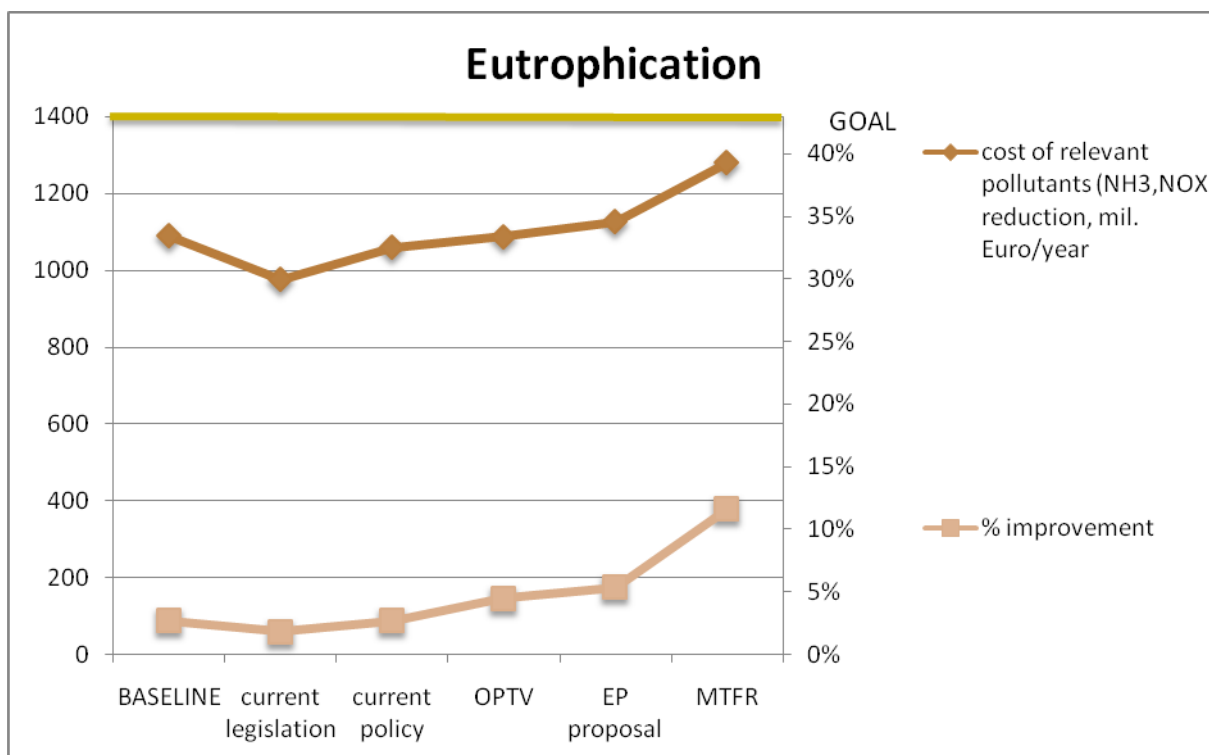
Source: GAINS [30]

Table 9: Eutrophication in the Czech Republic

EUTROPHICATION	ecosystem area receiving deposition in excess of critical loads, 1000km2					
goal:43%	BASELINE	current legislation	current policy	OPTV	EP proposal	MTRFR
2000	2020					
11.2	10.9	11	10.9	10.7	10.6	9.9
% improvement	3%	2%	3%	4%	5%	12%

Source: GAINS [30]

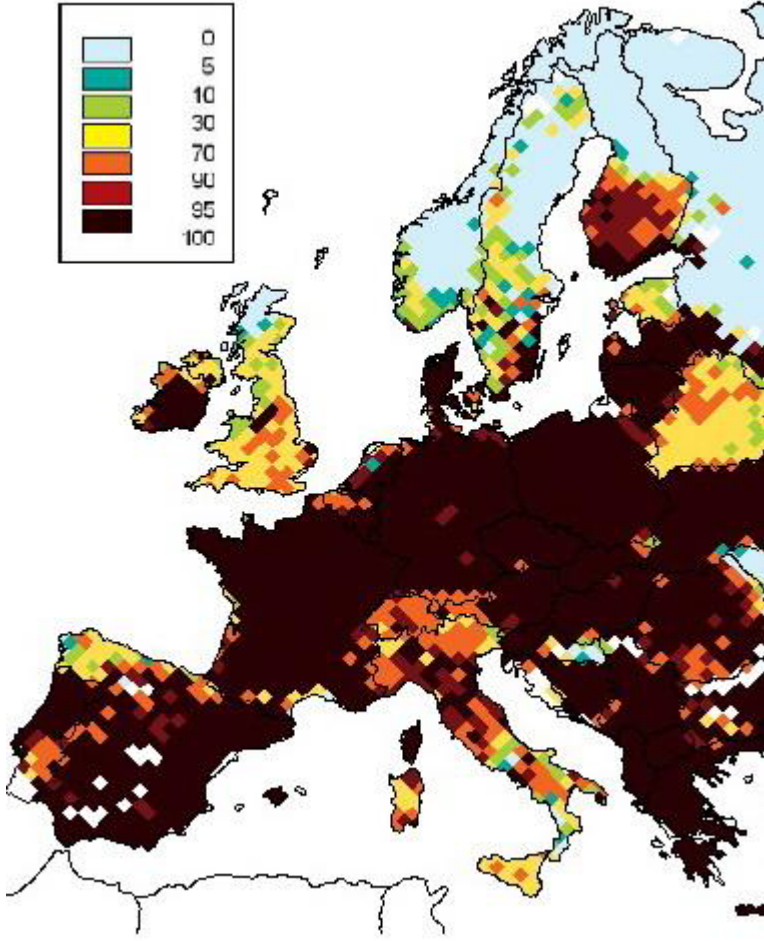
Figure 10: Eutrophication in the Czech Republic



Source: GAINS [30]

Apparently, the Czech Republic will not be able to change the extent to which are the ecosystems areas receiving excessive load of eutrophication pollutants. **The difference between the optimised and non-optimised scenarios is only a slight one, it is not even feasible to meet the eutrophication goal for the Czech Republic.** This corresponds to the EU-27: in case of whole Europe, only costly maximal technically feasible scenario would ensure a tight overstepping of the goal value of eutrophication. The eutrophication levels are critical all around the Czech Republic, and any of the proposed policies is not enough to change that.

Figure 11: Percentage of ecosystems area where nitrogen deposition exceeds the critical loads for eutrophication in the year 2000, EU-27



Source: GAINS [30]

Figure 12: Percentage of ecosystems area where nitrogen deposition exceeds the critical loads for eutrophication in the year 2020, the Current Policy and OPTV scenarios



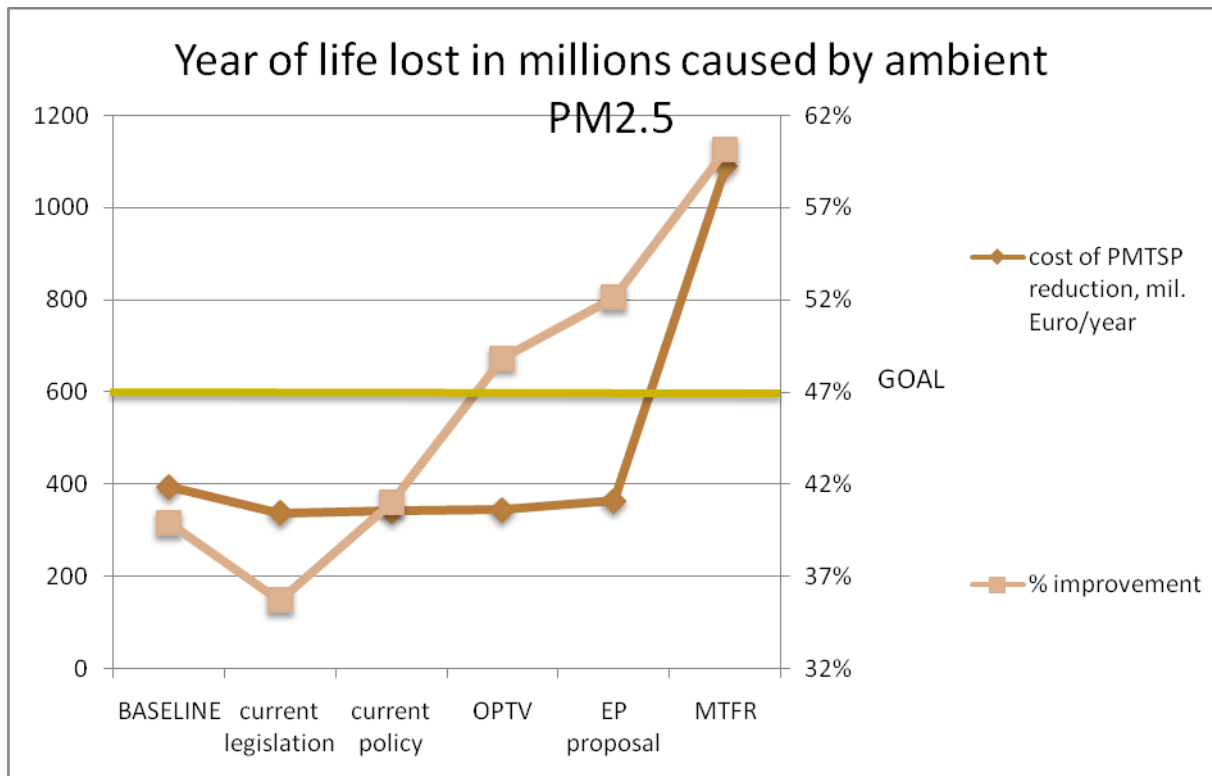
Source: GAINS [30]

Table 10: Years of life lost caused by PM_{2.5} in the Czech Republic

YOLL	Year of life lost in millions caused by ambient PM _{2.5}					
	BASELINE	current legislation	current policy	OPTV	EP proposal	MTFR
goal:47%						
2000	2020					
5.4	3.244	3.471	3.185	2.762	2.585	2.153
% improvement	40%	36%	41%	49%	52%	60%

Source: GAINS [30]

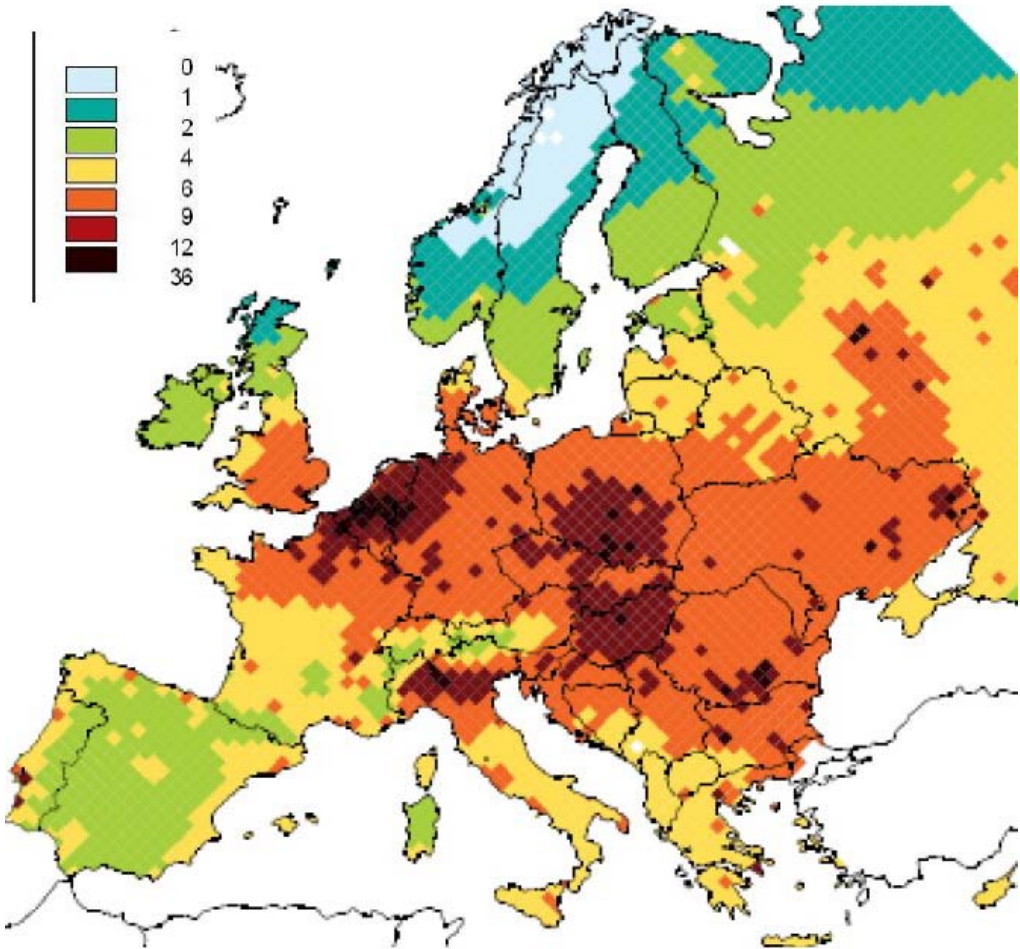
Figure 13: Years of life lost caused by PM_{2.5} in the Czech Republic



Source: GAINS [30]

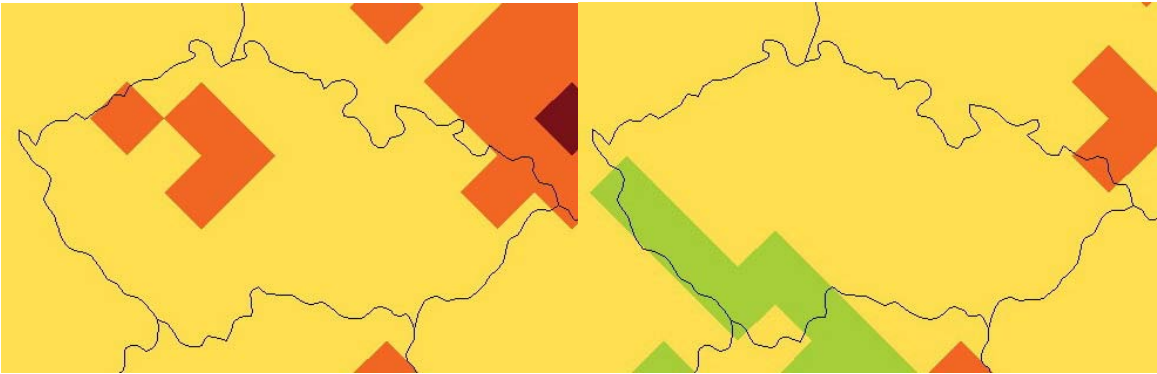
With exception of the MTRF scenario, it is clear that **only a modest investment into the particulate matter control would mean a many more years of life saved from the ambient PM**. Even the EP proposal scenario is performing much better than in case of other TSAP goals. These are the same results as in case of the EU-27. The 6 to 9 or even 9 to 12 months by which is average length of life reduced because of the particulate matter will go down to 4 to 6 months and to even lower values in the south-western Bohemia, at least for the optimised scenario. The Current Policy scenario performs worse, above all expectably in the central and north-western Bohemia.

Figure 14: Loss in statistical life expectancy attributable to the exposure of fine particles in year 2000, in months, EU-27



Source: Amman et al. [29]

Figure 15: Loss in statistical life expectancy attributable to the exposure of fine particles in year 2020, the Current Policy and OPTV scenarios, in months



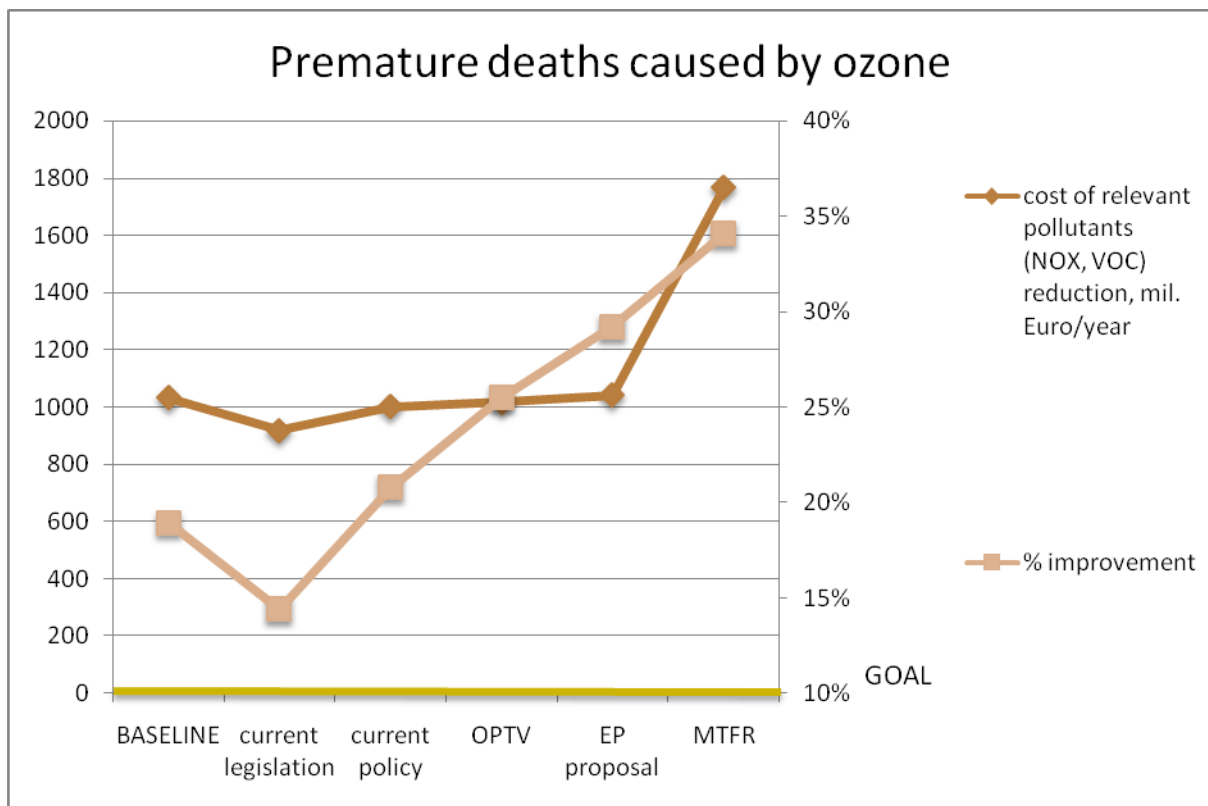
Source: GAINS [30]

Table 11: Premature deaths caused by ozone in the Czech Republic

OZONE	Premature deaths caused by ozone					
	BASELINE	current legislation	current policy	OPTV	EP proposal	MTFR
goal:10%						
2000	2020					
514.0	416.6	440	407.2	382.9	363.9	338.7
% improvement	19%	14%	21%	26%	29%	34%

Source: GAINS [30]

Figure 16: Premature deaths caused by ozone in the Czech Republic



Source: GAINS [30]

While there need to be much invested into attaining the ozone goals in the EU-27, **the Czech Republic would fulfill the obligation to meet the goal even without any additional policies.**

6. Conclusions

The aim of this work was to describe the ancillary benefits of integrated approach to greenhouse gas mitigation and air quality control. The basic information on the impacts of greenhouse effect as well as air pollution was provided, along with a review of relevant Czech and European policies. The mathematical foundations of the GAINS model used in the analysis were discussed. Finally, the analysis of the scenarios most relevant to the future development was carried out, with special care dedicated to difference between the usual and integrated approach to current European policies.

The model has proven to be a powerful tool that would be of great relevance in the search for the optimal way to the goals of these policies. However, there have been some caveats that need to be resolved in the future versions of the model. Unrealistic expectations about agriculture development and nuclear energy development are the two most troublesome issues met during the analysis.

A number of conclusions could be drawn from the analysis of the scenarios:

Firstly, sole implementation of the Climate & Energy package of the EC would shrink the costs for air protection by some 300 million Euro⁷ a year.

Secondly, the integrated approach to air pollution and greenhouse gasses emissions reduction would bring a major improvement in terms of air quality, even though both costs for air protection and greenhouse gasses emissions would slightly rise.

Thirdly, there is still a plenty of room left for further improvements, as the improvements that would be brought by maximal application of the best available techniques. However, while feasible, this would not be favourable, as the maximum technically feasible reduction scenario sent the costs sky-rocketing.

Finally, the substantial cost reductions from integrated approach are indeed present in case of the Czech Republic. In two out of four observed indicators of the EU Thematic Strategy on Air Pollution, the policy goals could be met only in case of the integrated approach. The emerging integrated approach has proven to be the right one.

⁷ Year 2000 Euros

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8. Annex

8.1 Legislation included in the CLE scenario

The basis for the *Current Legislation* scenario is composed of following legislation.

8.1.1 Legislation considered in the CLE scenario for SO₂ emissions

- Large Combustion Plants Directive
- Directive on the sulphur content in liquid fuels
- Directives on quality of petrol and diesel fuels
- IPPC requirements for industrial processes as currently laid down in national legislation
- Sulphur content of gasoil used by non-road mobile machinery and inland waterway vessels (reduction from 1000 ppm to 10 ppm) according to the Proposal COM(2007) 18 of the Directive of the European Parliament and of the Council to amend Directives 98/70/EC and 1999/32/EC.
- National legislation and national practices (if stricter)

8.1.2 Legislation considered in the CLE projection for NO_x emissions

- Large Combustion Plants Directive
- EURO-standards, including adopted EURO-5 and EURO-6 for light duty vehicles
- EU emission standards for motorcycles and mopeds
- Legislation on non-road mobile machinery
- Higher real-life emissions of EURO-II and EURO-III for diesel heavy duty and light duty vehicles compared with the test cycle
- IPPC requirements for industrial processes as currently laid down in national legislation
- National legislation and national practices (if stricter)

8.1.3 Legislation considered in the CLE projections for NH₃ emissions

- IPPC Directive for pigs and poultry production as interpreted in national legislation
- National legislation including elements of EU law, i.e., Nitrates and Water Framework Directives
- Current practice that includes implementation of *Code of Good Agricultural Practice* which is mandatory under the CLRTAP Gothenburg Protocol

8.1.4 Legislation considered in the CLE projection for VOC emissions

- Stage I Directive (liquid fuel storage and distribution)
- Directive 91/441 (carbon canisters)
- EURO-standards, including adopted EURO-5 and EURO-6 for light duty vehicles
- Fuel Directive (RVP of fuels)
- Solvents Directive
- Products Directive (paints)
- National legislation, e.g., Stage II (gasoline stations)

8.1.5 Legislation considered in the CLE projections for PM_{2.5} emissions

- Large Combustion Plants Directive
- EURO-standards, including the adopted EURO-5 and EURO-6 standards for light duty vehicles
- Emission standards for motorcycles and mopeds
- Legislation on non-road mobile machinery
- IPPC requirements for industrial processes as currently laid down in national legislation
- National legislation and national practices (if stricter)

Source: Amman et al. [29]

8.2 Sensitivity analysis

The six scenarios described in the work are subject to a large number of uncertainties. While the possible errors in future development predictions cannot be corrected such as GDP growth or energy production patterns, the scenarios can be adjusted to include different development of legislation. The sensitivity analysis is used to include these differences in the model results. All the following cases are based on the optimized scenario. The description is based on Amman et al. [29].

The first considered case is that there is **no trade in renewable energy**. The uncertainty stems from the fact that as for other legislative of the EU, renewable energy trade is subject to opt-out, in which the member country chooses not to take part in some common policy. The emission ceiling for both ETS and non-ETS targets would have to be achieved by each member state with its domestic sources. The impact of this is rather marginal, with the main outcome that there would be less variable energy production pattern and slightly higher fuel consumption.

The second case adds **full implementation of the nitrates directive**⁸. Nitrate directive could possibly be included in the Current policy scenario, it is however unclear what impact it would have on national agricultural systems. This sensitivity analysis provides emission forecast for the case that the directive was fully implemented. The used data is taken from activity projections for nitrogen fertilizer use and animal manure application on soil from the MITERRA model. Compared with the NEC baseline, full implementation of this legislation would cause decline of livestock by a few percent and one quarter drop in nitrogen fertilizer usage. Both air quality management costs and NH₃ emissions would be slightly lower. However, this holds true only for comparison with the NEC baseline scenario that uses different historical levels of emission and actually underestimates the year 2000 NH₃ emissions. Furthermore, there is no way in which could be quantified the revenue losses to farmers caused by livestock reduction, the real cost would therefore be higher.

The third case considers **the recent scientific developments of knowledge about the particulate matter PM**. The scenarios use the standard approach for health impact quantification that is given in the WHO review of 2003. According to the review, mortality is caused by population exposure to both primary and secondary particles of PM_{2.5}. However, in the 2007 WHO report only the effect of primary emissions, while the secondary emissions are supposed to have little to none impact on

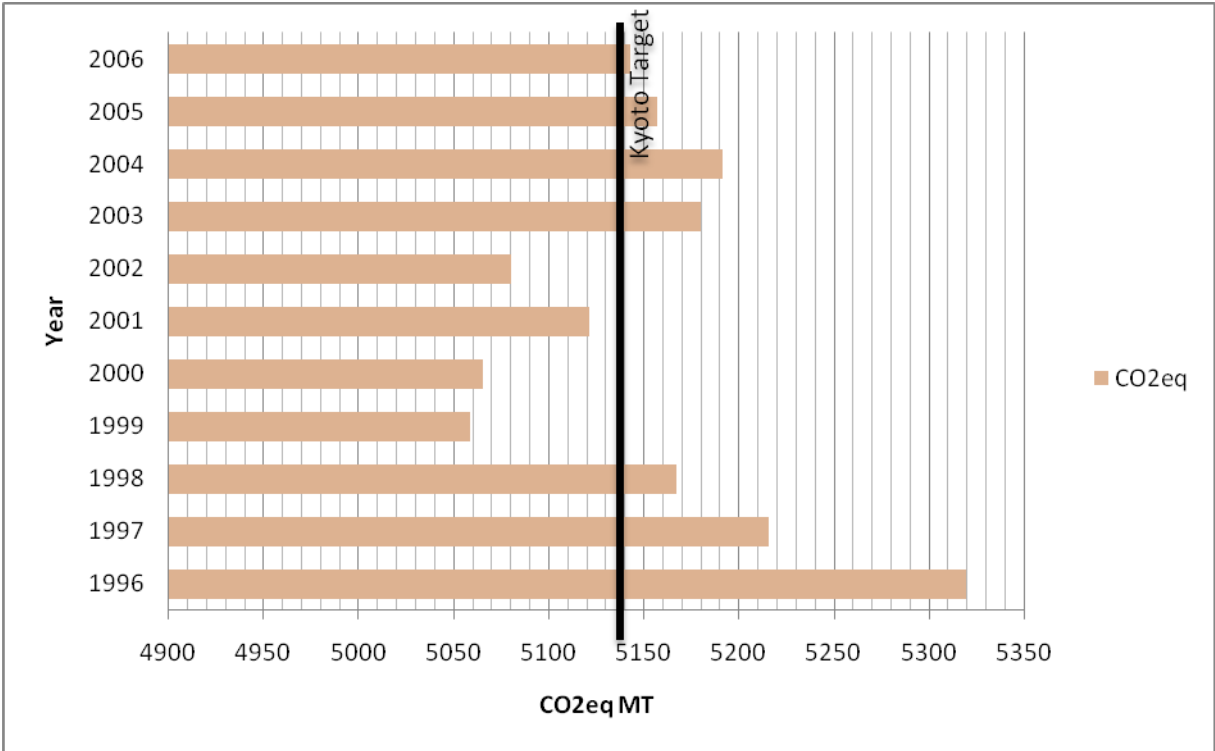
⁸ Aim of the Nitrate directive is among others to limit nitrate discharges for groundwater protection and agricultural emissions of non-CO₂ gasses.

human health. There is however still a lot of doubts about this. However, if the hypothesis holds true, the air pollution costs will be significantly different, hence the alternative scenario. In this scenario, the costs to attain the target level of PM_{2,5} emissions rise severely, as there are no co-benefits and the control of primary emissions therefore needs to be more strict.

The fourth and last case describes situation in which **the emissions of GHGs and air pollutants are influenced not only by surrounding countries, but also by marine shipping**. While there were no ambitions for any emission reduction for marine shipping for a long time, recent development indicates that this sector will employ some measures to reduce sulphur share in fuel. In April 2008, Marine Environment Protection Committee of International Maritime Organization agreed on new emission limits to be implemented by year 2020. According to the analysis, the gradual decline of sulphur in fuel from 4,5% to 0,5% by year 2020 would lower the costs of air pollutants emissions reduction in EU from 1,5 to 0,95 billion Euro per year.

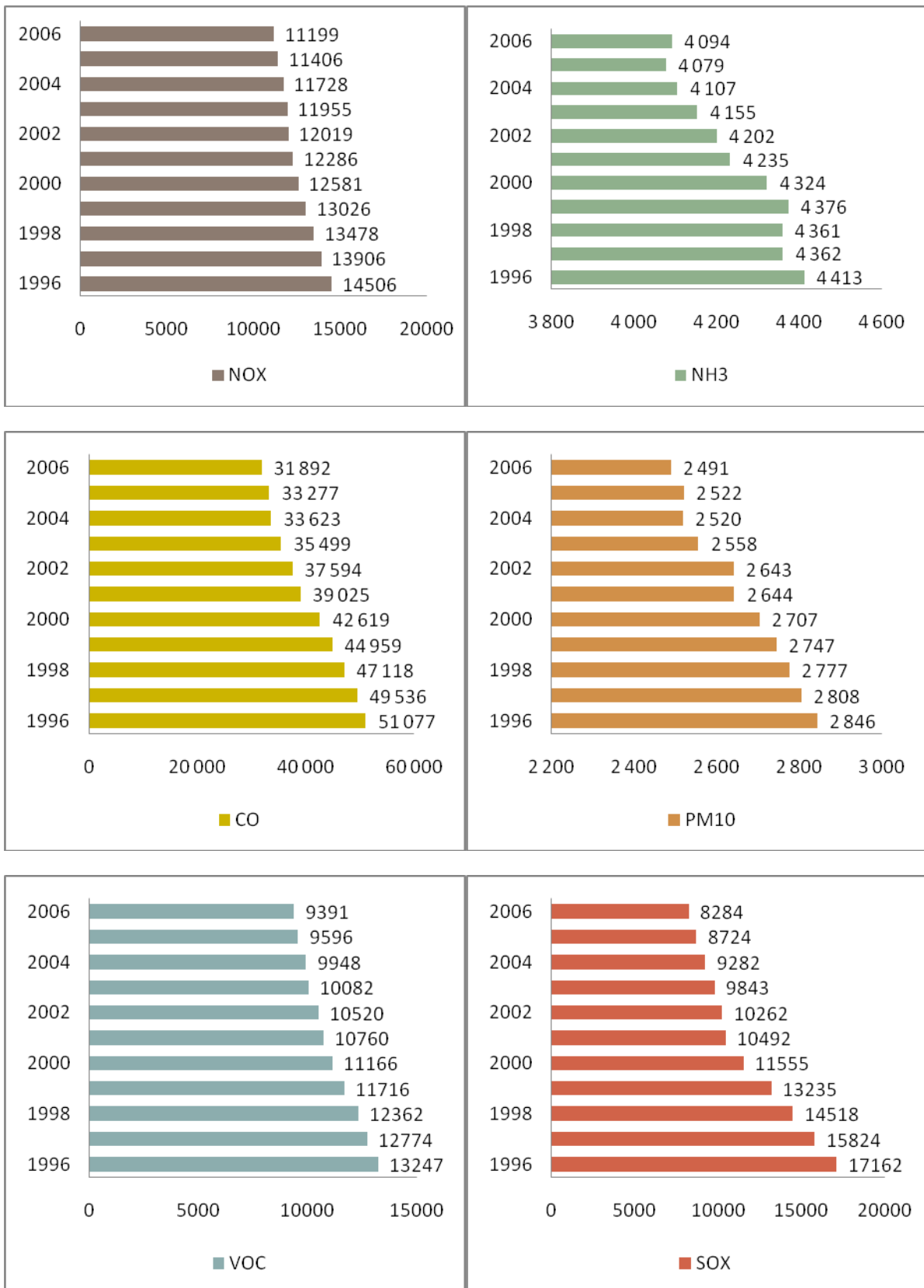
8.3 Current situation in the EU-27

Figure 17: Historical emissions of GHGs in the EU-27



Source: Eurostat [33]

Figure 18: historical values of air pollution in the EU-27, in kt.



Source: Eurostat [33], [34]

8.4 Analysis for the EU-27

The main goal of this work is description of the integrated approach benefits for the Czech Republic. However, it is important for context of the analysis to have some sort of reference. On following pages, the EU-27 is described in a way that is similar to the Czech Republic description in the main part of the work.

8.4.1 Economic activity pathways – General Macroeconomic drivers of the EU-27

Table 12: General Macroeconomic drivers of the EU-27

	2000	2005	2010	2015	2020
GDP, bn. Yr2000 Euro	10046.06	10949.26	12429.99	14059.19	15686.91
Value added - total, bn. Yr2000 Euro	9081.18	9920.93	11252.35	12736.27	14213.27
Value added - tertiary sector, bn. Yr2000 Euro	6444.95	7129.33	8132.3	9235.84	10335.02
Value added - industry, bn. Yr2000 Euro	1842.57	1947.81	2195.07	2477.42	2760.94
Total population, millions	480.51	489.09	492.95	495.35	496.41

Source: GAINS [30]

8.4.2 Economic activity pathways – activity data of the EU-27

Table 13: Energy data aggregated by activity, EU-27, in PJ

source	EUROSTAT	CaE package scenarios	NEC2007 baseline	CaE package scenarios	NEC2007 baseline
year	2000	2000	2000	2020	2020
Coal	13440	12737	13456	10489	14081
Heavy fuel oil		5062		3914	4540
Medium distillates		11074		12581	13767
Gasoline and LPG		10526		10800	11218
Oil (total)	27580	26662	27231	27295	29525
Natural gas (incl, other gases)	16472	18310	16472	20034	23144
Nuclear	10206	10152	10206	9086	9273
Biomass and waste		2545		8490	5543
Other renewables		1629		3810	2691
Renewables (total)	4162	4174	4241	12299	8234
Electricity (import)		45	71	44	44
Sum	71859	72081	71676	79246	84300

Source: GAINS [30], CaE package scenarios: data for year 2000 from Amman et al. [29], NEC2007, Baseline scenario: data from Capros et al. [31], EUROSTAT 2000: data from Eurostat webpage [33]

Generally, a **switch from coal to natural gas is expected, with no change in oil, slight decline in nuclear energy and growth of share of energy from renewable sources**. These effects are less intense in case of the baseline data, there is even a slight growth in generation of energy from coal. It is apparent that the Climate and Energy package puts pressure on renewable energy production and will be followed by much lower rise in energy consumption than there would be without the package.

Table 14: Energy data aggregated by sector, EU-27, in PJ

source	EUROST AT	CaE package scenarios	CaE package scenarios	NEC2007 baseline
year	2000	2000	2020	2020
Conversion	N/A	4337	6798	6685
Residential, commercial, services, agriculture, etc	18164	16974	20451	21996
Industry	13729	13132	14912	15386
Non-energy use of fuels	N/A	4453	5243	5255
Power sector	N/A	17758	13272	15349
Transport	14210	15427	18569	19628
Sum	72135	72081	79246	84300

Source: GAINS [30], CaE package scenarios: data for year 2000 from Amman et al. [29], NEC2007 Baseline scenario: data from Capros et al. [31], converted using IAEA [32], EUROSTAT 2000: data from Eurostat webpage [33]

Following the development of the macroeconomic drivers, **energy consumption will rise in future years in all the sectors with exception of power sector**, where the policy measures should lower the consumption of energy fuels by roughly one quarter. The baseline scenario is once again slightly less “environment-friendly”, however, the exact data on development in the sectors are not available.

Table 15: Agriculture data, EU-27

AGRICULTURE: LIVESTOCK NUMBERS (1000 heads)		
Year	2000	2020
Cattle and fur animals	95 684	106 161
Pigs	155 582	165 657
Chicken and poultry	1 493 955	1 665 133
Sheep and goats	139 213	124 681
Horses	5 413	5 873
AGRICULTURE: MINERAL FERTILIZERS PROD AND CONS (kilotons of N)		
Year	2000	2020
N - fertilizer consumption	11839	11088
N - fertilizer production	12827	11212

Source: GAINS [30], Data for year 2000 from Amman et al. [29]

Data on agriculture are delivered by the CAPRI model and are common for all the six scenarios. The rise in all the parameters reflects growth in food and animal products that follows the macroeconomic drivers. The fertilizer production and consumption stays more or less the same, with decline in unit percents.

8.4.3 Analysis – emissions and costs for EU-27

Table 16: Emissions, EU-27

EMISSIONS, sorted by cost									
scenario		EUROSTAT	6th EAP	BASELINE	current legislation	current policy	OPTV	EP proposal	MTFR
year		2000	2000	2020	2020	2020	2020	2020	2020
CO ₂	mt/yr	4100	N/A	4564	3904	3904	3904	3904	3904
N ₂ O	kt/year	1354	N/A	1459	1458	1462	1738	1756	1743
CH ₄	kt/year	22847	N/A	17096	16214	15097	27463	27400	27291
F-GAS	mt/yr	N/A	N/A	198	81	196	215	215	215
NH ₃	kt/year	4235	4020	3710	3763	3711	3139	3079	2394
NO _x	kt/year	12581	12155	6036	6348	5684	5158	4838	4446
PM _{2.5}	kt/year	N/A	1857	1257	1298	1263	1006	957	655
PM ₁₀	kt/year	2644	N/A	1913	1969	1899	1551	1490	1094
PM _{TSP}	kt/year	N/A	N/A	3607	3650	3554	3098	3007	2417
SO ₂	kt/year	10492	10352	3255	3445	2931	2336	1938	1755
VOC	kt/year	11166	10867	6074	6381	6151	6072	5523	4138

Source: GAINS [30], CaE package scenarios: data for year 2000 from Amman et al. [29], EUROSTAT 2000: data from Eurostat webpage [33]

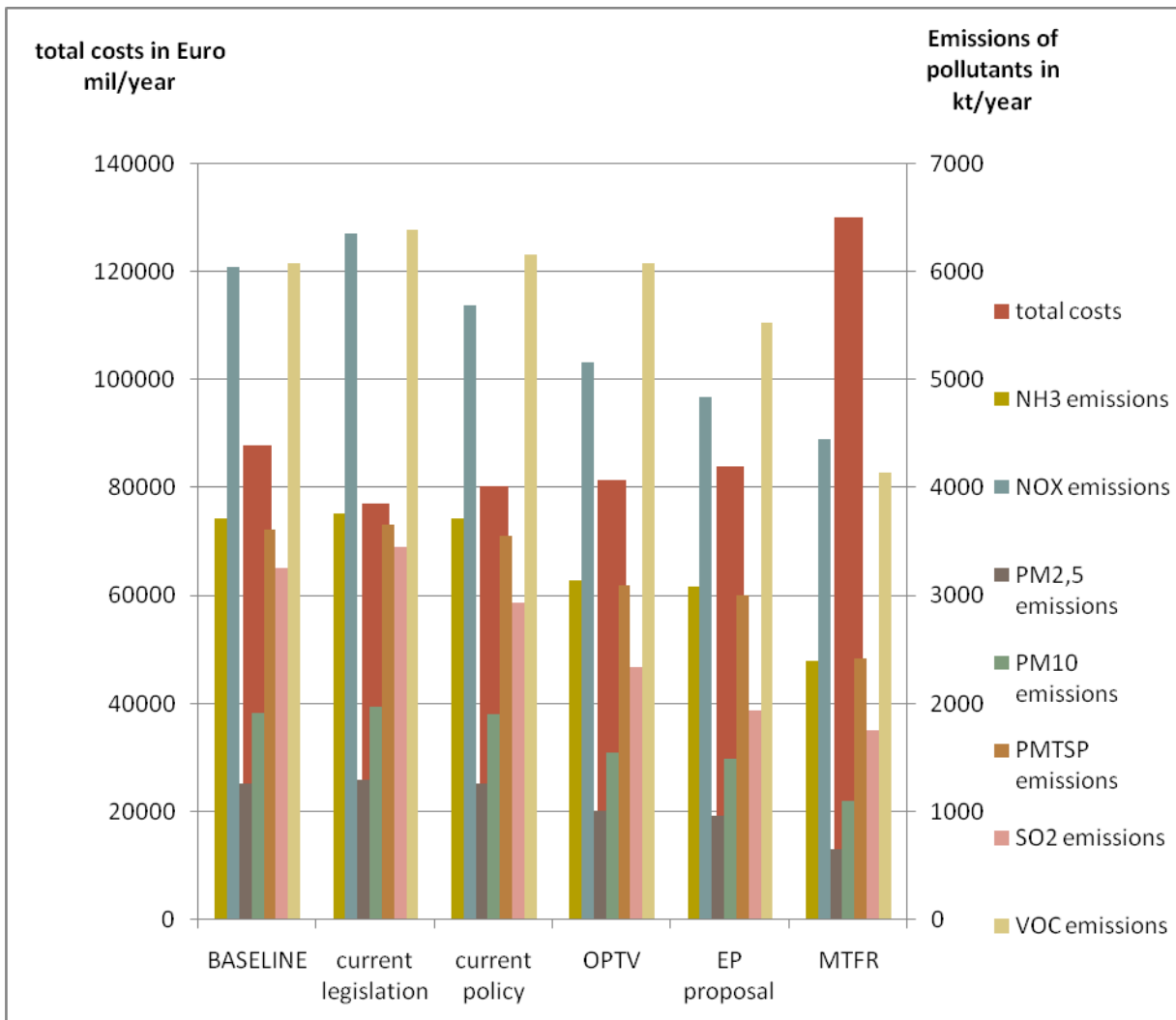
Table 17: Costs, EU-27

COSTS in year 2020, total in yr 2000 million Euros, sorted by cost						
	BASELINE	current legislation	current policy	OPTV	EP proposal	MTFR
N ₂ O	13	13	13	N/A	N/A	N/A
CH ₄	17745	21176	19357	N/A	N/A	N/A
F-GAS	499	3273	499	N/A	N/A	N/A
NH ₃	3086	2765	3086	3773	4015	10376
NO _x	50459	44711	46953	47290	48154	51227
PM _{TSP}	11963	11274	11356	11486	11878	31305
SO ₂	19393	15397	15996	16228	16806	18558
VOC	2771	2771	2742	2675	3097	18558
All Air Pollutants	87671	76917	80133	81452	83950	130025
All GHGs	18257	24462	19869	N/A	N/A	N/A

Source: GAINS [30]

Expectably, costs of *Current Policy* scenario are slightly higher than the costs of *Current Legislation* scenario, as there are new legislative constraints that generate new costs. The same holds true for the *EP proposal* scenario, as there are even more constraints needed to achieve more strict TSAP goals that are followed by a rather large growth of costs. Steep growth of costs is also expectable in the maximum technically feasible reduction scenario, as the emission reductions are by far largest in compare to other scenarios. The 2020 costs of air protection for all scenarios are almost triple compared to the year 2000 costs of 30322 Euro a year (EEA [20]).

Figure 19: Air pollution and its costs, EU-27



Source: GAINS [30]

The slightly higher costs of the OPTV scenario are more than offset by the relative decline in emissions of air pollutants. As apparent from the figure, the EP proposal on more ambitious environmental goals of the Thematic Strategy still pays off, but the costs for the maximal emission reduction would be way too high when compared to environmental benefits this investment would bring.

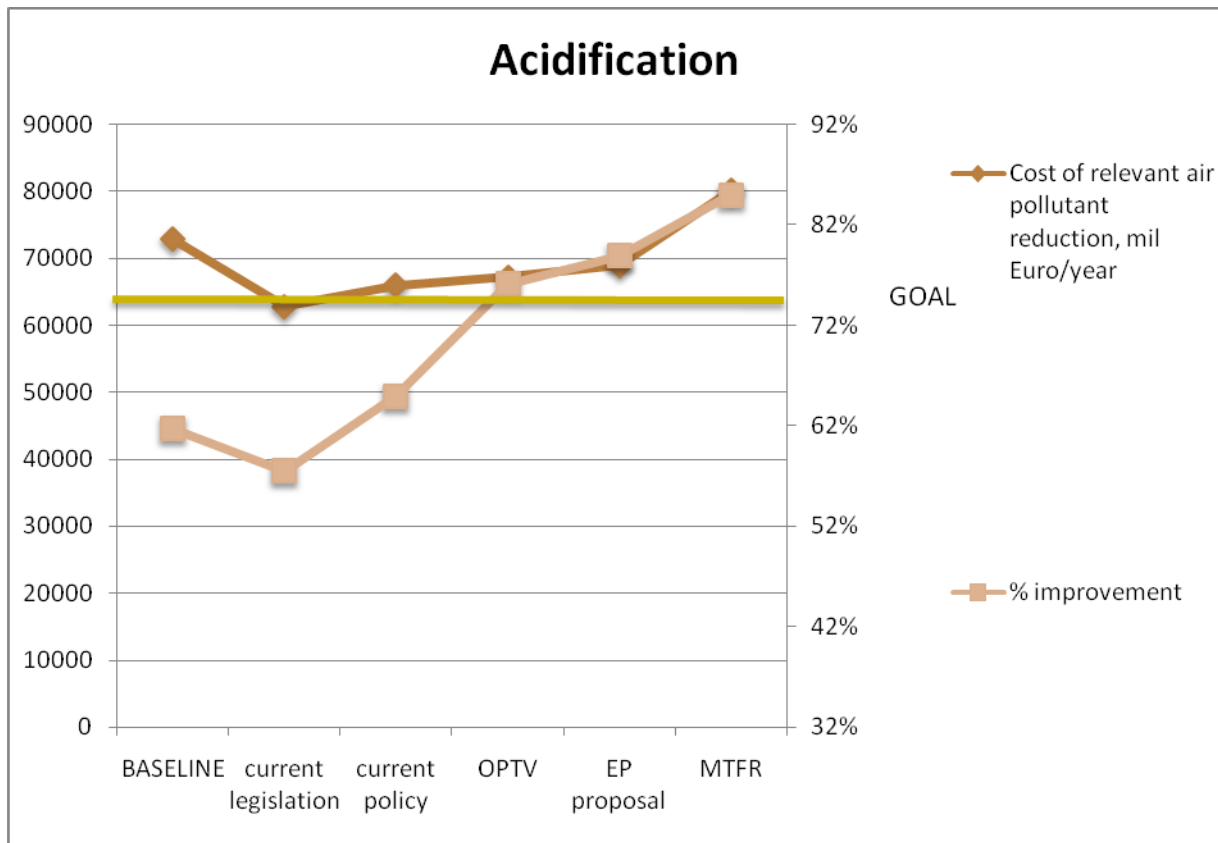
8.4.4 Analysis – impacts on the EU-27

Table 18: Acidification in the EU-27

ACIDIFICATION	forest area receiving deposition in excess of critical loads, 1000km2					
	current policy	current legislation	OPTV	MTFR	BASELINE	EP proposal
goal:74%						
Year 2000	Year 2020					
259	91	110	62	39	99	55
% improvement	65%	58%	76%	85%	62%	79%

Source: GAINS [30]

Figure 20: Acidification in the EU-27



Source: GAINS [30]

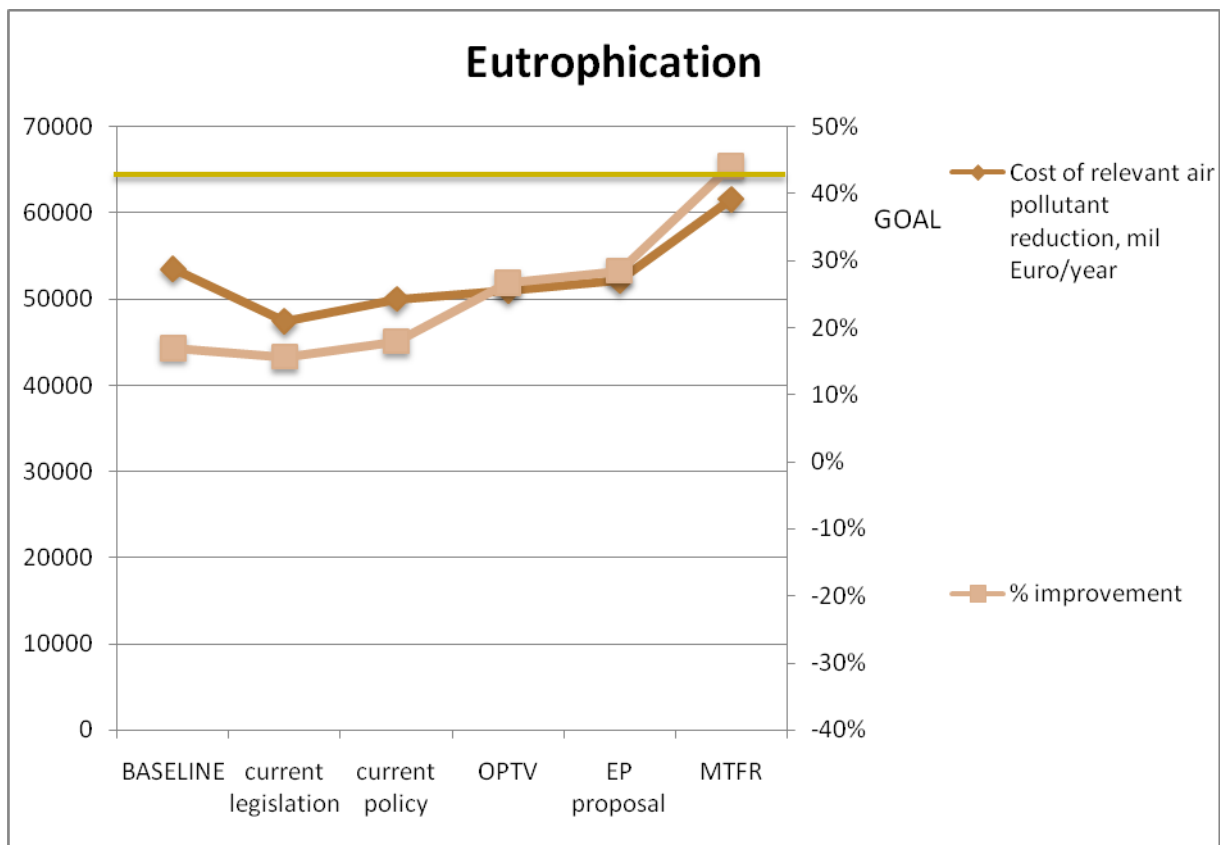
The acidification goals of the Thematic Strategy would be achieved only optimised scenario and more costly scenarios, the non-optimised scenarios would fail to do so.

Table 19: Eutrophication in the EU-27

EUTROPHICATION	ecosystem area receiving deposition in excess of critical loads, 1000km2					
goal:43%	current policy	current legislation	OPTV	MTFR	BASELINE	EP proposal
2000	2020					
1020	836	860	747	569	846	728
% improvement	18%	16%	27%	44%	17%	29%

Source: GAINS [30]

Figure 21: Eutrophication in the EU-27



Source: GAINS [30]

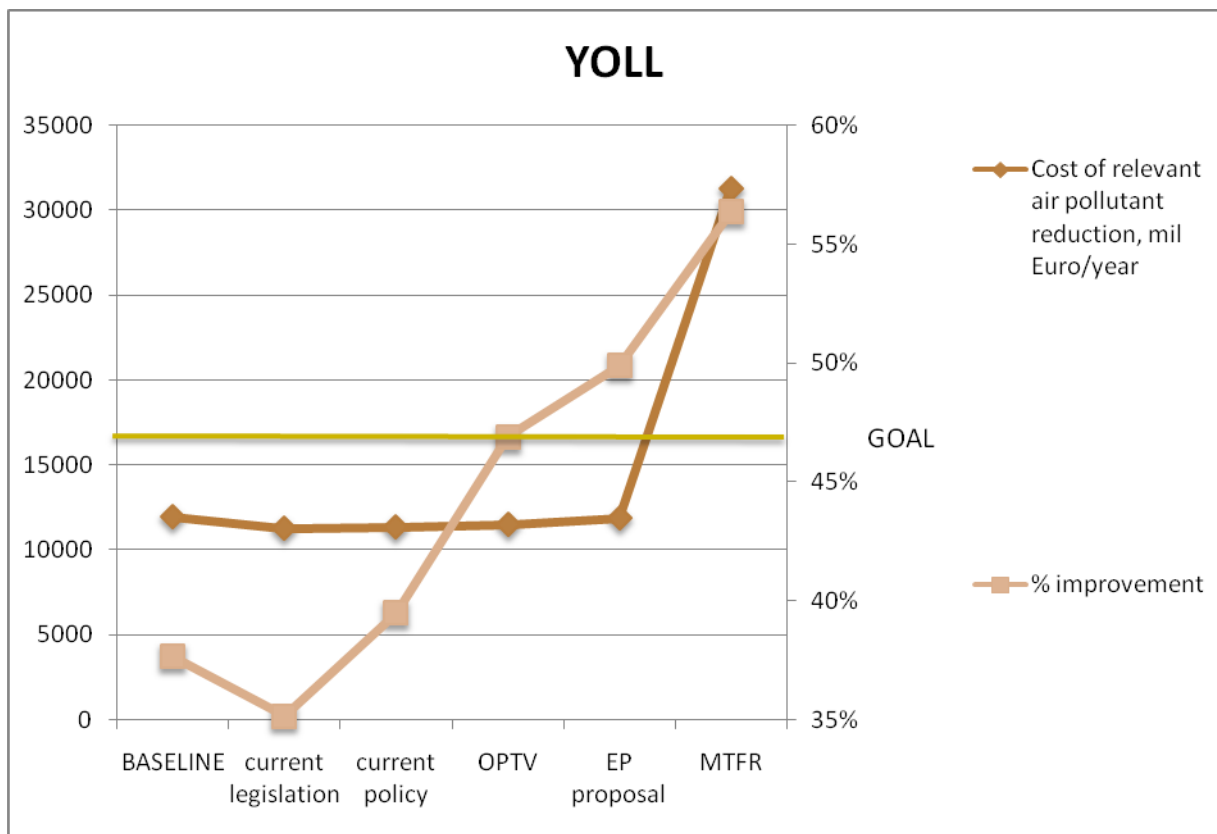
Apparently, the acidification goals are technically feasible, but the costs would be relatively very high. The optimised scenario fails to achieve the goals by rather a large margin.

Table 20: Years of life lost in millions caused by ambient PM_{2.5} in the EU-27

YOLL	Year of life lost in millions caused by ambient PM _{2.5}					
	current policy	current legislation	OPTV	MTFR	BASELINE	EP proposal
goal:47%						
2000	2020					
216	130	140	114	94	134	108
% improvement	39%	35%	47%	56%	38%	50%

Source: GAINS [30]

Figure 22: Years of life lost in millions caused by ambient PM_{2.5} in the EU-27



Source: GAINS [30]

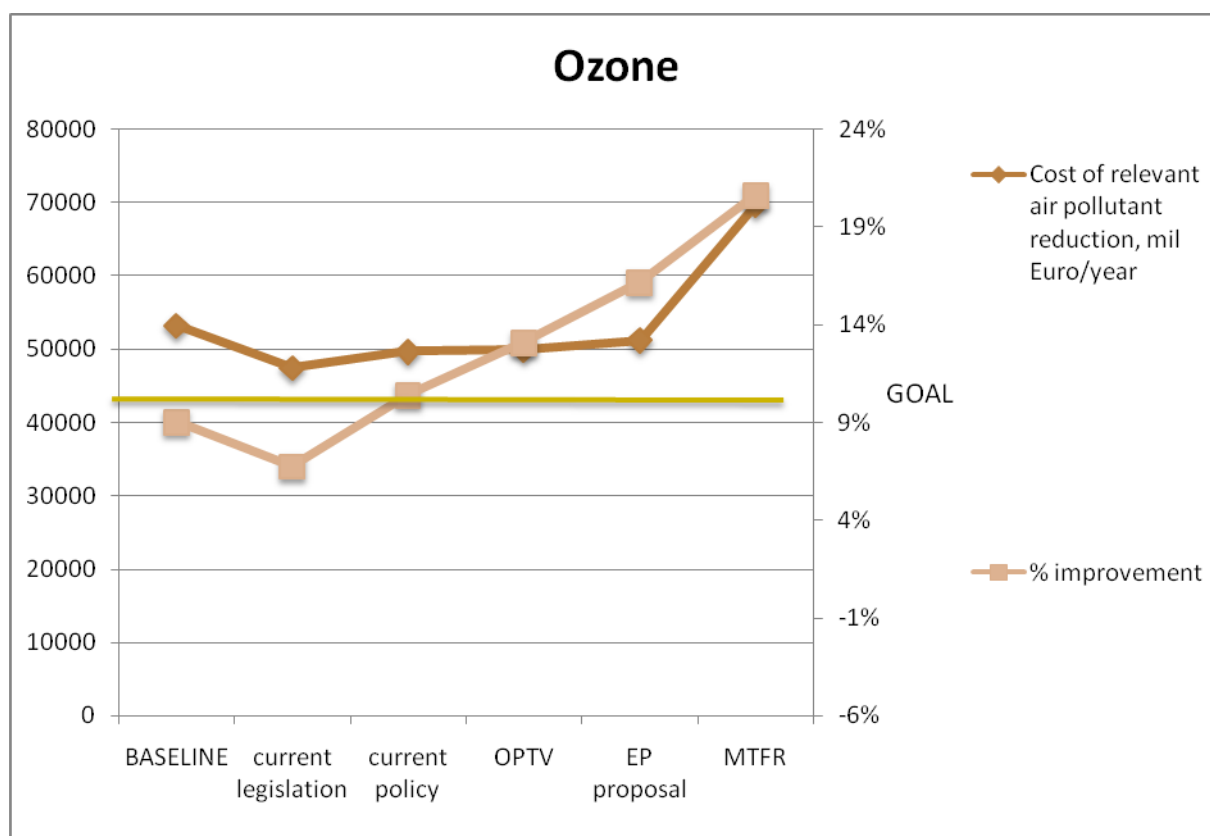
The goal of the Thematic Strategy on Air Pollution is achieved only with optimized scenario, neither CP nor CL generate emission levels that would be sufficient.

Table 21: Premature deaths caused by ozone in the EU-27

OZONE	Premature deaths caused by ozone					
goal:10%	current policy	current legislation	OPTV	MTFR	BASELINE	EP proposal
2000	2020					
20295	18181	18928	17642	16107	18464	17009
% improvement	10%	7%	13%	21%	9%	16%

Source: GAINS [30]

Figure 23: Premature deaths caused by ozone in the EU-27



Source: GAINS [30]

The ozone goals are even overstepped by the optimised scenario. On contrary, the non-optimised scenarios would not achieve the desired level.

