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Atingir os tetos de redução de emissão de forma custo-eficaz.

Meeting air pollution reduction targets, cost-effectively across Portugal.

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia do Ambiente, realizada sob a orientação científica do Doutor Peter Roebeling, equiparado a Investigador Auxiliar no Departamento de Ambiente e Ordenamento da Universidade de Aveiro e co-orientação da Doutora Joana Ferreira, Investigadora Auxiliar no Departamento de Ambiente e Ordenamento da Universidade de Aveiro.

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palavras-chave

poluição atmosférica, cenários de redução de emissão, objetivos para 2030; economia ambiental, custo-eficência; custo-eficácia.

resumo

O tema da redução de emissões tem sido uma grande preocupação na Europa pois, embora as emissões de poluentes tenham diminuído, a poluição do ar continua a constituir um problema. O presente trabalho tem como objetivo preencher a lacuna existente na literatura, encontrando soluções espacialmente distribuídas que atinjam as metas de emissões impostas pela Diretiva Tetos de Emissão Nacional (TEN) para 2030, usando Portugal como estudo de caso. O principal objetivo desta dissertação é encontrar tecnologias que permitam atingir os tetos para Portugal ao mais baixo custo. Para esse fim, foram identificadas as categorias de atividades mais relevantes de cada setor em relação às emissões e as tecnologias mais baratas que permitirão o alcance das metas, recorrendo à base de dados do modelo GAINS sobre nível de atividade, emissões e custos por tecnologia. Foram também identificadas as áreas de Portugal para as quais essas medidas devem ser aplicadas de forma a atingir os objetivos de forma económica através da utilização do modelo EESIP-Air, usando dados de emissões espacialmente distribuídos retirados do EMEP.

As áreas de Portugal com emissões de poluentes mais elevadas são a costa oeste, com incidência nas áreas urbanas do Porto e Lisboa e, no que diz respeito ao NH_3, também as áreas do Alentejo e Trás-os-Montes (áreas agrícolas). O NOx é o poluente para o qual as simulações do cenário CLE2030 estão mais próximas do teto devido às medidas adotadas no setor de transportes (normas europeias de emissão), de modo que o esforço extra a ser feito não é tão relevante quanto para outros poluentes NH_3, SO_2, NMVOC e PM2.5. O cenário OPT2030 apresentou as melhores soluções para atingir os TEN (43 kt / ano para NH_3, 95 kt / ano para NOx, 27 kt / ano para PM2,5, 30 kt / ano para SO_2 e 132 kt / ano para VOC), permitindo a redução da emissão em 14% (NH_3), 25% (NOx), 45% (PM2,5), 35% (SO_2) e 21% (NMVOC) em comparação com o cenário CLE2015.

Os custos obtidos para cada cenário são: 543 m€ / ano (CLE2015), 509 m€ / ano (CLE2030) e 518 m€ / ano (OPT2030). O OPT2030 implica um aumento de 2% em relação ao custo do cenário CLE2030, no entanto, o mínimo necessário para atingir os TEN.

Este trabalho fornece informações essenciais para apoiar e definir uma estratégia integrada para atingir os TEN.

keywords

air pollution, emssion reduction scenarios, 2030 targets; environmental economy, cost-efficiency; cost-effectiveness.

abstract

The topic of emission reduction has been a big concern in Europe as, although the emissions of pollutants have been decreasing, air pollution remains a problem. The present work aims to bridge the existing gap on the literature, finding spatially distributed solutions that achieve the emissions targets imposed by the National Emission Ceilings Directive (NEC) for 2030, using Portugal as a case study. The main objective of this dissertation is to find technologies that can achieve Portugal's NEC in a cost-effective way. For this purpose the identification of the most crucial sector activity categories regarding the emissions and the identification of the cheapest technologies that will enable the achievement of the targets, through the GAINS model database in activity level, emissions and costs by technology was performed, as well as the identification of the areas of Portugal for which those measures should be applied to achieve the target in a cost-effective way through the EESIP-Air model application, using spatially distributed emission data taken from EMEP. This work provides essential information to support and define an integrated strategy to fulfil NEC.

Results show that the areas of Portugal with the highest levels of pollutant emissions are the west coast, with an incidence in the urban areas of Porto and Lisbon and, concerning NH_3, also the areas of Alentejo and Trás-os-Montes (agricultural areas). NOx is the pollutant for which CLE2030 simulations are closer to the ceiling due to the measures related to the transport sector (European emission standards) so that, the extra effort to be done is not as relevant as for the other pollutants - NH_3, SO_2, NMVOC and PM2.5. Scenario OPT2030 led to the best solutions to achieve the NEC targets (43 kt/year for NH_3, 95 kt/year for NOx, 27 kt/year for PM2.5, 30 kt/year for SO_2 and 132 kt/year for VOC), allowing the reduction of the emission in 14% (NH_3), 25% (NOx), 45% (PM2.5), 35% (SO_2), and 21% (NMVOC) comparing with the scenario CLE2015. The costs obtained for each scenario are: 543 m€/year (CLE2015), 509 m€/year (CLE2030) and 518 m€/year (OPT2030). OPT2030 implies an increase in 2% relative to the cost for scenario CLE2030, however it represents the minimum required to achieve the NEC targets.

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Abbreviations and Acronyms

CLE	Current legislation emissions
I^an	Annualised investments
mc	Marginal costs
p	Pollutant
CO	Carbon monoxide
HM	Heavy metals
A	activity
ALC	Ambient Least Cost
APA	Agência Portuguesa do Ambiente (Portuguese Environmental Agency)
BaP	Benzo[a]pyrene
BAT	Best available technology
BC	Black Carbon
C_i	Control cost across all relevant pollutants in country i;
ca	Abatement costs
CBA	Cost-benefit assessment
CEA	Cost-Effectiveness assessment
CGE	Computable General Equilibrium
CLE2015	Current Legislation Emissions for 2015
CLE2030	Current Legislation Emissions for 2030
CLETAP	Convention on Lon-Range Transboundary Air Pollution
CH_4	Methane
EEA	European Environmental Agency
EESIP	Economic Spatial Investment Prioritisation
EMEP	Evaluation Monitoring and Evaluation Programme
ER	Emission reductions
ERM	Emission reduction model
ERSD	Emission Reduction Strategies Database
ES	Energy saving
ETC	Emission trading Scheme
EU	European Union
GHG	Greenhouse gases
Hg	Mercury
IFAMM	Inexact fuzzy-chance-constrained air quality management model
kt	Kilotons
LP	Linear Programming
MAPLIA	Moving from Air Pollution to Local Integrated Assessment
MB	Marginal benefit
MC	Marginal cost
MILP	Mixed Integer Linear programming model
MS	Member states

NEC	National Emission Ceilings Directive
NH_3	Ammonia
Ni	Niquel
NMVOC	Non-methane volatile organic compounds
NO_2	Nitrogen dioxide
NOC_p	“No-control” technology
NO_x	Nitrogen oxides
O_3	Ozone
OF	Objective function
OM^fix	Operating costs
OM^var	Variable costs
OPERA	Optimal Integrated Emission Reduction Alternatives
OPF	Optimal Power Flow
OPT2030	Optimum 2030
PM	Particular matter (PM10 and PM2.5)
POP	Persistent organic pollutants
RIAT+	Regional Integrated Assessment Modelling Tool
SNIERPA	Sistema Nacional de Inventário de Emissões por Fontes e Remoções por Sumidouros de Poluentes Atmosféricos (National System of Inventory of Emissions by Sources and Removals by Sinks of Air Pollutants)
SO_x	Sulphur oxides
SO_2	Sulphur dioxide
UNECE	United Nations Economic Commission for Europe
WHO	World Health Organization

1. Introduction

Air pollution is a topic of great importance as, despite lately reductions on emissions and ambient concentrations of pollutants, in some areas of Europe, air quality remains poor (EEA, 2019).

Air quality depends, amongst others, on the sources of emissions. Emissions can be classified as natural or anthropogenic. Natural emission are associated with volcanic activity, earthquakes, tsunamis, and spontaneous forest/wild fires. Anthropogenic emissions derive from human activities, such as industrial emissions, traffic, residential heating, shipping, construction, agricultural activities, wars and fires (Kim et al, 2018).

Based on the 2019 report of the European Environmental Agency (EEA) on Air Quality in Europe, the main sectors of anthropogenic emissions are: transport; commercial, institutional and households; energy production and distribution; industry, agriculture and waste. The transport sector was the largest contributor to total nitrogen oxides (NOx) emissions. The commercial, institutional and households' sector was the main responsible for benzo[a]pyrene (BaP), particular matter (PM10 and PM2.5), carbon monoxide (CO), and black carbon (BC) emissions. The energy production and distribution sector were the largest contributor to sulphur oxides (SOx), mercury (Hg) and niquel (Ni) emissions. The agricultural sector was the largest contributor to ammonia (NH_3) and methane (CH_4) emissions. Finally, the waste sector contributed a significant amount of CH_4 (EEA, 2019).

Emissions are vital to comprehend the air quality of a region, but it is important to understand that, not only local emissions will influence the air quality of that place. Air quality may also be influenced by pollutants emitted from neighbour places (transported by the air) as well as impact of the weather and topography on this transport, by chemical reactions that may occur among pollutants in the air and among pollutants and sunlight and emission heights (Watson et al., 1988). Air pollutants are classified as primary or secondary, where primary air pollutants are those that are directly emitted to the atmosphere and secondary pollutants are the result of chemical reactions of precursor pollutants (EEA, 2018). In the case of particulate matter (PM), for example, it is possible to identify a primary and secondary origin. PM is constituted directly by emitted elemental and organic carbon, and indirectly by chemical reactions between SO_2, NOx, NH_3 and organic gases in the atmosphere (Sharma et al., 2007). Fossil fuel combustion for power generation and transportation, are considered the main responsible for the emission of primary air pollutants emission (US EPA, 2009).

In the 20th century some episodes supported the belief that air pollution has an impact on health. In December 1936, in Meuse Valley (Belgium), there was a significant number of deaths, resulting from a 4-day long sulphuric fog (Firkey, 1936). Some years later, in 1949, a short episode of smog in Donora, Pennsylvania, resulted in the increase in death rates and respiratory diseases (Schrenk et al., 1949). Following these two events, there was the London's great smog in 1952, that caused around 3000 deaths in the three weeks after the event and 12000 deaths until a year later (Bell & Davis, 2001.). These events contributed to raise awareness regarding the negative health effects of air pollution (EEA, 2018).

Air pollution has a significant impact on human health, mainly in urban areas. Air pollution is classified as carcinogenic to human beings by the World Health Organization (WHO) causing around 400 000 premature death per year (WHO, 2018)

In Europe, particulate matter, nitrogen dioxide and ground-level ozone, are recognised as the three pollutants that most significant affect human health. The impact of long-term exposure to these pollutants include respiratory diseases, cardio-vascular diseases and premature deaths. PM2.5 reduces the life expectancy in EU by more than eight months (EEA, 2018). Regarding the most significant pollutants the most frequently impacts are: reduced life expectancy, bronchitis and cough in children and asthmatics, respiratory and cardiovascular hospital admissions asthma episodes and restricted activity (Brandt et al., 2013).

Besides health impacts, air pollution also has a negative impact on vegetation and ecosystems affecting fauna and flora directly, as well as water and soil quality and the ecosystem services they support. Related to ecosystems damage, ozone (O3), NH3 and nitrogen dioxide (NO_2) are considered the most harmful ones. Air pollution can be responsible for acidification, eutrophication and crop damage. Acidification comes from the deposition of excess sulphur and nitrogen compounds, while eutrophication results in the input of excessive nutrients into ecosystems and crop damage outcomes from the exposition to high ozone concentrations. Although acidification and eutrophication were reduced between 1990 and 2010, a lot of agricultural crops are still exposed to high levels of ozone concentration (EEA, 2018).

On one hand air pollution can also be related to climate change as many airs pollutants impact on climate and global warming in the short-term, as for example tropospheric ozone and black carbon (component of PM). On the other hand, changes in the weather patterns by climate change may affect the transport, dispersion, deposition and formation of air pollutants in the atmosphere.

Once understanding the negative consequences of air pollution, it is easy to conclude that emission reductions are essential for improving air quality. It is necessary to reduce emission of air pollutants in order to achieve values that are not harmful and represents risks to humans, the environment and the economy. Emission can be reduced by three types of control measures: behavioural measures, structural measures and technical measures. Behavioural measures reduce anthropogenic driving forces that lead to air pollution which can emerge autonomously, can be facilitated by institutional approaches, can be fostered by command-and-control instruments or triggered by economic incentive instruments. Structural measures refer to mitigation providing the same level of services to the consumer with less pollution, what can be achieved by fuel substitution or energy efficiency improvements, for instance. Finally, technical measures capture emissions at their sources before they enter the atmosphere. Technical measures can be achieved by changes in the driving forces of the emissions or by changing the structural composition of energy systems or agricultural activities (WHO, 2017).

For Europeans, air pollution is the second biggest environmental concern (right after climate change), and so that, citizens expect that authorities take actions on the reduction of air pollution and its effects (EEA, 2018). Bearing this in mind, authorities have been working on air quality legislation (see chapter 4.1) and scientists around the world have been studying the topic of emissions reductions as well as the economic impacts of this reductions.

From authorities' point of view, the design of pollution reduction policies is restricted to a limited budget. Decision-makers must balance the economic and environmental aspects. On one hand, decision-makers must find the measures that will reduce the impact of pollutants on air quality, on the other hand, decision-makers must consider economic impacts and the budget (Carnevale et al., 2014). To plan air quality polices having in mind this balance, environmental agencies require Decision Support Systems that assess the efficiency of proposed emission reduction strategies for air quality improvement (Carnevale et al., 2011).

Some modelling and/or statistical studies based on projections (having different scenarios) (Cofala et al., 2004; S. Zhang et al., 2015) and focused on the impact assessment of policy implementation and climate change on future air quality and health (Hedegaard et al., 2013; Li & Patiño-Echeverri, 2017); have been released. However, there is a gap on spatially distributed researches since the current studies have been focus on a whole region (focus on a country, a continent or even a part of a country but always as a whole) which leads to uncertainties related to emissions inventories. Ma et al. (2015) assessed the cost, benefits and cost-effectiveness of different energy efficiency measures in order to promote their implementation. In this study only energy and environmental data was used in a national level, not being assessed the potential of the implementation of the measures in a sub-national level (Ma et al., 2015). Even in studies which only a part of a country is assessed as is the case of the Grande Porto Region, in Portugal (Miranda et al., 2016) or the study done in Peral River Delta Region in China (Liu et al., 2017), the assessment done does not considered space variations on the implementation of measures within those regions. In order to have more realistic results it is necessary to study the variability in emission patterns within a country/region, that can come from socioeconomically specific characteristics, differences in the urbanization or even meteorological and chemical conditions.

Having these two problems (the necessity of implement measures having the economy as a concern and the gap of spatially distributed studies) and within the context of FUTURAR Project, the main objective of this study is to explore patterns of emission reduction technologies that most cost-effectively achieve specific emission reduction targets and estimate corresponding spatially explicit emission reduction cost, having Portugal as case study. This main objective depends on more specific goals namely:

i: intensive review on similar studies in order to understand current development and gaps;

ii: to use GAINS model to simulate emissions under different scenarios;

iii: to use EESIP-Air to spatially distribute emissions reduction over Portugal;

The main outcomes of these goals will be: (a) a review on environmental economic approaches to air pollution emission management; (b) survey of emission reduction technologies (c) inventory of emission reductions costs for Portugal.

As emission reduction technologies and costs of emission reductions targets have been estimated only for Portugal as a whole, this research aims to be innovative by estimating the spatial distribution of emission reduction technologies and costs for Portugal.

To accomplish the dissertation objectives the structure presented in figure *Figure 1* was followed and the work is presented in 6 chapters.

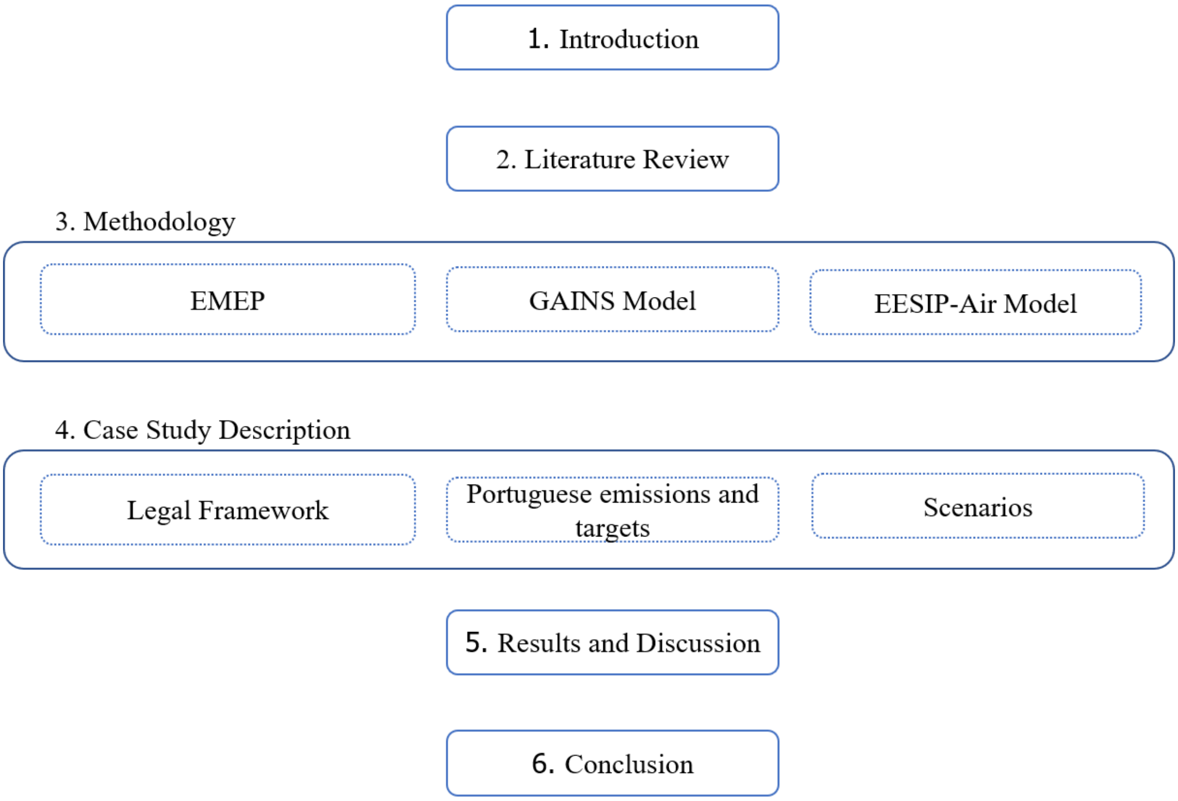

Figure 1 Dissertation overview

Chapter 1 provides an overview of the dissertation topic. Air quality, emission sources in Europe, historical cases of pollution disasters are introduced. The objectives and structure are presented.

Chapter 2 provides the literature review on economic approaches to atmospheric emissions management. In this Chapter cost-effectiveness, cost-efficiency and cost-benefit assessment studies are analysed and interpreted. For each one of the three economic approaches a general description is given, examples of existing studies are presented, and benefits and cons of their use are stated.

Chapter 3 presents the methodology used for reaching the goal. This chapter focus on the description of GAINS and EESIP-Air models as well as on the description of the simulated scenarios.

Chapter 4 describes the case study. In this chapter, besides being contextualised the Portuguese legal obligations, it is specified the scope of the study, the historical Portuguese emissions and the pathway that Portugal has been taking to reach the targets.

Chapter 5 collects the mains results of this dissertation.

Chapter 6 summarizes the main conclusions of the study and suggests further developments as future work.

2. Literature review on economic approaches to air pollution emission management

In order to get to know the topic, the research that has been done in this field and to find some gaps of information, a literature review was performed.

A literature review must follow a clear pathway, so that, it was essential to plan which topics were important to search. For that, a primary review of general topics was done. In this first step, general articles about concepts as “pollution”, “air quality” and “environmental economy” were chosen and read in order to select the topics of interest of the literature review.

For this review two bibliographic databases were used (Scopus and ScienceDirect) in order to adequately identify all literature related. Each article was selected by title, keywords and abstract and it was given priority to articles published in international journals, articles published in recognize national journals, books published by recognized editors, thesis and dissertations, papers from international conferences, and papers from national conferences. A total of 250 articles were found from where only 49 of these articles were considered relevant and only 42 were available and were read in full. The other 201 were rejected because they were too specific or out of scope. From this 42, 39 were considered environmental economic articles from which 7 represent cost-benefit assessments, 19 cost-effective assessments, 5 cost-efficiency assessments, 6 focus simultaneously cost-benefit and cost-effective assessments and 2 tackle simultaneously cost-effective and cost-efficiency assessments.

As in environmental economy field there are different approaches, it was essential to divide and do the research for each approach: cost-effectiveness, cost-benefit and cost-efficiency. For each of these approaches it was analysed the definitions, components, benefits and cons as well as examples or case studies having as base each approach (see Section 2.1, 2.2 and 2.3.)

Costs associated with implementing environmental policies may be divided into private sector costs (including direct and indirect costs), societal costs and governmental regulatory costs (S. Voorhees et al., 2001)..

Direct costs may be capital costs or operating costs. The capital costs include expenses for facilities and equipment, as well as changes in production processes that reduce or eliminate pollution generation and can be amortized over time. Operation costs include all the costs and expenses for the operation and maintenance of pollution control processes. Indirect costs are the costs are from pollution control requirements (Voorhees et al., 2001)..

Societal costs are those forcefully acquired by punctual expenses caused by the partial alternative allocation of resources, effect of environmental regulatory compliance.

Regulatory costs are part of governmental agency budget used to implement environmental programs (S. Voorhees et al., 2001).

In the next sections, different approaches that have been used to inform the negotiations on air pollution control agreements in Europe and to identify sets of measures that improve air quality and reduce emissions at least cost, are presented.

2.1 Cost-Effectiveness assessment studies

Cost-Effectiveness assessment (CEA) aims to find the best alternative activity, process or intervention, that minimizes resource use to achieve a desired result (Görlach, 2004). Cost-effectiveness assessments are frequently used, mainly at continental and national level, to help estimating the costs associated with the implementation of measures or scenarios, identifying those scenarios that achieve the improvement targets at least cost as well as the combinations of measures that provide largest emission reductions and/or air quality improvements given a fixed limited target (Roebeling et al., 2015). The effectiveness of those measures and scenarios is based on sector activity levels, uncontrolled emission factors, measured removal efficiencies and measured application rates (Voorhees et al, 2001).

In general, a CEA is relevant when different measures have the same annual effectiveness but at different cost. The first step of a CEA is to define the specific policy objective. This objective can be defined in terms of pressures (reducing pollution levels) or in terms of impacts (achieving a certain level of environmental quality). After that, it is important to see how far it is from the objective (distance to target) and establish a baseline ("business as usual" or "do nothing scenario"). Then, is important to assess which human activities have a negative impact on the environmental objective. After that, it is possible to decide which policy intervention, comparing to the baseline scenario, can achieve the target. A CEA then seeks to find out which of these interventions should achieve this goal at the lowest cost. Having this policy, it is essential to calculate the costs of implementation. This calculation is something complex and, not only the marginal costs (not already sunk or fixed costs) should be taking in consideration, as saving cost should be discounted from the total cost. It is important to realize if marginal costs increases/decreases with increasing intervention. Finally, having the costs, it is essential to calculate the effectiveness of the measures that can be done in terms of pressures (how much PM10 are expected to be removed, from policy intervention?) or in terms of impacts (how is the population's health improved due to pollution reduction?) (Görlach, 2004).

CEA may be integrated in different kind of studies. It may be used to find the most effective way to offset some environmental problems as K. J Liao et al. did, in 2010, finding measures as well as costs and effectiveness of those measures to mitigate the effect of climate change on air quality (K. J Liao et al., 2010). It may also be applied to look for effective means to reduce emissions of certain pollutants in order to comply with polices or agreements (Webb et al., 2006), to support the development of those policies (Karvosenoja & Johansson, 2003) or to evaluate which mix of policies can reduce the human exposure to some pollutants (Relvas et al., 2017).

No matter the goal of the CEA, it is a complex process and, in order to simplify it, different tools started to be implemented and studied. Some studies evaluated tools that would support air quality management (Cheng et al, 2007; Xu et al,2010) and tools that evaluated pollution control measures and regulations implemented (Vlachokostas et al., 2009; Akhtar et al., 2013; Relvas et al., 2017).

Cheng et al. (2007), used a Gaussian-box modelling system to quantify the contribution of different emission sources to the quality of the air during the heating and non-heating seasons.

Gaussian-box modelling considered emission reduction goals, strategies, and resources limitations providing, for different pollution control measures, an emission control strategy and cost, demonstrating that this tool can be useful to decision makers in cost-effective air quality management (Cheng et al., 2007).

Xu et al. (2010) opted for the development of an inexact fuzzy-chance-constrained air quality management model (IFAMM) that allows the expression of uncertainties not only as possibilistic distributions but also discrete intervals in air quality management systems.

In the IFAMM, the fuzzy variables allow the achievement of different solutions since it can be satisfied at different confident levels. This model proved to be a valuable tool in the selection of the best air quality management policies once it was applied to a case of air quality management where different solutions were obtained, making it possible to relate the costs of the regional quality management with the system failure risk (Xu et al., 2010).

Vlachokostas et al. (2009) studied an integrated assessment methodological scheme that presents a set of air pollution control options by bringing together air quality modelling and mathematical programming techniques.

It was developed a framework where different input data were inserted in a mathematical modelling approach, in order to find out optimal strategies to reduce pollution level in regional areas. Inputs as transfer coefficients, demographical data and population density were considered, as well as the marginal costs that were calculated through the costs and effectiveness of all available control options. This methodology was successfully implemented in Tessaloniki, Greece, for the case of PM, proving being a useful tool to find the most cost-effective options and, consequently, a useful tool to support decision-making process (Vlachokostas et al., 2009).

Akhtar et al. (2013) developed GLIMPSE framework that allows the identification of cost-effective measures that can achieve air quality, health and climate impact goals (Akhtar et al., 2013). In this study, GLIMPSE, a framework that has as goal offering a shared platform to show multiple environmental outcomes of energy policies, was applied. This tool comprehends the variability in possible regional modifications in aerosol and greenhouse gases emissions and evaluates impacts of health and climate policies at spatial and temporal scales, being an easy and quick way to calculate energy/environmental system response to policies modifications (Akhtar et al., 2013).

Relvas et al. (2017) used RIAT+ (Regional Integrated Assessment Tool) to identify the most cost-effective mix of local policies that can decrease the human exposure to PM10 and NO_2. RIAT+ is able to identify in which sectors is more cost-effective to invest, the health benefits (avoided costs) from the investments and the main pollution control options for both pollutants, proving to be a useful tool that contributes to cost-effectively solve the problem of reducing pollutant concentration in the atmosphere (Relvas et al., 2017).

Cost-effectiveness can be used to evaluate the expected impacts of alternative policy measures before they are implemented (ex-ante) or to assess the effectiveness of a measure that is already implemented (ex-post) (Görlach et al., 2005).

An ex-ante CEA is performed when the goals of the public policy have been pinpointed, being the objective to identify the least-cost alternative to achieve those objectives (Görlach et al., 2005).

Ex-ante cost-effectiveness assessment is based on assumptions and projections as well as on the cost and effectiveness data from different contexts, in order to help decision makers identifying the most cost-effective actions and to anticipate the impacts of future measures (Görlach, 2004).

Some studies analyse the least-cost measures to achieve targets of a single pollutant (Cofala et al., 2004) or to achieve targets for multiple pollutants (West et al, 2004). Some models have been used to support the performance of ex-ante studies, as for example RAINS-Asia (Regional Air Pollution Information and Simulation) (Cofala et al., 2004), OPERA (Optimal Integrated Emission Reduction Alternatives) (Liao & Hou, 2015), USIAM (Urban Scale Integrated Assessment Model) (Mediavilla-Sahagún & ApSimon, 2003) and OPF (Optimal Power Flow) model (Sun et al., 2012).

RAINS-Asia calculates the costs of the emission control for each source through technology-specific and country-specific cost parameters of individual technology (Cofala et al., 2004). In case of OPERA it is associated with AirControlNet model to calculate the emission control costs associated with the amount of reduction of different species for different regions (Liao & Hou, 2015). For USIAM, all strategies associated with their effects as well as the cost are taken from "Emission Reduction Strategies Database" (ERSD) (Mediavilla-Sahagún & ApSimon, 2003). OPF model was used by Sun et al. (2012). to study the cost-effectiveness of controlling emissions of ozone precursors in days when ozone concentrations are highest, achieving the strict targets for ground level ozone concentrations. Different price scenarios were created and the costs were calculated by the change in variable cost of electricity generations, relative to a base case (Sun et al., 2012).

An ex-post CEA evaluates the extension of the achievement of the objectives and their costs (Görlach et al., 2005). Ex-post cost-effectiveness provides a measure of the efficiency of policy implementation. This may be reached in different ways, as for example, comparing actions taken by others that would be taken in alternative, or analysing if the targets were reached at the projected costs, assessing if the effectiveness of the measures were the same as the projected before the implementation (Görlach, 2004). The studies realized by van Harmelen (2002) and by Cheng et al (2015) are examples of ex-post CEA. The first one used TIMER model to access to what extent the effectiveness of future or already implemented policies to reduce air pollution in Europe will be changed (or vice versa) (van Harmelen et al., 2002) and the second uses Computable General Equilibrium (CGE) model to evaluate the effectiveness of implemented carbon cap and Emission trading Scheme (ETC) policies (Cheng et al., 2015). TIMER has an emission reduction model incorporated (ERM) that ranks the reduction options and potentials into a marginal reduction curve, making it possible to implement an ex-post CEA by allowing the calculation of the effects of applying an emission tax (van Harmelen et al., 2002). CGE projects the trajectory of CO_2 and air pollutants under business as usual and policy scenarios, allowing the evaluation of implemented policies (Cheng et al., 2015). Both studies showed that the implemented policies have positive results on mitigation and reduction costs (van Harmelen et al., 2002) as well as reducing energy and carbon intensity (Cheng et al., 2015). Van Harmelen et al. (2002) also conclude that, in order to achieve long term goals, additional policies or strategies need to be implemented in the future.

Pursuing co-benefits of implementing some plans (Zhang et al., 2013) for air quality improvement strategies (West et al., 2004), improving energy efficiency (Zhang et al., 2015) or the co-benefits of reducing certain pollutants (Dong et al., 2015) are strategies to cost-effectively achieve different problems simultaneously.

To access the co-benefits of two plans (Local Air Particulate Matter plan and Greenhouse Gas control plan) in a coal-fired power industry, the Ambient Least Cost Model (ALC) was used (Zhang et al., 2013). West et al. used a linear programming approach to study the co-benefits of PROAIR (air quality plan for Mexico City) (West et al., 2004). GAINS model, in combination with energy conservation supply curves, was used to study the co-benefits of energy savings on CO_2 and air pollutants emission, in order to implement co-control options of energy efficiency measures (Zhang et al., 2015). GAINS was also combined with AIM/CGE (Asia–Pacific Integrated Assessment Model/Computational General Equilibrium) to calculate the co-benefits of improving energy efficiency and reducing emission of CO_2 and air pollutants (Dong et al., 2015). All the studies showed that all the options that bring co-benefits can reduce substantially the costs of control measures, so that, evaluating co-benefits can be a strategy to find cost-effective solutions.

GAINS can estimate current and future emissions through data bases and uncontrolled emission factor and removal efficiency of emission control measures. This way, it is possible to capture critical differences between countries that can justify different emission control requirements in a cost-effective strategy. GAINS have important data bases for all European countries which allows it to reproduce national reported emissions with large accuracy. In order to assess atmospheric dispersion GAINS has integrated the Unified EMEP (Eulerian

Model) which describes the fate of emissions in the atmosphere, considering more than one hundred chemical reactions involving 70 chemical species (Amann et al., 2011).

The main advantage of cost-effectiveness assessment is that it is very useful to select and evaluate measures, constituting an important input for the decision-making process. Calculating the cost of a measure is generally easier than calculate its benefits so that, cost-effectiveness assessment is considered, for a lot of economists, easier to perform than cost-benefit assessment (Görlach, 2004).

Although it is considered really useful, CEA has also some disadvantages. In cases where the costs of a measure/scenario are experienced in later periods, it is hard to define the discount rate (used to discount cost and benefits over time), mainly if the same measure has more than one target objective. Other disadvantage associated with this economic approach is the fact that as it is not possible to convert benefits into common unit measures, it is impossible to compare situations with different benefit streams. Therefore when one or more measure provide a significant co-benefit it is advisable to proceed to a cost-benefit assessment (Görlach, 2004).

2.2. Cost-benefit assessment studies

Cost-benefit assessment (CBA) is carried out in order to compare the economic efficiency implications of different alternative measures (Sonawane, et al 2012; Schrooten et al., 2006).

CBA is an economic evaluation in which all the costs of a certain decision are expressed in the same units, usually monetary. The costs can be presented in terms of exact values or, as ranges where extremes represent plausible assumptions based on available data as Li and Patiño-Echeverri (2017) did to evaluate benefits and costs of 5 policies.

With cost-benefit analysis it is possible to determine if an investment represents an efficient use of the resources or not. This tool supports decision makers in objective evaluations by providing relevant information about the level and distribution of benefits and costs of a project (Reniers, G., 2016).

In the context of air pollution, there are some examples of cost benefit analysis to find out strategies to reduce pollutants emissions (Schrooten et al., 2006), to improve air quality (Sonawane et al., 2012) and to evaluate benefits that air quality improvements can bring and facilitate the identification of measures and scenarios that provide major positive gains (Silveira et al., 2015). Cost-benefit assessment may link the emissions reduction costs with the benefits that this reduction can bring. The association of costs and benefits in monetary terms, allows CBA to assess if a policy measure is worth to be implemented (Görlach et al., 2005).

Cost and benefit assessment should consider the following properties: time (prospective and retrospective), pollutant (single or multiple) and scale (urban, regional or national).

To evaluate the relationship between pollution and time it is possible to do a prospective analysis including “non-control” scenarios, where the impacts are based on real levels of air pollution, the benefits are the expenses for pollution control equipment that industries are not paying and the costs consist of the value of actual medical expenses that society is paying while exposing to pollution. It is also possible to include “control” scenarios where impacts are hypothetical future clean air, benefits are the value of potential medical expenses that society will not pay if not exposed to pollution, and the costs are the expenses industries will have to pay in the future for pollution control equipment (Voorhees et al., 2001).

In a retrospective analysis, the impacts are based on air pollution that was prevented by air pollution control policies in the past, the benefits consist on the value of those potential medical expenses that society did not pay because it was not exposed to pollution and the costs consist of the actual expenditures for pollution control equipment that industry paid. This kind of assessment is also very affected by the choice of assumptions and inputs, what influences the valuation of benefits and costs, however, if consistent data and right assumptions are made, doing a cost-effective assessment may perform several valuable functions evaluating environmental policies (Voorhees et al., 2001).

The use of some tools makes the process of cost-benefit evaluation easier. MERGE model is an example of a tool that allow the simulations of the costs for different greenhouse gases emission reduction abatement policies (Bollen et al, 2009; Bollen et al., 2010). MERGE, being a model developed to study the interaction between global economy, energy use and impacts of climate change, allows the cost benefit analysis of different policies in order access the benefits that they bring by being implemented together that were not possible if they were implemented separately. Bollen et al. expanded MERGE to quantify damages of regional economy that happens as a result of air pollution (2009) and lack of energy security (Bollen et al., 2010). With the application of MERGE model, it was possible to conclude that combining climate change, air pollution and energy security policies brings multiple benefits and the study of synergies between these policies brings large gains. So that, this tool showed that it can be useful for decision making because it brings the possibility of assessing different policies and the interactions between them that, with another tool would be impossible (Bollen et al, 2009; Bollen et al., 2010).

CBA can also be used to evaluate policies supporting air quality planning. In China, Gao et al., used a CBA to evaluate industrial energy-saving and emission-reduction policies in their Air Pollution Prevention and Control Plan (Gao et al., 2016) and Porto Litoral was used as a case study to the development, implementation and testing of an integrated assessment model MAPLIA to evaluate designed measures in a cost-benefit way (Miranda et al., 2016a).

The first case focused on the calculation of the cost to society of abating emissions of different pollutants. The costs of energy saving (ES) and emission reductions (ER) policies, coming from eliminating small coal-fired boilers and backward productivity and from mitigation of different pollutants, respectively, were calculated. The benefits of both polices includes health and crop benefits resultant from emission reduction. This study proved to be useful once it was possible to conclude the viability of ES-ER policy. As the present value calculated was higher than the present cost, is was proved that ES-ER policy should be continued (Gao et al., 2016).

In the second case two different integrated assessment systems were applied, the RIAT+ and the MAPLIA (Moving from Air Pollution to local Integrated Assessment). RIAT+ was chose by its ability to solve a multi objective problem, although, it is not prepared to direct include local abatement measures. So that, MAPLIA system, developed to support air quality planning and based on scenario analysis where different measures/strategies are identified and translated into their impacts on air quality quantified using modelling tools, was chosen. After selecting the models, it was necessary to collect some input information such as, emission inventory, emission projections, age distribution of the population, health indicators, source-receptor links and reduction measures and related costs. With RIAT+ model it was possible to identify what type of technical measures should be considered to air quality improvement at optimal cost-benefit. The scenario approach in the MAPLIA system allows the evaluation of technical and non-technical measures in terms of costs, emissions, air quality, health impacts and associated external benefits. This study allowed the comparison between different abatement scenarios, permitting the selection of the most benefit measures at the lowest cost of investment and operation. MAPLIA added cost-benefit analysis to Air Quality Plans, that is rare to find although it is essential for decision-making process (Miranda et al., 2016a).

Although CBA is a great tool to evaluate economic efficiency and the ability of relate the benefits with the costs is useful to decision makers, it has some disadvantages. Besides the efficiency, it is needed to consider economic utility and equity. The utility will depend on what each individual considers a benefit and equity requires balance interests between “losers” and “gainers”. Also, he benefits identification sometimes has some limitations as not every pollution effect is amenable to market valuation. Ecosystem health, for example, typically does not have a market value since it is hard to link people’s behaviour to any preference for a healthy or unhealthy environmental system. The impacts must be transformed and stated in monetary terms, what is very difficult once many environmental resources cannot be converted into monetary values. This is not a good analysis to do in small-scale projects (Jain et al., 2012, Rao et al., 2017). Other criticism regarding benefit cost analysis is related to the practice of discounting benefits and costs that occur in the future, being considered inappropriate, by some that do not find proper to compare harm to the welfare of the current generation to the future one (Verchick, 2005).

2.3 Cost-Efficiency assessment studies

Cost-efficiency assessment aims to identify scenarios that provide the largest net welfare gains, quantifying proposals for system optimization in terms of costs and, thus, making it possible to verify the impact of measures on the cost of system implementation/maintenance

(Perman et al., 2011). Indeed, this methodology combines the effects of numerous emission abatement measures on the air quality, and potential human health and economic impacts associated with the implementation of measures.

Pollution targets can be set using an efficiency criterion. It is natural to think that zero level of pollution is desirable, however, besides the fact that reduction of pollution have economic impacts, pollution may also be inevitable. Emissions reductions are an expensive process that could lead to an economic crisis, if the reductions are not well evaluated. Pollution may be inevitable as, without pollution, it may be impossible to produce some useful goods and services (Perman et al., 2011). Hence, cost-efficiency assessment is needed not only to justify the necessity for the reductions but also to identify where and to what extent the reductions have to be done (Zlatev, 1995; McRae et al, 1982).

Some tools or strategies can be used, in order to perform cost-efficiency assessment studies. Marginal benefit (MB) curves are an example of a measure to cost-efficiency analysis of air quality, where the CEA relies in the calculation of the cost per ton of emission reduction (marginal abatement cost). When MB equals the marginal cost (MC), it represents the highest net social benefit of a given policy. If the abatement level is lower than this equilibrium (MB=MC) further control of emissions is encouraged since the benefit exceed the cost, the opposite happens when the abatement level is higher than the equilibrium because rising costs are no longer permitted and compensated by the expected returns. This tool is really useful for CEA since it quickly estimates the rate-of-return of potential investment made in emissions abatement (Pappin et al., 2015).

As other economic approaches, cost-efficiency assessments are complex so that a lot of different studies including different models (Carnevale et al. 2009; Miranda et al., 2016; Shaban et al., 1997) and strategies (Budh, 2007) were applied.

Models as Mixed Integer Linear programming model (MILP) (Shaban et al., 1997) is an example of a model that can be applied to air pollution decision making support by selecting the best combination of measures to reduce the emissions to a certain level. It allows a comparison of emissions under different emission reduction scenarios. With MILP it is possible to select sources of pollution and associate several control options (for each option the cost and the reduction capability are identified) and technologies (including new and retrofit emission control devices and revised operating procedures) for each source. The ability to select the best option among variable possible alternatives proves that this model is an excellent tool to perform cost-efficiency assessments (Shaban et al., 1997).

The complex dynamics caused by air pollution are represented by equally complex physically distributed models that compute pollution levels. The performance of these models are, however, very time consuming as their output must be post-processed to obtain suitable values that are assumed to be linked to the original air quality problem and due to the fact that these models can only assess the effect of a given pollutant reduction measure but not the opposite problem (e.g. find the right measures that can achieve a specific reduction target). Hence, these models are surrogate to more efficient ones. Carnevale et al.

(2012) used Northern Italy as a case study to identify air quality models able to describe relation between emissions and air quality indices. Secondary pollutants vary from interactions between precursor emissions, so that Carnevale et al. (2012) identified neuro networks to link emission reduction scenarios and air quality indicators, through deterministic model simulations. These models proved to be useful to solve multi-objective efficiency problems that, as require thousands of model runs, would be impossible with the original processed-base models (Carnevale et al, 2012).

It is also common to see cost-efficiency studies applied into the development of air quality planning. Carnevale et al. (2014). identified source–receptor statistical models (neural network and neuro-fuzzy) to help in the development of efficient air quality plans.

Carnevale’s tool allows the assessment of the impact of emission reduction strategies on pollution indexes and the costs of that emission reduction. Neural network (composed by simple connected element characterized through a function relating inputs and outputs operating in parallel) and neuro-fuzzy (use neural networks to tune the membership functions of a fuzzy system and to extract fuzzy rules from numerical data) models are applied once it is not reasonable to apply 3D multi-phase modelling systems to identify the relationship precursor-pollutant due to its very time consuming performance. There are some important outcomes that can be taken from this study. First, it was showed that neural network and neuro-fuzzy models can estimate nonlinear source-receptor relationships between precursor emission and pollutant concentration. Then it was proved that these models are able to solve multi-objective air quality control problems and that they can reproduce simulations of the deterministic model for ozone and PM10 (related with the case study applied) with big accuracy. Moreover, the to quickly performance and evaluation of quality index makes these models vert useful to select efficient emission control strategies (Carnevale et al., 2009; Carnevale et al., 2014).

Miranda et al (2016b), applied RIAT+ (Regional Integrated Assessment Tool Plus) model into two different regions, Brussels in Belgium and Porto in Portugal. In the study, a scenario approach was used in Brussels and an optimization approach in Porto, having both the use of RIAT+ IA system as base. This study showed that there are tools which can be applied in an IA of air quality that, besides taking into consideration the compliance of concentration to limit values, also consider the internal and external costs of different available abatement options (Miranda et al., 2016b)

Predicting the impact of some control strategies or options can be seen, as well, as a cost-efficiency assessment. Budh (2007), tried to understand if integrated control strategies for multiple emissions had an impact on the environmental policy. Hence, he calculated marginal abatement costs for five main emissions using a separate and an integrated version of the deterministic linear programming model. In the case study referred in the study, there were no big efficiency benefits of integrating control strategies once the measures that are important for the reduction of some pollutant are not important to other emissions. Nevertheless, as this approach helped easily to understand optimization impacts of some policies or measures, it showed to be a useful approach that can be applied to cost efficiency studies (Budh, 2007).

Cost-efficient models are complex demanding big and detailed input data (meteorological and emission data) and description of all relevant physical and chemical processed (Dimov & Zlatev, 2002).

Although cost-efficiency assessment performance is considered useful and is applied in many studies, as shown in the section, it has some disadvantages and criticism associated. A cost-efficiency assessment attempts to put monetary values on the benefits resultant from the activities, and compares these values with the costs from the activities and calculates the internal rate of return that equalizes the present value of benefits and costs. A disadvantage that comes from this, is that putting a monetary value on the outputs is complex and sometimes based on controversial assumptions that can lead to mistakes. Another criticism that is associated to cost-efficiency assessments is that it may be restrictive. First because if there is limited or imperfect information it will be difficult to find economically efficient targets. Second, economy is not the only thing that matters to policy makers as they are likely to have multiple objectives. These objectives may be health, equality or sustainability. The fact that cost-efficiency models must be defined on large space domains due to long range transport of air pollution, and the fact that air pollution is not confined where the high emissions sources are, it can also be considered as a disadvantage. (Miranda et al., 2016b)

3. Methodology

This section provides the description of the methodology used, which integrates national EMEP emissions data (Section 3.1), GAINS model (Section 3.2) and EESIP-Air model (Section 3.3; see Figure 2).

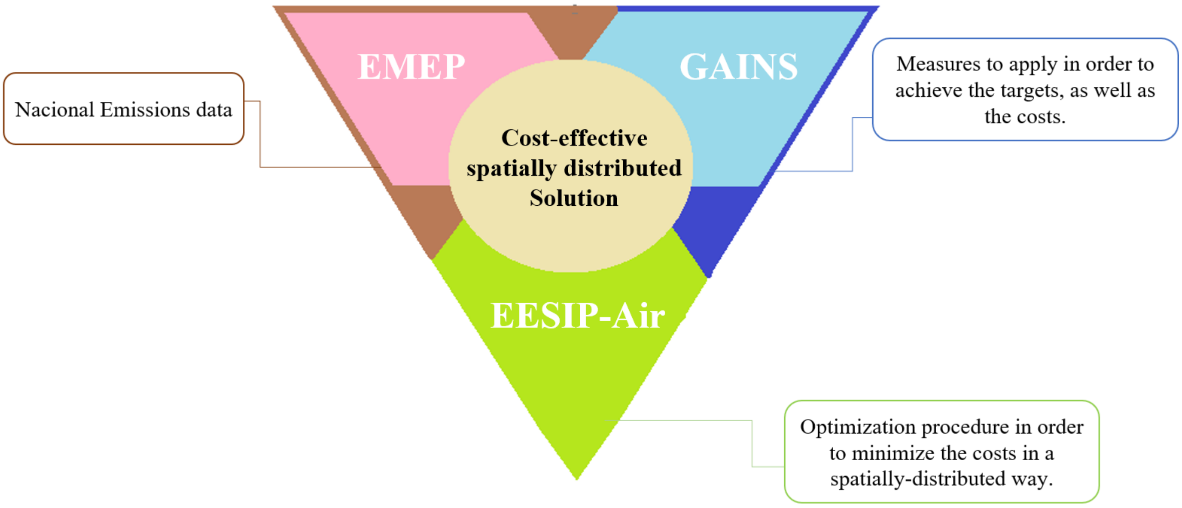

Figure 2: Schematic representation of the components of the methodology.

In order to find out measures to meet air pollution reduction targets, it is necessary to have information on the emission levels as well as where those emissions happen. Since the European Monitoring and Evaluation Programme (EMEP) emissions inventory, give information of the emissions concerning their spatial distribution, this database was considered ideal to achieve the goals of this dissertation.

Since GAINS effectiveness approach has been successfully used to inform air pollution policy at the European and national level, GAINS model was carefully chosen to achieve the goals of this dissertation. This model allows the identification of the measures that achieve the Portuguese NEC targets at the lowest cost.

GAINS approach, however, is based on national total, not considering geographic specification of emission sources making the measures provided not spatial distributed, but generic. Hence, this model is not enough to reach this dissertations' goals, being necessary the complementation with another tool (EESP-Air model).

EESIP model was selected since it proved to be effective in water quality management (Roebeling et al., 2009), so that, it was considered that, with some adjustments this model would be suitable to be used for air simulations. Therefore, the use of sector, technology and activity data from GAINS as well as the EMEP spatially distributed emissions data as inputs in EESIP-Air, allowed to understand in which part of the country the reductions should be more significant, in order to achieve the targets at the lowest cost.

3.1 National Emissions

The emissions' data used in this dissertation was taken from the European Monitoring and Evaluation Programme (EMEP) emissions inventory. EMEP aims to monitor and evaluate the Long-range Transboundary Air Pollution (LRTAP), providing Governments and subsidiary bodies with qualified scientific information to support the development and further evaluation of the international protocols on emissions reductions (negotiated within the LRTAP Convention).

As a party to the United Nations Economic Commission for Europe (UNECE) LRTAP convention and in order to comply with National Emissions Ceiling Directive, each year Portugal needs to provide and update the emissions.

The national inventory estimates emissions for each civil year and includes the pollutants Carbon Monoxide (CO), Nitrogen Oxides (NOx), Non-methane Volatile Organic Compounds (NMVOC), Sulphur Oxides (SOx), Ammonia (NH_3), particulate matter (TSP, PM10, PM2.5 and BC), Heavy Metals (HM) and persistent organic pollutants (POP).

Emissions are estimated and reported for the following source sectors: energy production and transformation, combustion in industry, domestic, agriculture, fisheries, institutional and commerce sectors, transportation (road, rail, maritime and air), industrial production and industrial and non-industrial use of solvents, waste production (urban, industrial and hospitals solid wastes, and domestic and industrial waste water treatment), agriculture and animal husbandry emissions as well as emissions from coverage.

In Portugal, this inventory is coordinated by APA (Portuguese Environmental Agency), which has the responsibility of making an annual compilation of the Portuguese Inventory of air pollutant emission. This includes GHGs and sinks, acidifying substances and other pollutants.

This report has to obey to all national and international legal developments, so that a national inventory system was created (SNIERPA: Sistema Nacional de Inventário de Emissões por Fontes e Remoções por Sumidouros de Poluentes Atmosféricos). This system covers the estimation of emissions by sources and removals by sinks of air pollutants making the process of inventory planning, implementation and management more cost-effective.

In order to achieve NEC Directive requirements, each year, Member States must report to the Commission and the EEA, the emissions totals for Sulphur Dioxide (SO_2), NOx, NMVOC, PM2.5, NH_3 and other pollutants, as well as emissions projections, gridded data and large point source data, for which the EU is required to report to the LRTAP Convention.

3.2 GAINS emission reduction technologies and costs

The GAINS model allows, as discussed in Chapter 2, the simulation of costs, health and ecosystems benefits of abatement measures, the cost-effectiveness assessment to select least-cost packages that achieve predefined targets and the cost-benefit assessment to analyse the net benefits of policy interventions at the country scale (IIASA, 2014).

The GAINS database contains detailed information on sector activity levels and technology application rates as well as corresponding emissions and technology application costs. Hence, the GAINS database contains three main components: sectors, activities and technologies. The complete list of sectors, activities and technologies presented in GAINS can be found in Annex 1, Annex 2 and Annex 3, respectively.

A sector represents an economy area in which businesses share the same or related product/service, and can be divided into several subsectors. For example, the Fuel conversion (CON) sector includes on-site consumption of fuel and energy in coal mines, refineries, coke and briquette plants and gasification plants, own use of electricity and heat in the power and district heating sector and, finally, transmission and distribution losses for electricity, heat and gas. The sector CON is divided into fuel used in combustion process (CON_COMB) and own use and losses that occur without combustion (CON_LOSS). The sub-sector CON_COMB covers fuel combustion in furnaces used in the energy sector. The sub-sector CON_LOSS includes losses in the transmission and distribution to the final consumer. All sectors and subsectors are, from now on, only denominated as “sectors”, for the sake of ease

Each sector is associated with different activities. The activities correspond to the different actions or components necessary for the good functioning of the sector in which they operate. For instance, sector CON_COMB needs different fuels to operate so that, it can be associated with different combustion activities as: GAS (Gaseous Fuel), HF (Heavy Fuel Oil), LPG (Liquefied petroleum gas) and MD (Diesel).

Finally, each activity is associated with several technologies (abatement measures for different pollutants). In particular, activity HF in sector CON_COMB, can be associated with technologies GHIND (good housekeeping: industrial oil boilers), IOGCM (combustion modification on oil and gas industrial boilers and furnaces), LSHF (Low sulphur fuel oil: 0.6 % Sulphur) and NOC (no control).

The GAINS database includes information about activity level (e.g. PJ in the CON sector), emission factor (i.e. pollutant emission per unit of activity) and technology implementation (i.e. percentage of technology implemented in a certain activity) essential to calculate emission levels and emission reduction costs. GAINS calculates the emissions of each pollutant taking into account the activity level of type k (eg. Coal consumption in power plants) in a given sector s in country i ($A_{i,k}$), the emission factor $ef_{i,k,m,p}$ (usually expressed as the weight/volume/distance/duration of the activity emitting the pollutant) and the share of total activity of type k in country i to which a control measure m for pollutant p is applied ($X_{i,k,m,p}$). In GAINS emissions E per country i and pollutant p is calculated for each activity type k and abatement measure m, as follows:

$$E_{i,p} = \sum_k \sum_m A_{i,k}\, ef_{i,k,m,p}\, X_{i,k,m,p} \qquad \text{Equation 1}$$

GAINS calculates the cost of application of each measure, taking into account annualised investments (I^{an}), variable (OM^{var}) and (OM^{fix}) operating costs and how they depend on technology, country and activity type. Abatement costs AC per country i, activity type k and abatement measure m, related to one unit of activity level A, are calculated as follows:

$$\mathrm{AC}_{i,\mathrm{k,m}} = \frac{I^{an}{}_{i,\mathrm{k,m}} + OM^{fix}{}_{i,\mathrm{k,m}}}{A_{i,\mathrm{k},}} + OM^{var}{}_{i,\mathrm{k,m}} \qquad \text{Equation 2}$$

3.3 EESIP-Air

EESIP (Economic Spatial Investment Prioritisation) is a model used, in its original form, to the cost-effective evaluation of water quality management in linked terrestrial and marine ecosystems. In the scope of FUTURAR project, this model was adapted to air (EESIP-Air) in order to be suitable to perform the work proposed to attain the objectives of the current dissertation

EESIP includes three main models that share the same database containing both geographical and non-geographical references data and information. These models are: an agricultural production system simulation model, a catchment quality model and a spatial environmental-economic land use model (Roebeling et al., 2009). The agricultural production system simulation model evaluates, for a large range of agricultural and use and management practices, the plot-level production and the water pollution characteristics. The catchment quality model evaluates the relation between local water pollution supply and end-of-catchment water pollution delivery. The spatial environmental economic land use model allocates agricultural land use and management practices in a way that they contribute more to the regional agricultural income, given specific targets of water pollution for the end-of-catchment.

In order to reach the objective, the EESIP-Air was applied to the case of Portugal, within a spatial grid of 5 by 5 km^2 cells, considering the current and projected air pollutant emissions of the country in the scope of the implementation of the National Emission Ceilings Directive (NECD).

EESIP-Air uses EMEP spatially distributed data and sector, activity and technology data from GAINS as an input. This way, it is able to find out the regions of Portugal for which the application of the technologies suggested by GAINS should be more significative, in order to achieve the NEC targets at the lowest cost.

The objective of EESIP-Air is to find out, for each grid cell (re), SNAP (sn, described and explained later), sector (se), activity (ac) and measure (m), the solutions that allow the achievement of the targets at lowest cost, which depend on the cost of each measure ($\mathrm{c}_{\mathrm{sn,se,ac,m}}$) and on the activity level ($\mathrm{A}_{\mathrm{re,sn,se,ac,m}}$). This goal is achieved as follows:

$$Obj = \underset{\mathrm{A}}{\mathrm{Min}} \sum\nolimits_{\mathrm{re,sn,se,ac,m}} \mathrm{c}_{\mathrm{sn,se,ac,m}} * \mathrm{A}_{\mathrm{re,sn,se,ac,m}} \quad \text{Equation 3}$$

Since EESIP-Air aims to find out spatially distributed solutions that achieve the NEC targets, some constraints regarding it, need to be imposed. So that, it consider the activity level for Portugal ($[a_{re,sn,se,ac}]_{PT}$) (Equation 4) and implies that the emissions (which depend on the emissions of each technology, $e_{sn,se,ac,t}$, per activity level $A_{re,sn,se,ac,t}$) are always equal or lower than the emissions ceiling imposed for Portugal, $[ec]_{PT}$, (Equation 5).

$$\sum\nolimits_{m} A_{re,sn,se,ac,m} = [a_{re,sn,se,ac}]_{PT} \quad \text{Equation 4}$$

$$\sum\nolimits_{re,sn,se,ac,m} e_{sn,se,ac,m} * A_{re,sn,se,ac,m} \le [ec]_{PT} \quad \text{Equation 5}$$

With these impositions, the model will deliver spatial detailed information, allowing to identify in which areas of the country the application of the abatement measures should be more incident in order to achieve the ceiling at the lowest cost.

4. Case study description

The objective of this dissertation is driven by the NECD requirements for Portugal, and thus Portugal is the case study to investigate to what extent current and projected air pollutant emissions will allow to reach the emission targets. To frame the topic, the first section of this chapter includes a brief review on air pollution legislation in order to better understand how it developed over the years as well as how it is organized.

Having clear the idea that Portugal has legislation constraints relative to emissions, it is essential to understand to what extent Portugal has been fulfilling its legal obligations. Indeed, section 4.2 focused on the emission inventory as well as its compliance or not, with the emission ceilings, in the last years.

4.1 Air pollution legislation

Regarding air quality legislation, an intensive reading of published directives and papers was done. It was essential to select the relevant documents for this study, and to organize the information in a simple and informative way. Hence, the topic of legislation was divided into air quality directives, source-specific emission standards and national emission ceilings.

Legislation is an important tool for the control of environmental hazards to environment and health protection. After recognising the importance of air pollution due to its impacts, it was imperative that air quality legislation needed to be implemented. The European Union has been working hard over the last decades to control air pollution. EU's clean air policy is based on ambient quality standards, source-specific emission standards and national emissions reductions targets.

Regarding air quality legislation, in September of 1996, the first Air Quality Framework Directive 96/62/CE was published, concerning the environmental quality assessment management. In this directive the main goals were to define and stablish targets to air quality among the community, evaluate the environmental air quality of the member states, being aware of air quality performances and inform the population about it by stablishing alert values and keep environmental air quality or upgrade it when necessary (EC, 1996). This directive was replaced by the most recent one, the Directive 2008/50/EC (EC, 2008). This directive was so published based on the Framework Directive and in other previously existing legal documents, introducing new concepts, simplifying and reorganising guidelines and being transposed to the national Portuguese Law by the Decreto-Lei 102/2010, de 23 de Setembro (Ministério do Ambiente e do Ordenamento do Território, 2010) This new directive added to the previous goals, the goal of promoting a bigger cooperation among the member states (MS) in order to reduce the atmospheric pollution. So that, not only limit values for atmospheric pollutants concentration are recognised but also politics for the exchanging the information and data among MS are established (*EC, 2008)*. The directives require MS to establish and implement air quality programs and comply with the standards in order to protect human health and the environment. The directives are currently under revision by EC in a 2-year process (that begun in 2017) in order to examine their performance.

In what concerns the regulation on atmospheric emissions, source-specific emission standards specify emission and energy efficiency standards for key sources of air pollution from vehicles emissions to products and industry. In this field there are several directives as Industrial Emission Directive (e.g. Directive 2010/75/EU), Medium Combusting Plants Directive (e.g. Directive 2015/2193/EU), Eco-design Directive (e.g. Directive 2008/50/EC), Energy Efficiency Directive (e.g. Directive 2012/27/EU), and Euro and fuels standards Directive (e.g. Directive 2016/802/EU) (EEA, 2018).

National emission reduction targets are established in the National Emission Ceilings Directive (NEC). In 2001, the European Commission adopted the first NEC directive 2001/81/EC. NEC were created in order to limit the negative environmental impacts of acidification, eutrophication and ground-level ozone, establishing for each European MS for 2010 a cap on emissions of SO_2, NOx, NMVOC and NH_3 (*EC,2001*).

It was necessary to review and update the annual emission ceilings set by NEC Directive, once the levels of air pollution remain a problem in Europe. For this purpose, the Commission published the clean air programme for Europe in December 2013. This programme includes the proposal for a new NEC Directive, that was published later, and a ratification of the amended Gothenburg Protocol.

The new NEC Directive 2016/2284/EU, from 2016, establishes stricter targets for the EU and MS committed to achieve defined ceilings. This legislation sets the 2020 and 2030 limit values of the main five pollutants NOx, SO_2, VOC and NH_3, adding as well PM2.5 to what was previously defined (EC,2016).

The NEC Directive was transposed into the Portuguese national legislation by the Decreto-Lei n°193/2003 from 22 August (*Ministério Das Cidades, Ordenamento Do Território e Ambiente, 2003*). Until 2010 Portugal had, as ceilings, 250 Kton for NOx; 180 Kton for NMOVC, 160 Kton for SO_2 and 90 Kton for NH_3. Regarding NMOC, the emissions trends shown an accomplishment of 2010 ceilings. The decrease of NMOVC emissions was not enough to accomplish the 2010 emissions ceiling, being it only fulfilled one year later.

Portuguese emissions trends did not follow the European reduction rates, which means that an effort is still needed to reduce the emissions of these pollutants.

The new Directive on national emission ceilings (NECD) published in December of 2016, updates the national emission ceilings as a percentage reduction in relation to the 2005 emissions by 2030. Portugal must decline the emission of SO_2 in 83%, of NO_x in 63%, of PM2.5 in 53%, of NH_3 in 15% and NMVOC in 38% (EC, 2016).

Although, in general, Portugal has been reducing its total emissions, it is still facing air pollution problems, mainly in urban areas. Consequently, it is imperative to access national emissions having in consideration the spatial variability in order to, not only achieve the NECD commitments, but also fulfil the air quality objectives/standards (Ferreira et al., 2017).

4.2 Portuguese achievements and pathway

In order to understand how to reduce the future emissions, it is important to analyse the pathway of the country concerning the emissions and the compliance with the imposed targets.

In this point, it is analysed the evolution of the national emission data as well as the annual and source contributions (by SNAP sector) reported for Portugal in the scope of NEC Directive regarding the addressed pollutants: NOx, NMVOC, SO_2, NH_3 and PM2.5 for the period of 1990-2015 (Agência Portuguesa do Ambiente (APA), 2017). The Figure *3* represents the total annual emissions of NOx, NMVOC, SO_2, NH_3 and PM2.5 since 1990 until 2015.

Regarding the first NEC targets compliance, as referred before, the ceilings for Portugal, for the year of 2010 for NOx, NMVOC, SO_2 and NH_3 were 250 kt, 180 kt, 160 kt and 90 kt, respectively. All ceilings were achieved with exception of NMVOC (only achieved the targets one year later).

The new NEC commitments for 2030 set that Portugal must reduce the emissions of NOx, NMVOC, SO_2, NH_3 and PM2.5 in 68%, 38%, 83%, 15% and 53%, respectively, related to the year of 2005, as it is possible to analyse in Table *1*. The emissions for the year of 2005 are updated every year and consequently the ceiling for each pollutant. In this study, the emissions for 2005 submitted in 2017 were considered (APA, 2017).

The Figure *3* represents the historic of emissions for Portugal (2005-2015) for NOx, NMVOC, SO_2, PM2.5 and NH_3.

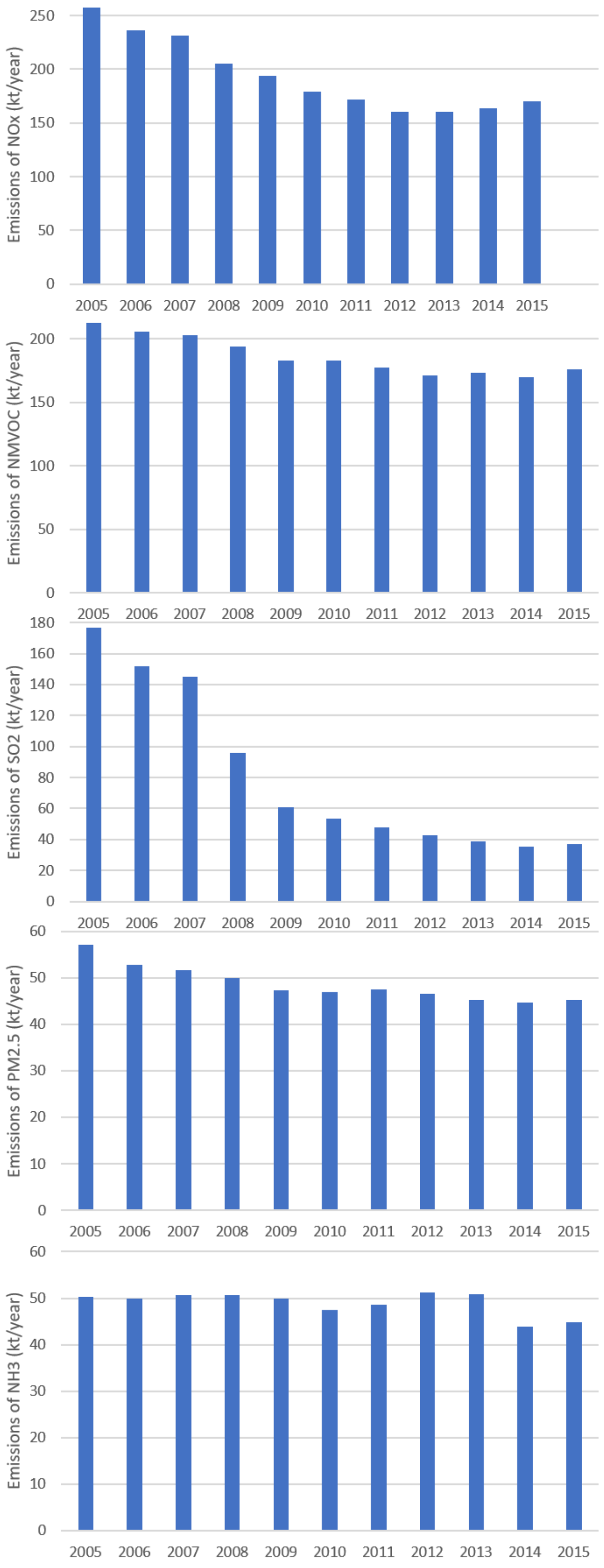

Figure 3: Annual emission totals (kt/year) in Portugal for the period 2005 - 2015 for NO_x, NMVOC, SO_2, PM2.5 and NH_3.

Table 1: Emissions and commitments for Portugal.

	NOx	**NMVOC**	**SO_2**	**NH_3**	**PM25**
Emissions in 2005 (kt/year)	257.3	212.5	176.5	50.3	57.1
Emissions in 2015 (kt/year)	170.4	176.1	37.2	44.9	45.2
Reduction until 2030 relative to 2005 emissions (%)	63	38	83	15	53
2030 ceiling (kt)	95.2	131.8	30.0	42.7	26.8

Trough Figure *3* it is possible to conclude that Portugal, in general, has been reducing its total emissions, although, as displayed in *Table 1*, to achieve 2030 targets, significant reductions need to be attained, and that is only possible if additional emission reduction measures are taken.

The contribution of the different activity sectors for the emissions of NOx, NMVOC, SO_2, NH_3 and PM2.5, reported for Portugal, in the scope of the NEC Directive, for the period of 1990-2015, was also analysed (Figure *4*, Figure *5*, Figure *6*, Figure *7*, Figure *8*). Through these figures it is possible to identify which pollutants are more important regarding each sector (SNAP classification) allowing a future association with the obtained results. SNAPS is the acronym for "Selected Nomenclature for Air Pollution" and the description of each SNAP is represented in Table *2* Description of each SNAP.

Table 2 Description of each SNAP

SNAP Code	SNAP Description
1	Combustion in the production and transformation of energy
2	Non-industrial combustion
3	Industrial combustion
4	Production Processes
5	Extraction and distribution of fossil fuels and geothermal energy
6	Use of solvents and other products
7	Road Transport
8	Other mobile sources and machinery
9	Waste treatment and disposal
10	Agriculture

An overall decrease on the emissions is reported. Although in the most recent years some pollutants face a slight increase, what may be associated with the economic recovery, after the crisis.

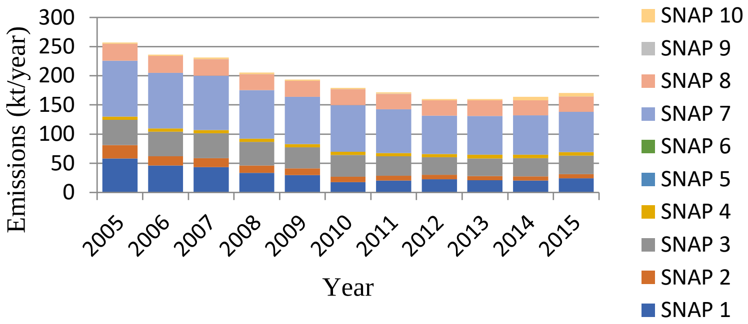

Figure 4: Annual emissions of $NO_x$and source contribution (by SNAP) for Portugal for the period 2005 - 2015.

It is possible to verify that Transport sector (SNAP 7) is the main source of NOx. Energy production (SNAP 1) although being a relevant source of NOx emissions, experiments a decline across the years.

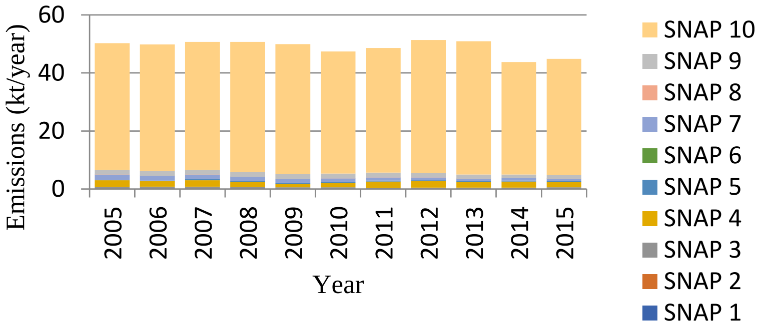

Figure 5: Annual emissions of NH_3 and source contribution (by SNAP) for Portugal, for the period 2005-2015.

Agriculture (SNAP 10) is the main source of NH3. The emissions associated with this SNAP do not exhibit drastic changes throughout the years, being verified a slightly decrease in the last years. This pollutant, among all, is the one that is closer to the 2030 target.

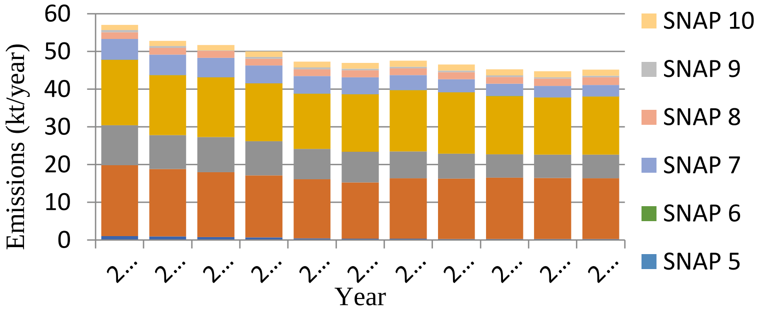

Figure 6: Annual emissions of PM2.5 and source contribution (by SNAP) for Portugal Portugal, for the period 2005-2015.

The main contributing sectors to PM2.5 emissions are non-Industrial Combustion Plants (SNAP 2) and Industrial Processes (SNAP 4) From 2005 to 2010 it is verified a constant decrease and in the most recent years, the emissions are practically constant.

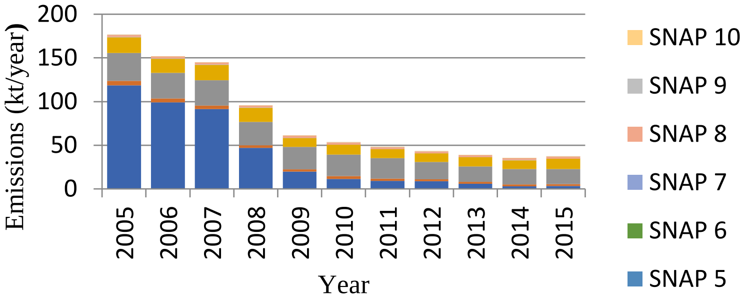

Figure 7: Annual emissions of SO_2 and source contribution (by SNAP) for Portugal Portugal, for the period 2005-2015.

SO_2 emissions faced a significant decrease related with the decrease on the energy production (SNAP 1). The contribution of this SNAP for the emissions of SO_2 is almost irrelevant in the recent years, appearing Industrial Combustion Plants and Industrial processes sectors (SNAP 3 and 4) as the main contributors currently.

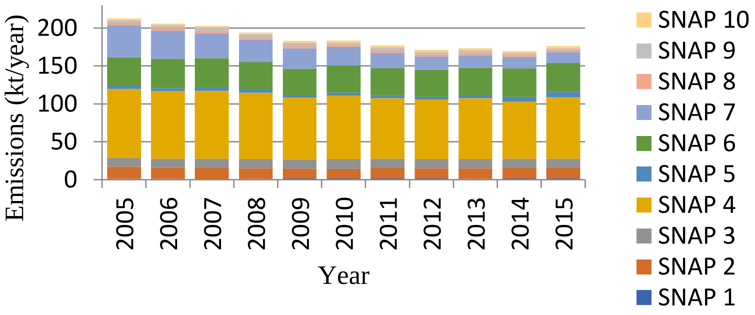

Figure 8: Annual emissions of NMVOC and source contribution (by SNAP) for Portugal Portugal, for the period 2005-2015.

The emissions of NMVOC have not drastically decreased, being the Industrial processes (SNAP 4) the main source of emissions. The share of emissions caused by transport (SNAP 7) sector suffer a decrease.

It is clear that SNAP 1, SNAP 2, SNAP 4, SNAP 7 and SNAP 10 have been the main sources of emissions in Portugal. Identifying the sectors that contributes to the emissions may be the key to reduce the emissions and achieve the targets.

4.3 Scenario simulations

The analysis of the Portuguese emission trends and their main sources allowed to better understand whether Portugal will be able to comply with the NEC targets for 2030 and if additional efforts to further reduce emissions are required. The GAINS model considers different scenarios for each Member State taking into account current emissions and future projections assuming the fulfilment of legislation in force up to 2030 (CLE- Current Legislation Emissions) and considering additional measures when CLE seems not enough to comply with NEC. This is the case of Portugal, as identified by Ferreira et al (2017). Hence, in this study the following three scenarios were considered:

- Current Legislation 2015 (CLE2015): the CLE2015 scenario is the baseline, which considers the implementation of existing air pollution control legislation in the EU in 2015;
- Current Legislation 2030 (CLE2030): the CLE2030 scenario considers the emissions projections for 2030, applying the legislation in force until that year; and
- Optimum 2030 (OPT2030): the OPT2030 scenario considers the additional emission reductions that need to be achieved beyond CLE2030 to meet emission targets for 2030 (set by the NECD) at least costs.

5. Results and discussion

This chapter presents and discusses the results obtained in this study. Firstly, in 5.1, information (activity level, emissions and cost) provided by GAINS on the cheapest technologies that allow the achievement of the NEC ceiling is presented by SNAP sector. Then, in 5.2, the spatially distributed results are presented for emissions and costs per SNAP sector over Portugal, to identify regions for which the effort on emission reduction should be bigger in order to achieve the target in a cost-effective way

5.1 Sector activity emissions and costs – National totals

In this section the results for the activity level, emissions and cost for CLE2015, CLE2030 and OPT2030, are presented and discussed by SNAP sector (Sections 5.1.1 to 5.1.11). Given the diversity of activities included in each SNAP, represented by different units, some considerations for graphical representation were made to simplify the reading and the analysis. This was particularly necessary for the SNAPS where the activity levels for a specific sector come from more than three activities with different units. For these cases (SNAP 4, 6 and 10) results were normalized by the calculation of an index that considered the scenario CLE2015 as 100%, and computed the variations of scenarios CLE2030 and OPT2030 in relation to the baseline scenario CLE2015.

In order to facilitate the representation of the figures, regarding the ones for which the results of emissions and costs are displayed the only sectors presented are those for which emissions and costs where registered, meaning, that if that sector is not represented in the figure it does not have associated any emission or cost (depending on the situation).

5.1.1 Combustion in the production and transformation of energy (SNAP 1)

SNAP1 is an important emissions source of NOx and SO_2 and thus the presentation, analysis and discussion of results for this SNAP are focused on those pollutants.

5.1.1.1 Activity Level

In *Figure* 9 the results of the activity level (in PJ/year) are presented for each sector and scenario, allowing to understand the evolution throughout the scenarios.

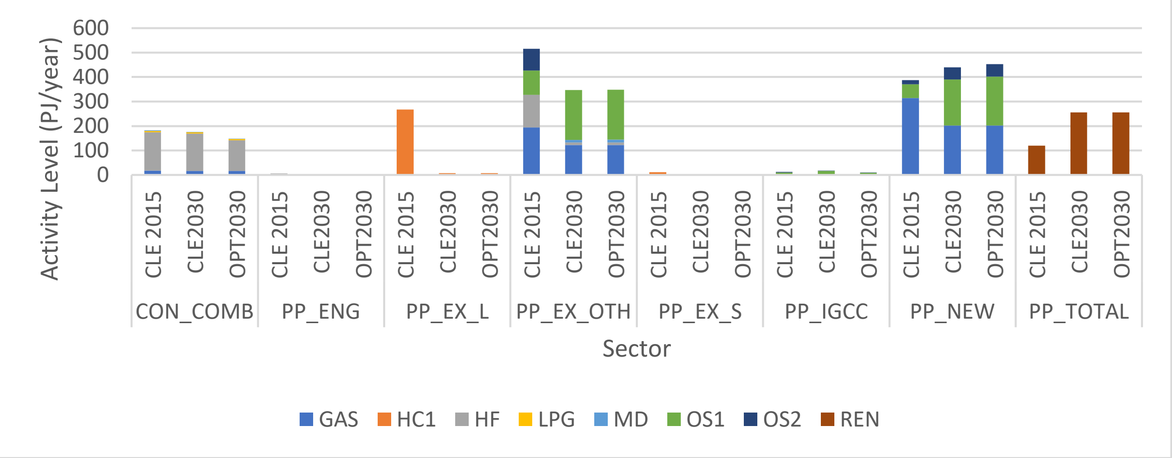

Figure 9: SNAP 1 activity levels (in PJ/year) per sector for CLE2015, CLE2030 and OPT2030.

Analysing the Figure 9, it can be observed that the most relevant sectors are combustion in fuel conversion (CON_COMB), existing coal power and district heat plants (>50 MWth) (PP_EX_L), existing power and district heat plants (excluding coal) (PP_EX_OTH), new power and district heat plants (excluding coal) (PP_NEW) and total power and district heat plants (PP_TOTAL).

In sector CON_COMB there is a decrease of 4% and 19% in the activity level of scenarios CLE2030 and OPT2030, respectively. Regarding sectors PP_EX_L and PP_EX_OTH there is a decrease of 97% (PP_EX_L) and 33% (PP_EX_OTH) in the activity level of the future scenarios. This is related to the decrease in the consumption of heavy fuel oil (HF) in sector CON_COMB, the decrease in the consumption of heavy fuel oil (HC1) in sector PP_EX_L and, in the case of sector PP_EX_OTH, also due to a decrease in the consumption of gaseous fuel (GAS) and increase in the use of biomass fuels (OS1).

In sectors PP_NEW there is an increase of 13% (CLE2030) and 17% (OPT2030) and in the sector PP_TOTAL an increase of 13% (CLE2030 and OPT2030) in the activity level. the activity level increases in future scenarios. The increase in activity level of PP_NEW is related to the increase in the consumption of biomass fuels (OS1) and other biomass fuels and waste (OS2) and a decrease in the activity level of GAS. In the sector PP_TOTAL the increase on the activity level is related to an increase in renewable energy consumption (other than biomass: REN).

5.1.1.2 Emissions

NOx and SO_2 emissions (in kt/year) are for SNAP 1 the most relevant emissions (see, respectively, *Figure* 10 and Figure *11*).

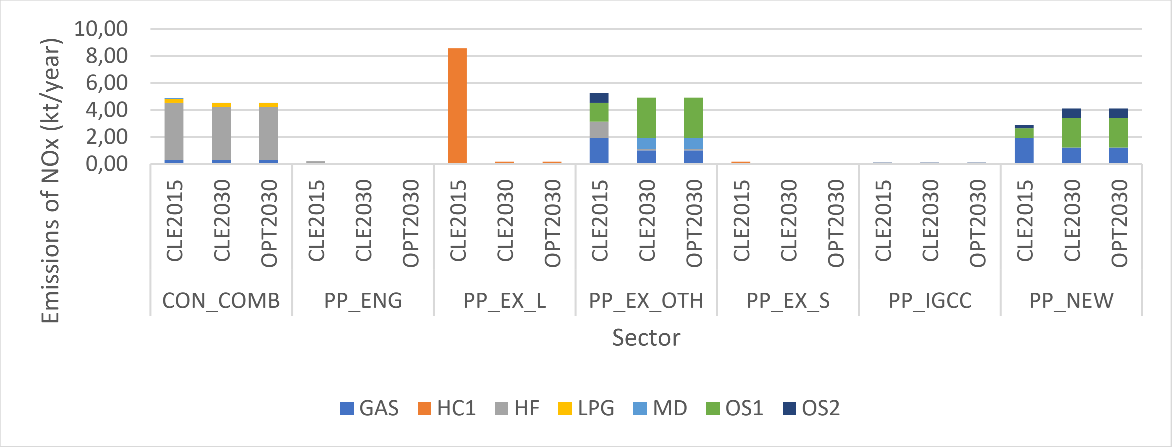

Figure 10: SNAP1 emissions of NO_x (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

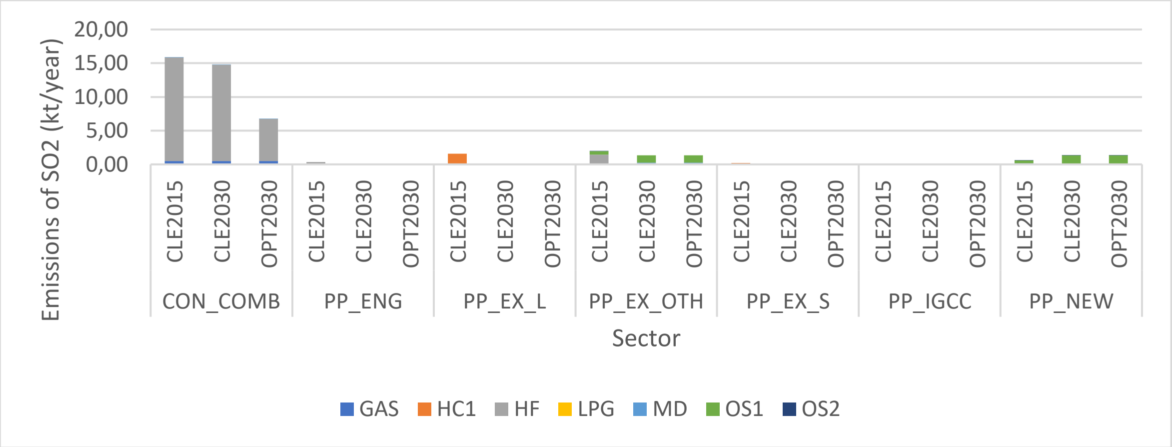

Figure 11: SNAP1 emissions of SO_2 (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

Emissions from sectors CON_COMB, PP_EX_OTH and PP_NEW follow the trend of the results of the activity level from the sectors with most relevance. The emissions of NO_x resultant of sectors CON_COMB and PP_EX_OTH decrease and the emissions of sector PP_NEW increase in the future scenarios. The sector PP_TOTAL, which assumes relevance in the future scenarios, has no emissions as it relates to renewable energy sources.

The sectors CON_COMB, PP_EX_L and PP_EX_OTH show a decrease in NO_x and SO_2 emissions. In the sector CON_COMB, the 7% decrease in emissions of NO_x in the scenarios CLE2030 and OPT2030 as well as7% (CLE2030) and 54% (OPT2030) decrease in emissions of SO_2 is related to the reduction in the consumption of HF. In this activity (HF) there is an increase in the use of low sulphur fuel oil (LSHF).

In the sector PP_EX_L, the 99% and 97% decrease in emissions of NO_x and SO_2 is related to the decrease in the consumption of HC1 (only activity associated with this sector). The elimination of combustion modification on existing hard coal power plants (PHCCM) in the future scenarios, is the reason for this large decrease on the activity level.

In the sector PP_EX_OTH, the 6% and 32% decrease in emissions of NOx and SO_2 is only related with the decrease in the activity level of activities GAS and HF in favour of activity OS1. The technologies applicable for each scenario remain constant.

The increase in 43% (NOx) and 33% (SO_2) in the future emissions of sector PP_NEW is related with the consumption of GAS, OS1 and OS2. There are no differences in the technologies throughout the three scenarios.

5.1.1.3 Cost

Figure 12 displays the SNAP1 emission control costs (in M€/year) for each sector and scenario. Decreases in costs are observed in PP_EX_L and PP_EX_OTH, while increases in costs are observed in CON_COMB and PP_NEW.

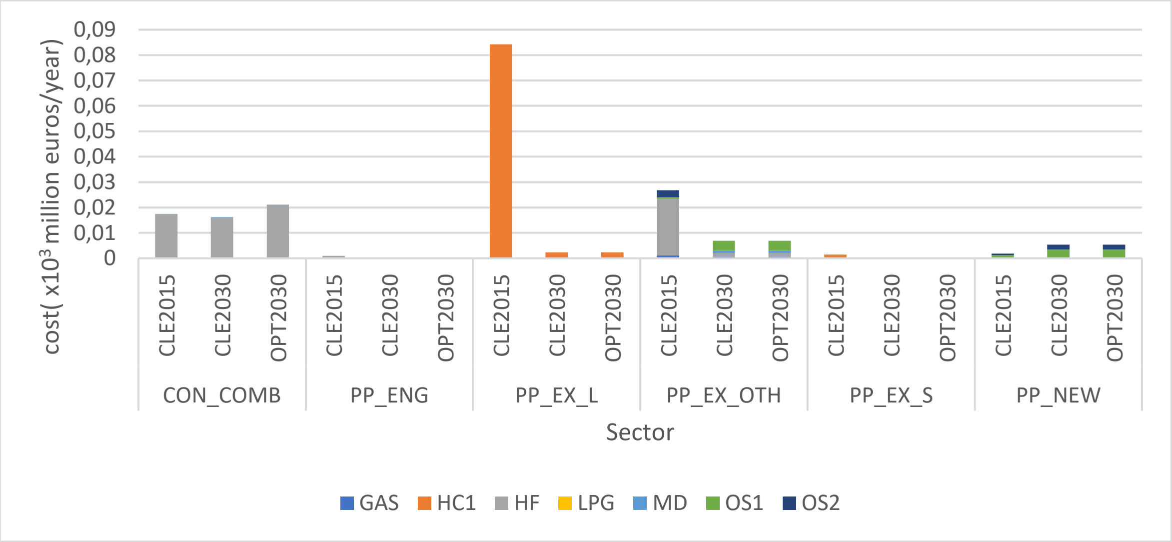

Figure 12: SNAP1 emission control costs (in m€/year) per sector for CLE2015, CLE2030 and OPT2030.

In sectors PP_EX_L and PP_EX_OTH there is, respectively, a 97% to 74% decrease in emission control costs in future scenarios, related to the decrease in activity level.

In the sector CON_COMB there is, a decrease of 8% (CLE2030) and an increase of 21% (OPT2030) in emission control costs. The sector CON_COMB, for which future activity level and emissions reductions are expected, shows an increase in the costs in scenario OPT2030 due to the increase in the application of LSHF, a technology with higher costs.

5.1.1.4 Discussion of SNAP 1 results

This SNAP brings together combustion in energy production and transformation, including coke production, collieries, gas production, nuclear fuel production, offshore-own gas use, power station, refineries (being related with combustion activities only), solid smokeless (fuel production) and town GAS production.

The results obtained for sectors CON_COMB, PP_EX_OTH and PP_NEW are identified as the most important for this SNAP.

Summarizing, the emissions decrease in the future scenarios. The cost of emission reduction is higher in scenario OPT2030 and, scenario CLE2030 is the one with the lowest cost. This difference between the future scenarios is due to the increase in the cost of activity HF in scenario OPT2030. This increase is related to the increase in the percentage of technology application of LSHF, meaning increase in the use of low sulphur fuel oil associated with requirements regarding the reduction in the combustion of fuels containing sulphur.

The reduction in the activity level of GAS, HC1, HF and LPG, reflects a reduction in the application of these fossil fuel-based activities in the future scenarios. GAS is recognized as a more environmentally friendly fossil-fuel, being possible to verify that the decrease in its activity level is not as significant as in other activities, for example HF. Although, as it is not a renewable source of energy a decrease on its use is expected. HC1, a hard coal of high quality also known as anthracite, is not a wide available fossil fuel. Although HF being considered cheap, heavy oil power plants have negative environmental impacts. LPG can be extracted from environmentally harmful sources (low standard oil industry, shale gas, etc.). Although in less quantity than other fuels, it emits such harmful substances as nitrogen oxides and sulphur dioxide.

Analysing the cases where the activity level increases in the future scenarios, it is possible to verify that this is associated to activities OS1, OS2 and REN (renewable energies). With the decrease on the use of fossil fuels it is understandable that an increase in the use of OS and REN in the future scenarios occurs. Biomass is a renewable source of energy, it is carbon neutral and it is less expensive than fossil fuels (in opposition to fossil fuel it not requires a heavy outlay of capital, such as oil drills, gas pipelines and fuel collection).

5.1.2 Non-industrial combustion plants (SNAP 2)

Activity level results as well as relevant emissions and costs from non-industrial combustion processes are displayed in this point. Regarding emissions, NO_x, PM2.5 and SO_2 are the most important in this SNAP, so that, the only discussed.

5.1.2.1 Activity Level

The results in this SNAP (PJ/year) are represented in *Figure 13*.

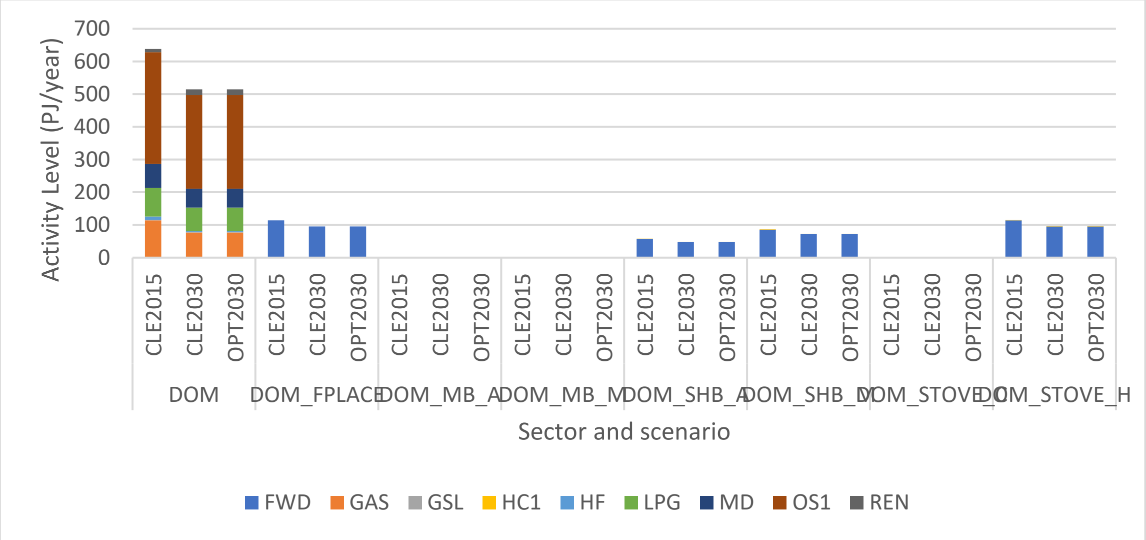

Figure 13: SNAP 2 activity levels (in PJ/year) per sector for CLE2015, CLE2030 and OPT2030.

Residential and commercial sector (DOM), solid fuelled fireplaces (DOM_FPLACE), automatic single house boilers (<50 kW) (DOM_SHB_A), manual single house boilers (<50 kW) (DOM_SHB_M) and heating stoves (DOM_STOVE_H) are the sectors for which higher activity level is registered in this SNAP. The activity level in these sectors decreases in the future scenarios. In the sector DOM there is a decrease in 19% in the activity level of the future scenarios due to the decrease in the consumption of GAS and OS1. In the sectors DOM_FPLACE, DOM_SHB_A, DOM_SHB_M and DOM_STOVE_H there is a decrease in 16% in the activity level of the future scenarios mainly related with the decrease in the consumption of fuelwood.

5.1.2.2 Emissions

NOx, PM2.5 and VOC were identified as the most relevant pollutants in this SNAP.

For NOx emissions the only sector presented is DOM since any other sector of this SNAP has emissions for this pollutant (*Figure 14*). The emissions of this sector decrease in 64% in the future scenarios, related with the decrease in the activity level of activity OS1, the activity also associated with the majority of the NOx emissions.

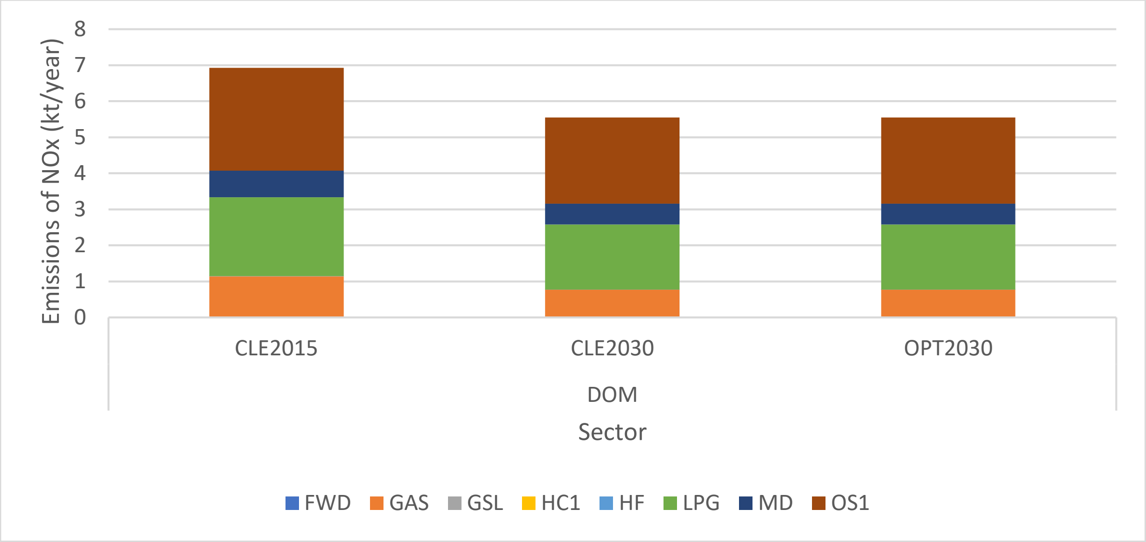

Figure 14: SNAP2 emissions of NO_x (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

The main sources of PM2.5 and VOC, as it is possible to conclude trough Figure *15* and Figure *16* are the same (DOM_FPLACE, DOM_SHB_M and DOM_STOVE_H). The associated emissions experiment a decrease in the future scenarios related with the decrease in the consumption of FWD.

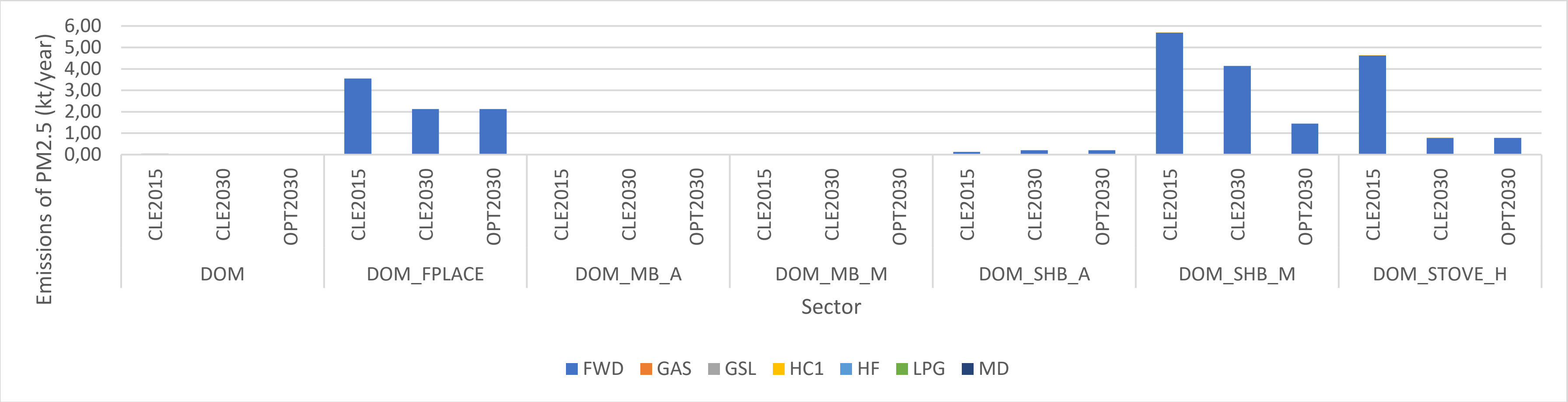

Figure 15: SNAP2 emissions of PM2.5 (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

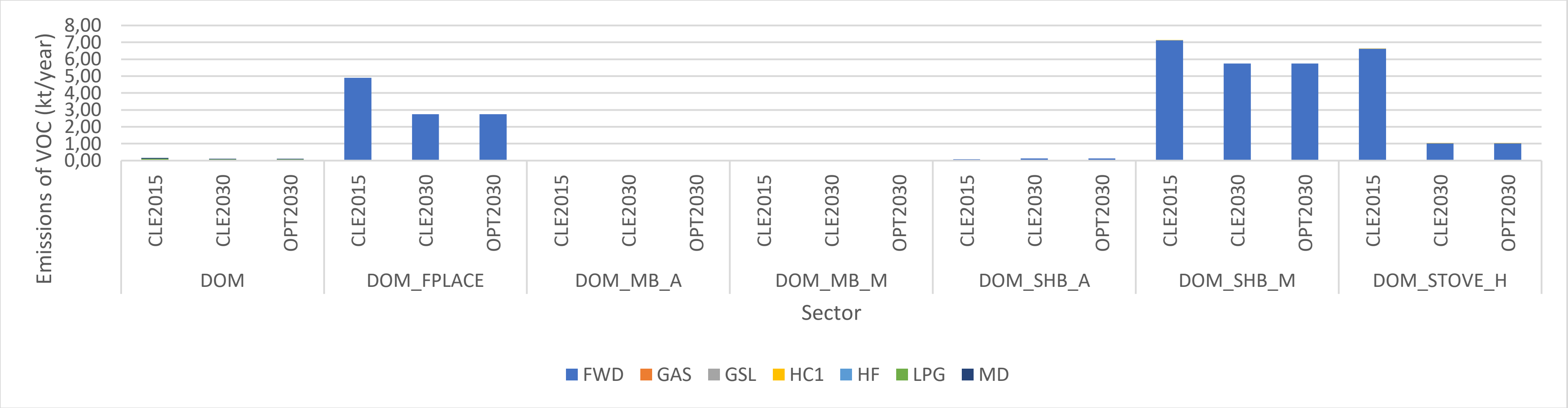

Figure 16: SNAP2 emissions of VOC (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

Regarding sector DOM_FPLACE, the emissions of PM2.5 decrease 23% and 89%, in scenarios CLE2030 and OPT2030, respectively and VOC emissions decrease 28% (CLE2030) and 89% (OPT2030). These decreases are related with the decrease in the use of no control technologies in favour of new (FP_NEW) and improved fireplaces (FP_IMP) in activity FWD.

In the sector DOM_SHB_M, not only a decrease in PM2.5 in 24% (CLE2030) and 63% (OPT2030) is verified as well as a decrease in 25% in scenarios CLE2030 and OPT2030 in VOC emissions. This decrease in the emissions is related with the decrease in the application of no control technologies in favour of improved biomass single house boilers (SHB_IM_B).

The PM2.5 emissions in sector DOM_STOVE_H decrease 31% in scenario CLE2030 and 90% in scenario OPT2030. Regarding VOC, emissions face a decrease of 37% and 94% in scenarios CLE2030 and OPT2030, respectively. The decrease in the emissions in this sector is related with the increase in the use of new biomass stoves (STV_NEW_B).

5.1.2.3 *Cost*

In the *Figure 17* the costs obtained for SNAP 2 (in M€/year) are presented, being, the sectors not presented the ones for which any cost is associated.

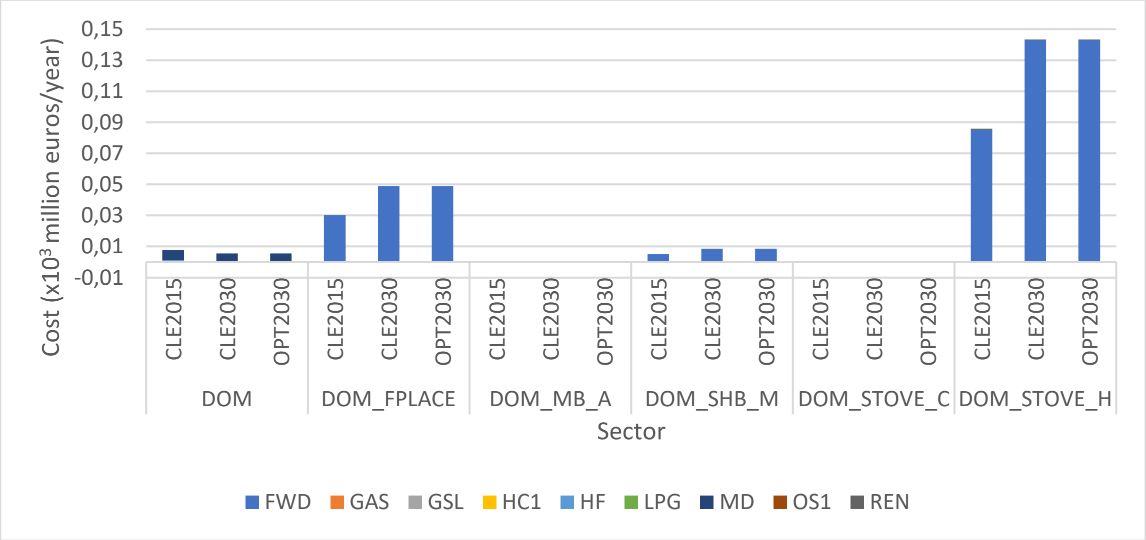

Figure 17: SNAP2 emission control costs (in m€/year) per sector for CLE2015, CLE2030 and OPT2030.

The relevant costs are associated with the sectors for which major emissions were identified: DOM_FPLACE, DOM_SHB_M and DOM_STOVE_H, which increases in the future scenarios in 61% (DOM_FPLACE), 30% (DOM_SHB_M) and 67% (DOM_STOVE_H).

This increases on the costs are related with the increase in the use of the mentioned more advanced technologies.

5.1.2.4 Discussion of SNAP 2 results

DOM sector is related with the small combustion installations as heating and preparation of the hot water in residential and commercials/institutional sectors. In the residential sector some of these installations are also used for cooking. In this sector it is verified a decrease in the consumption of biomass fuels in the future scenarios. The technologies associated with activity OS1 remain constant, so that the decrease in the emissions is only related with the decrease in the activity level. The costs in this sector are not relevant, being practically constant throughout the three scenarios.

In sector DOM_FPLACE, besides the decrease in the activity level an increase in the application of FP_IMP and FP_NEW technologies that, having lower emission factors results in the reduction of the emissions, is verified. There is a need to install new or upgrade the existent solid-fuelled fireplaces since they have associated high emissions levels. This is usually done by the transformation (or replacement) of the existent fireplaces into a closed one or into gas.

In the sector DOM_SHB_M the decrease in the emissions is related with the replacement of no control technologies by SHB_IM_B. These boilers of small capacity are usually applied in flats and single houses, being used not only for the generation of heat for the central heating system, but also for hot water supply.

In the sector DOM_STOVE_H there is a decrease in the application of no control technologies and an increase in the application of STV_NEW_B which together with the decrease in the activity level results in the decrease of the emissions. This stove is a heat accumulating one, so that, characterized with relatively low emissions of pollutants (comparing with radiating stoves), having, typically, an efficiency between 60% and 80%.

In this SNAP the emissions are related with solid fuel, being the emissions in this kind of fuels associated with the incomplete combustion. This is a particularly valid phenomenon not only frequent in small appliances, but also for manually fed appliances, being understandable the association with this SNAP.

The emissions related with incomplete combustion are mainly associated with insufficient mixing of combustion air and fuel in the combustion chamber/ combustion zone, combined with a lack of available oxygen, low temperature, short residence times and too high radical concentrations (Kubica et al., 2007).

The PM2.5 and VOC emissions tend to decrease as the capacity of the combustion installation increases, due to the use of advanced technique which is typically characterized by improved combustion efficiency. As it is possible to verify trough the results, in the future there is a tendency to improve and implement advanced technologies in fireplaces, stoves and boilers, resulting in the decrease in the emissions. These new technologies however, have extra costs associated, in opposition of what happens with no control technologies.

5.1.3 Industrial combustion plants (SNAP 3)

Regarding SNAP 3, the simulations results for each of the three components of study, activity level, emissions and costs, are presented.

5.1.3.1 Activity Level

In Figure 18 (PJ/year and Mt/year) the activity level results for SNAP 3 are presented.

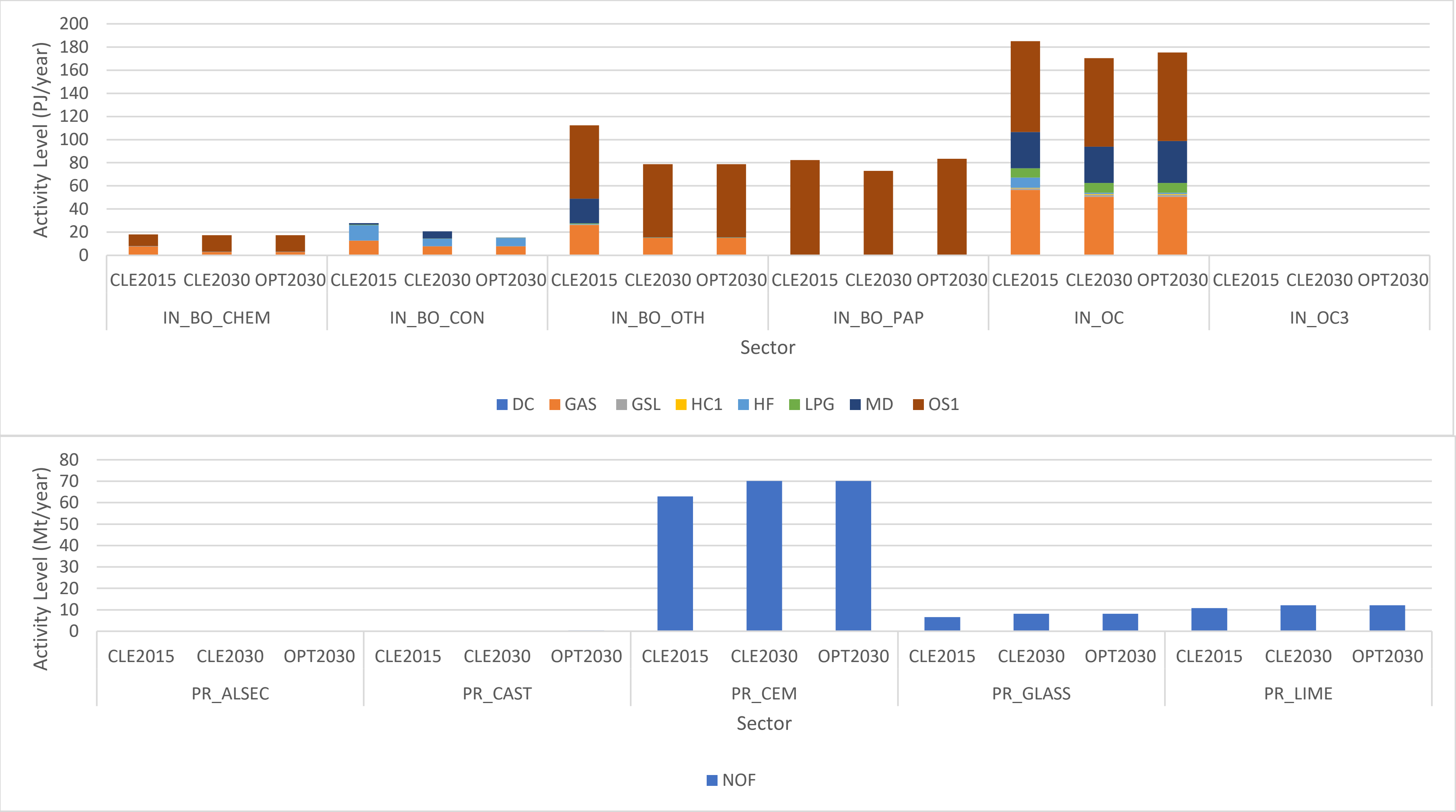

Figure 18: SNAP 3 activity levels (in PJ/year and Mt/year) per sector for CLE2015, CLE2030 and OPT2030.

Analysing the figures is possible to verify that the most relevant sectors of this SNAP are other industrial combustion in boiler boilers (IN_BO_OTH), paper and pulp industrial combustion in boilers (IN_BO_PAP), industrial furnaces in industrial combustion in boilers (IN_OC) and cement production (PR_CEM). Sectors IN_BO_OTH and IN_OC, have a decrease in the activity level in the future scenarios. In the sector IN_BO_OTH a decrease in 30% in the activity level in the future scenarios is registered, related with the reduction in diesel (MD) consumption. In the sector IN_OC a decrease in 8% and 5% in scenarios CLE2030 and OPT2030, respectively, is registered. The decrease in the activity level in scenario CLE2030 is related with the decrease in HF consumption, and the increase in scenario OPT2030 is related with the increase on MD consumption. In the sector IN_BO_PAP it is possible to confirm a decrease in 11% in the activity level in scenario CLE2030 and an increase in 1% in scenario OPT2030 related with the decrease in scenario CLE2030 and increase in scenario OPT2030 in HF consumption. In the sector PR_CEM there is an increase in 12% in the activity level of the future scenarios related with the increase in the no fuels use (NOF).

5.1.3.2 *Emissions*

The main pollutants emitted in this SNAP are NOx and SO_2 being the only pollutants presented and discussed. The results are presented in *Figure 19* and *Figure 20* (kt/year)

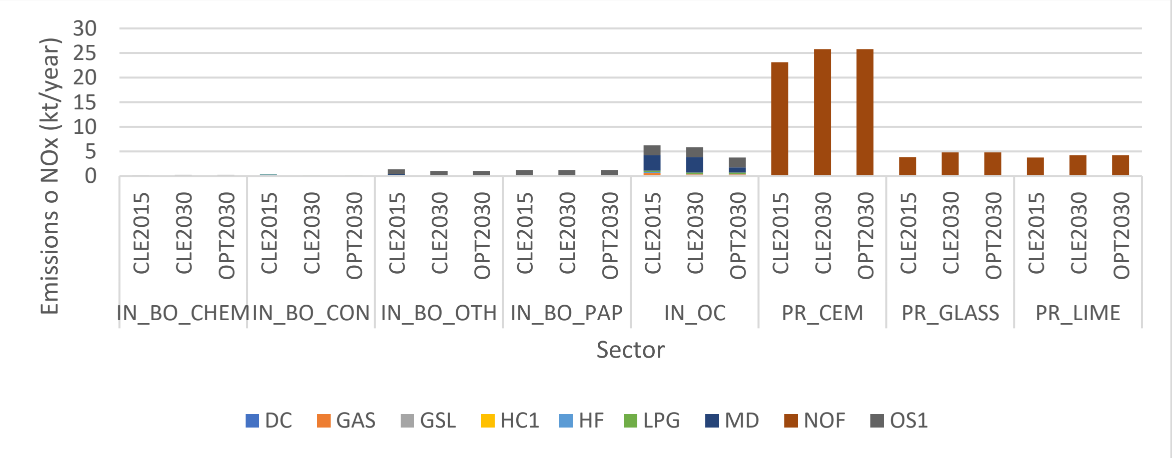

Figure 19: SNAP 3 emissions of NO_x (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

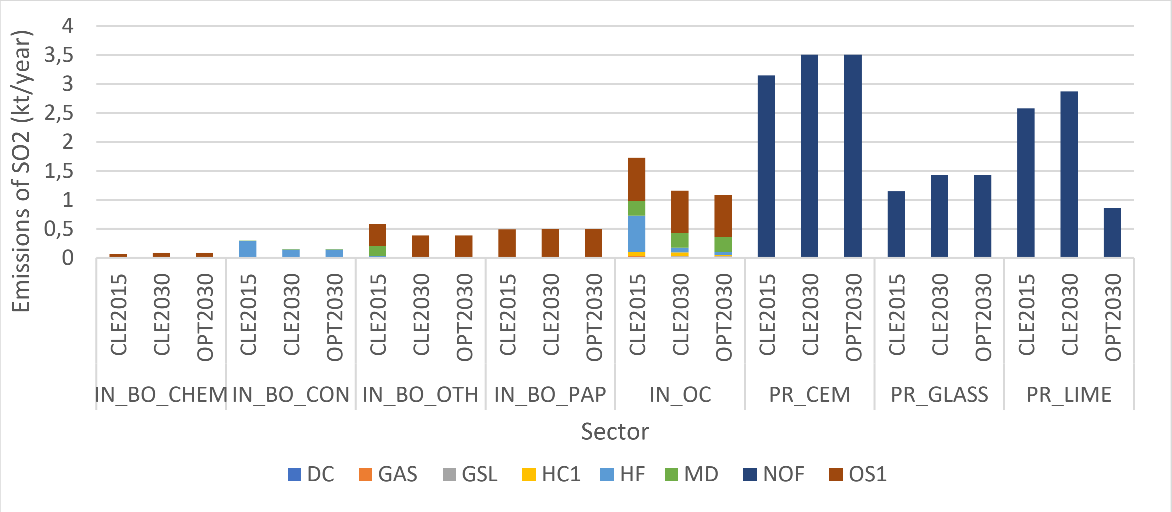

Figure 20: SNAP 3 emissions of SO_2 (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

Sectors IN_OC, PR_CEM, glass production (PR_GLASS) and lime production (PR_LIME), are the most important regarding emissions.

In sector IN_OC there is a decrease in 7% (CLE2030) and 40% (OPT2030) in NO_x emissions and a decrease in 33% (CLE2030) and 37% (OPT2030) in SO_2 emissions, related with the reduction in HF consumption. The emissions of NO_x in activity HF are related with the use of wet flue gases desulphurisation (IWFGD) and, as the percentage of technology remains constant throughout the three scenarios, the decrease in the emissions is related with the decrease in the activity level. Although the emissions of GAS are not as relevant as other activities it is verified that the increase in combustion modification on oil and gas industrial boilers and furnaces (IOGCM) with consequent elimination of no control technologies for NO_x helps in the reduction of this pollutant in the optimum scenario. Also, in activity HC1 the reduction of the no control technologies for SO_2 (NOC_SO2) and the increase in the application of LSHF helps in the reduction of SO_2 emissions in the optimum scenario.

In sectors PR_CEM and PR_GLASS an increase in 12% (PR_CEM) and 24% (PR_GLASS) in the NOx and SO_2 future emissions is verified. The increase is related to the increase in the activity level of NOF.

In the sector PR_LIME an increase in 11% in the emissions of NOx in the future scenarios and SO_2 in scenario CLE2030 is verified. Regarding scenario OPT2030, the sector PR_LIME verified a decrease in 67% in SO_2 emissions. The decrease in the emission in the optimum scenario is related with the substitution of no control of SO_2 technology (NOC_SO2), by the technology Stage 2 of process SO_2 control (SO2PR2), where stage 2 represents 70% in the SO_2 removal efficiency.

5.1.3.3 Cost

The costs of the different abatement technologies applied in the different scenarios are illustrated in *Figure 21*.

PR_CEM, PR_GLASS and PR_LIME are the sectors for which the highest cost is registered. In the sector PR_CEM and PR_GLASS there is a respectively increase in 12% and 24% in the costs of the future scenarios. In the sector PR_LIME the increase of the cost in scenario CLE2030 is of 12% while in scenario OPT2030 is of 30% (consequent of the introduction of a new technology). The sector IN_BO_CON, although not having high activity level or emissions, represents higher costs than the other combustion in boilers processes, being verified a decrease in 51% in the cost of the future scenarios.

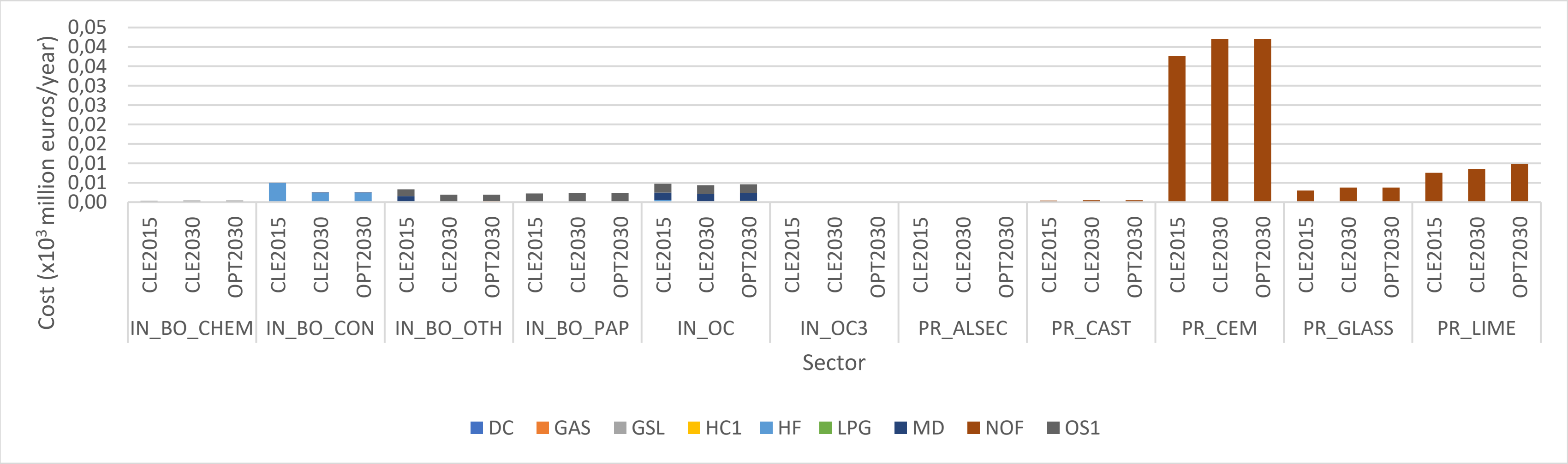

Figure 21: SNAP3 emission control costs (in m€/year) per sector for CLE2015, CLE2030 and OPT2030.

5.1.3.4 Discussion of SNAP 3 results

This SNAP brings together several sectors of combustion in industry for which the results obtained for sectors IN_BO_OTH, IN_BO_PAP, IN_OC, PR_CEM PR_LASS and PR_LIME are the more relevant.

It is clear that the reduction in the emission is related not only with decrease in the activity levels but also with the decrease in the quantity of control technologies and the application of new abatement technologies. Regarding technologies it is verified an increase in the application of LINJ to the activity HC1 and LSHF to the activity HF in sector IN_OC. The application of LINJ is related to a furnace sorbent injection, a technique where limestone is injected into the boilers in order to react with SO_2.The application of LSHF, in activity HF results in increase in the use of low sulphur fuel oil, due to requirements in the reduction in the combustion of fuels containing sulphur. Both technologies result, as expected, in the reduction of SO_2 emissions. It is shown an increase in the consumption of biomass fuel that, as explained in point 5.1.1.4, is a renewable source of energy.

In general, in this sector it is possible to conclude that the changes from scenario CLE2030 to scenario OPT2030 are not drastic, being the results for their simulations similar.

5.1.4 Industrial processes (SNAP 4)

In order to understand how the simulations, influence the behaviour of SNAP 4, this subsection analyses the obtained results for the activity level, emissions and costs.

5.1.4.1 Activity Level

The activity level results are displayed in Figure *22*. Since the results of the activity level are given in more than three units an index analysis was done. It considers the scenario CLE2015 as 100% and computes the differences for CLE2030 and OPT2030, scenarios comparing with scenario CLE2015. *Table 3* lists units in which each activity is expressed.

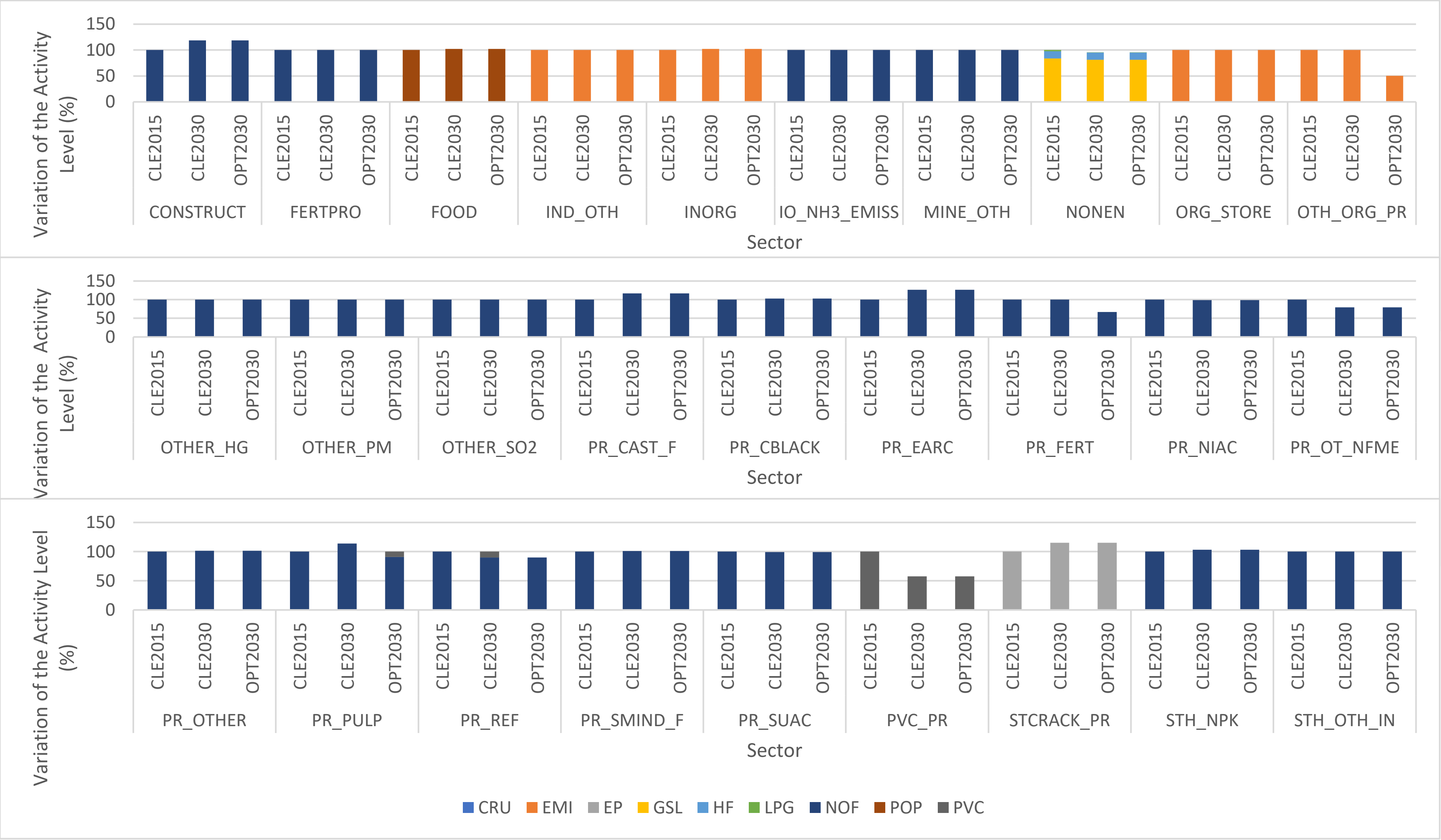

Figure 22 SNAP 4 activity levels variations (%) per sector for CLE2015, CLE2030 and OPT2030.

Table 3 Units for the Activities of the SNAP 4

Activity	Unit	Sector
CRU	Mt	PR_REF
EMI	kt VOC	IND_OTH
		INORG
		ORG_STORE
		OTH_ORG_PR
EP	kt	STCRACK_PR
GSL	PJ	NONEN
HF	PJ	NONEN
LPG	PJ	NONEN
NOF	M m2	CONSTRUCT
	kt N	FERTPRO
	kt NH3	IO_NH3_EMISS
	Mt	MINE_OTH
	t Hg/year	OTHER_HG
	kt PM (TSP)	OTHER_PM
	kt SO2	OTHER_SO2
	Mt	PR_CAST_F
		PR_CBLACK
		PR_EARC
		PR_FERT
		PR_NIAC
		PR_OT_NFME
		PR_OTHER
		PR_PULP
		PR_REF
		PR_SUAC
		STH_NPK
		STH_OTH_IN
	M people	PR_SMIND_F
POP	M people	FOOD
PVC	kt	PVC_PR

With this approach it is easier to identify which sectors present the most significant changes in the activity level.

The sectors for which more relevant (>5%) decreases in the activity level are registered are organic chemical industry sector (OTH_ORG_PR) with a decrease in 50% in the optimum scenario, fertilizer production sector (PR_FERT) with a decree in 33%, new rotogravure in publication (PVC_PR) with a decrease in 42%, non-ferrous metals sectors (PR_OT_NFME) with a decrease in 20% and petroleum refineries sector (PR_REF) with a decrease in 10%, in the future scenarios. In the sector OTH_ORG_PR the decrease in the activity level is related with the decrease in the activity level of EMI (emissions of NMVOC). In the sectors PR_FERT and PR_REF the decrease is associated with the decrease in the activity level of NOF. In the sector PR_REF it is possible to verify that the activity level of scenario CLE2030 has the same activity level as scenario CLE2015 since it has an addition of activity PVC (renewable energy other than biomass) that compensate the decrease of NOF. PVC is not present in scenario OPT2030. The sectors PR_OT_NFME and PVC_PR present a decrease in the activity level in the future scenarios, associated with the decrease in the activity level of NOF and PVC, respectively.

The activity level of construction sector (CONSTRUCT), production of cast iron (fugitive) (PR_CAST_F), electric and furnace sector (PR_EARC) and steam cracking in ethylene and propylene production (STCRACK_PR) increases in the future scenarios. The increase is correspondent to 19% in CONTRUCT, 17% in PR_CAST_F, 27% in PR_EARC and 15% in STCRACK_PR. This increase is related to the increase in the activity level of NOF, with exception of sector STCRACK_PR for which the increase in the activity level is related with the decrease in the activity level of EP (ethylene and propylene).

Sector PR_PULP presents an increase in the activity level in scenario CLE2030 (14%) and a decrease (9%) in the optimum scenario. This variation is related with activity NOF. In optimum scenario, besides the decrease of NOF is verified the addition of activity PVC.

5.1.4.2 Emissions

Emissions were analysed for the most relevant pollutants in this SNAP: PM2.5 (Figure 23) SO_2 (Figure *24*) and VOC (Figure *25*).

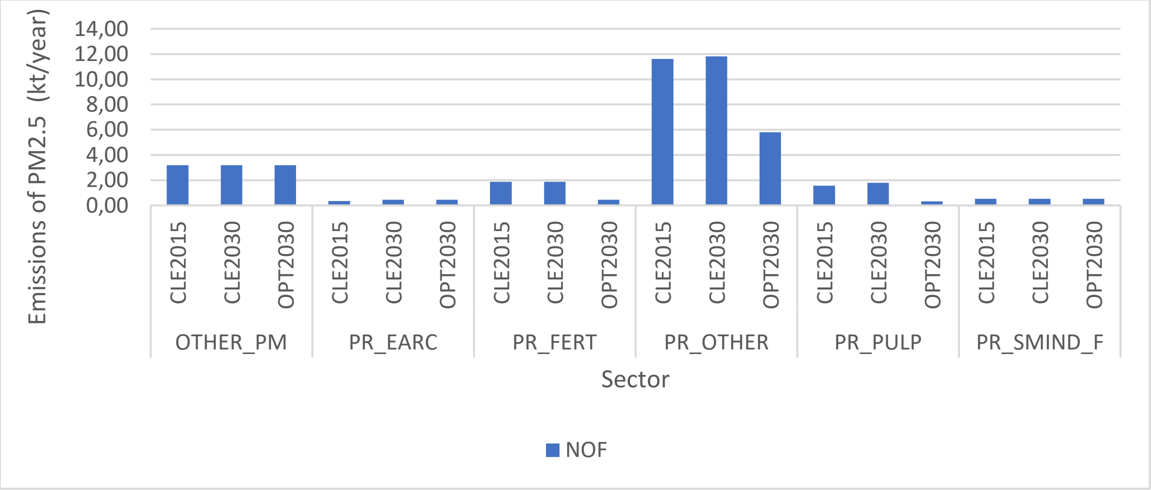

Figure 23: SNAP4 emissions of PM2.5 (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

As displayed in *Figure 23*, the sector PR_OTHER (production of glass fiber, gypsum, PVC, other) is the most important regarding PM2.5 emissions, verifying a decrease in 50% in the emission in the optimum scenario. The emissions of PM2.5 are only related with activity NOF. In scenario OPT2030 it is also verified a decrease in the application of cyclones (PR_CYC) and an increase in the application of electrostatic precipitators (ESP1).

The paper pulp mills sector (PR_PULP), sulfuric acid sector (PR_SUAC) and PR_REF sector are the ones with highest contributions for the emissions of SO_2, as shown in *Figure 24.*

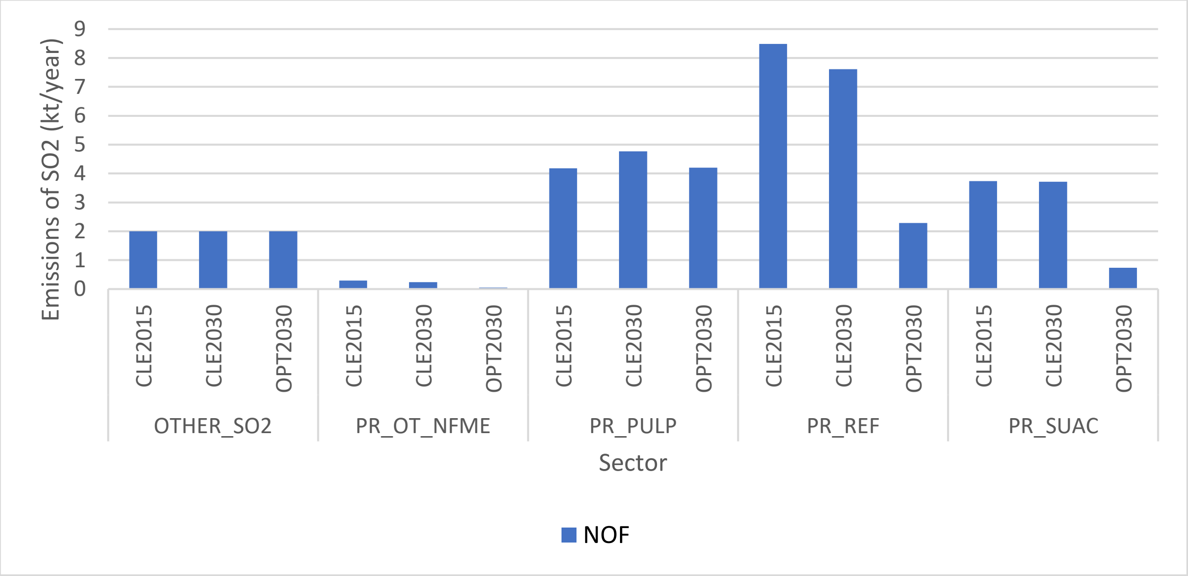

Figure 24: SNAP4 emissions of SO_2 (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

There is a decrease on the emissions of SO_2 in sectors PR_REF (10% in scenario CLE2030 and 73% in scenario OPT2030) and PR_SUAC (1% in scenario CLE2030 and 80% in scenario OPT2030) in the future scenarios. In sector PR_REF, Since the activity level of NOF is the same in scenarios CLE2030 and OPT2030, the decrease on the emissions of SO_2 may is related with the introduction of activity PVC in the optimum scenario. In the sector PR_SUAC the drastic decrease on the emissions of SO_2 in the optimum scenario is experimented. This is not influenced by the activity level, since it is constant throughout the three scenarios but is related with the elimination of NOC_SO2 and the addition of technology Stage 3 Process SO_2 control (SO2PR3), where stage 3 represents 80% on the SO_2 removal efficiency. In the sector PR_PULP there is an increase in 12% (CLE2030) in scenario OPT2030 related with the increase in the activity level.

Regarding VOC emissions (*Figure 25*), food and drink industry (FOOD), other industrial sources (IND_OTH), OTH_ORG_PR and PR_REF sectors are the most relevant.

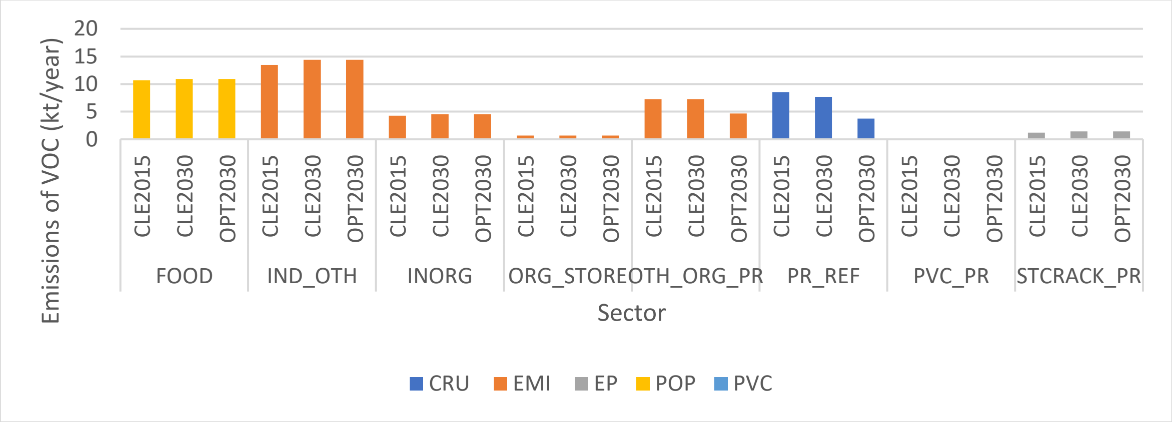

Figure 25: SNAP4 emissions of VOC (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

Sectors PR_REF is the main responsible for the decrease in the emissions of VOC in the optimum scenario corresponding to a decrease in 56% related with the decrease in the activity level. In the sector OTH_ORG_PR and PR_REF the decrease is not even 1%, being the emissions almost constant. PR REF represents an important sector concerning the emissions, presenting emissions of NOx, PM2.5, SO_2 and VOC, being verified a decrease in the future scenarios. The differences between scenario CLE2015 and CLE2030 are only related with the decrease in the activity level since the technologies presented in these scenarios as well as their percentage of application, remain constant. In the optimum scenario NOC_NOx and NOC_SO2 technologies are substituted by leak detection and repair program (LDARII) and SO2PR2 technologies, resulting in the decrease in the emissions.

In the sector FOOD there is an increase in 2% in the future emissions and in the sector IND_OTH an increase in 7%, related with the slight increase in the activity level.

5.1.4.3 Cost

In general, the cost for SNAP 4 (Figure *26*) remains constant throughout the three scenarios with any sector showing a significant change in the future scenarios and with the small industrial and business facilities (fugitive) sector (PR_SMIND_F) being the one with highest cost

Sectors OTH_ORG_PR and PR_REF present a negative number for the cost, for activity EMI and HF, respectively, what means that they are translated into savings instead of extra costs.

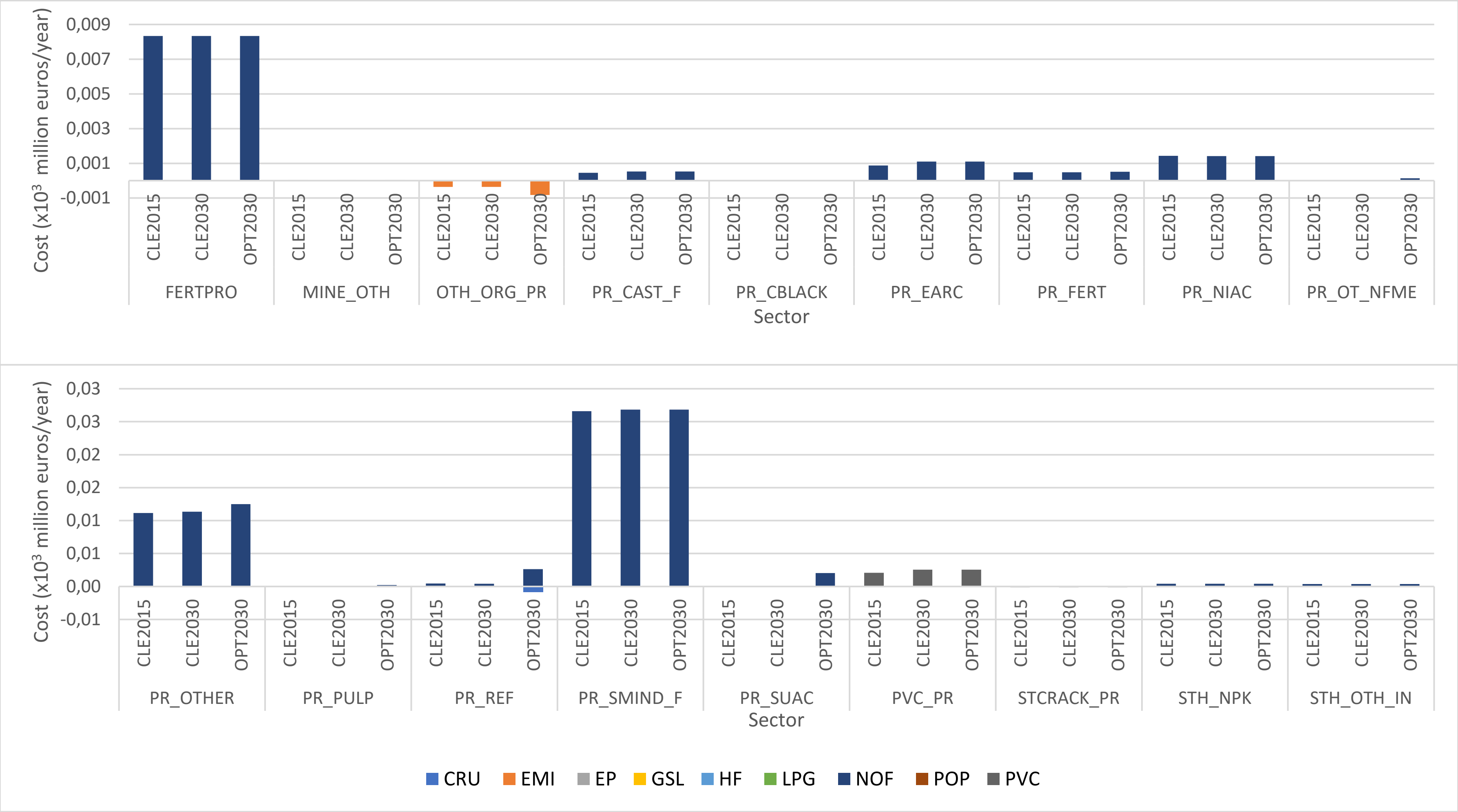

Figure 26 SNAP4 emission control costs (in m€/year) per sector for CLE2015, CLE2030 and OPT2030.

In sector OTH_ORG_PR there is an increase in 131% in the savings of the future scenarios. Regarding sector PR_REF, in scenario OPT2030 the cost is associated with a negative value for the cost of activity CRU, meaning a saving, associated to the technology LDAR_II. In the cost related to activity NOF it is possible to verify an increase in 484% in the cost in scenario OPT2030, due to the higher cost of new technologies added in scenario OPT2030. In the sectors PR PULP and PR_SUAC the cost is only associated with technologies added in scenario OPT2030, although not significant.

5.1.4.4 Discussion of SNAP 4 results

Regarding SNAP 4 it is verified that the reduction in the emissions is related with the decrease in no control technologies application, and addition of new technologies.

Concerning PM abatement technologies, it is possible to confirm the replacement of cyclones (PR_CYC) by high efficiency dedusters (PR_HED) and electrostatic precipitator (PR_ESP1) technologies that are much more efficient regarding emissions' control.

Regarding SO_2 abatement technologies it is registered an increase in the applications of SO2PR1, SO2PR2 and SO2PR3 and a decrease in the application of NOC_SO2. In this case, stages 1, 2 and 3 corresponds to a percentage of control efficiency of 50%, 70% and 80%.

About VOC abatement technologies, it is registered a decrease in the percentage of application of technologies LDAR_I and NOC_VOC from current legislation scenarios to scenario OPT2030, resulting in the addition of technologies LDAR_II and LDAR_IV. The LDAR technologies are related with leak detention and repair program, being the number associated in the code related with the different stages. The stages are related with the efficiency of the technology being stage 1, 50%, stage 2, 70% and stage 4, 80%. The bigger the number in the code, the bigger the efficiency of controlling VOC, resulting in a lower emission factor for VOC and consequent reduction of its emissions. Equipment Leaks are subject to strict regulation since EPA determined that this kind of equipment (valves, pumps, connectors...) are responsible for approximately 70,367 tons per year of VOCs emissions (Guide, 2016). Facilities can control emissions from equipment leaks by implementing a leak detection and repair (LDAR) program or by modifying or replacing leaking equipment with "leakless" components (it is possible to combine both methods under most equipment leak's regulations). LDAR is a work practice that allow the identification of leaking equipment so that emissions can be reduced through repairs. LDAR programs are required by many New Source Performance Standards (NSPS), National Emission Standards for Hazardous Air Pollutants (NESHAP), State Implementation Plans (SIPs), the Resource Conservation and Recovery Act (RCRA), and other state or local requirements. The implementation of LDAR not only result in the reduction of emissions but also can reduce product losses, increase safety for workers and operators and decrease exposure of the surrounding community. The cost of LDAR programs is likely to be highly site-specific and to vary with the leakages since reduced leakages means higher profits, under the simulation of this study, it application results in savings. After detection of leakages, there are different possibilities for repairs that are available at a wide range of costs. As we do not have access to industry data on the incidence of different types of leakages in Portuguese systems, it is not possible to make an assessment of the expected number and types of repairs that will be needed and the associated costs.

5.1.5 Extraction and distribution of fossil fuels and geothermal energy (SNAP 5)

In this point the results for the simulations done for SNAP 5 are presented and discussed. In terms of emissions, the only presented are for VOC, this SNAP is not a relevant source of emissions of any other pollutants.

5.1.5.1 Activity Level

The activity level results are displayed in *Figure 27* (in PJ/YEAR) and *Figure 28* (kton VOC).

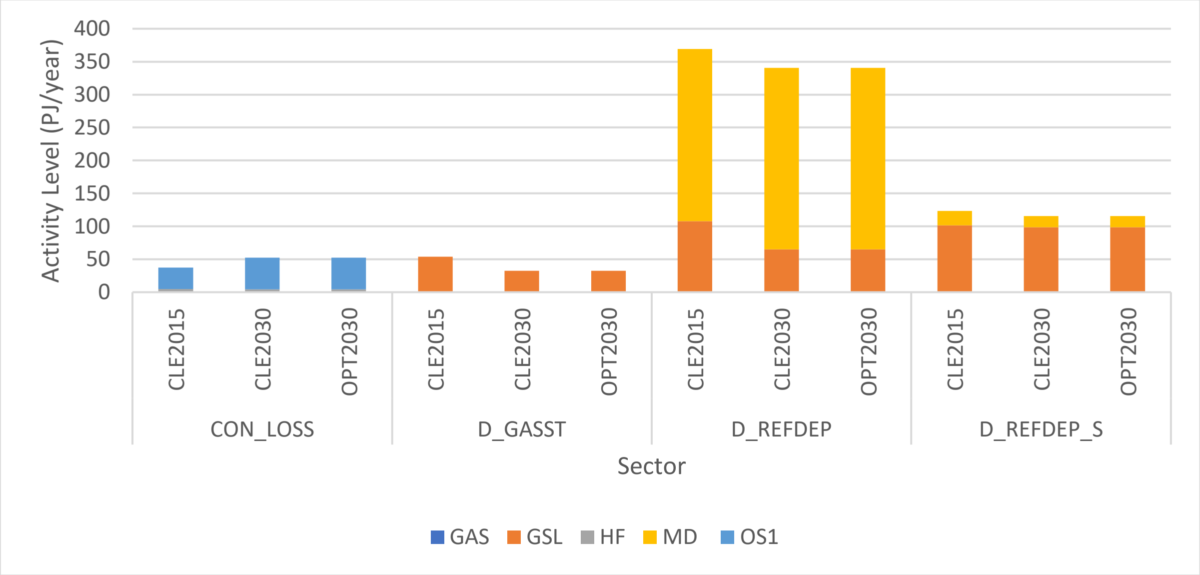

Figure 27: SNAP 5 activity levels (in PJ/year) per sector for CLE2015, CLE2030 and OPT2030

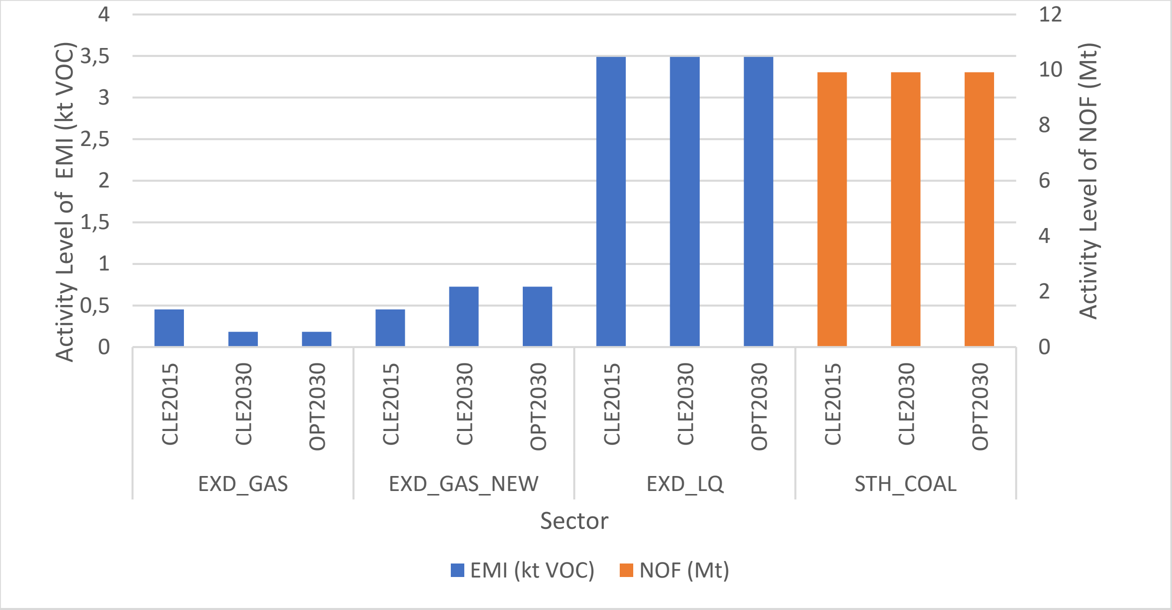

Figure 28: SNAP 5 activity levels (in kt VPC/year) per sector for CLE2015, CLE2030 and OPT2030P

Regarding activity level, gasoline storage and distribution excluding gasoline stations (D_REFDEP) and excluding transport sectors (D_REFDEP _S), extraction of oil (including delivery to terminals) (EXD_LQ) and storage and handling of coal (STH_COAL) sectors represent the most significant sectors of the SNAP. All of them, although, registered constant activity level throughout the three scenarios with the exception of sector D_REDFEP which has a slightly decrease (8%) on the future scenarios associated with activity GSL.

Although with lower activity level, in gasoline distribution (service stations) (D_GASST) and production and distribution of natural gas (EXD_GAS) there is a decrease in 39% (D_GASST) and in 60% (EXD_GAS) in the activity level of the future scenarios. In the sectors CON_LOSS and production and distribution of natural gas (new mains) (EXD_GAS__NEW) there is an increase in 39% and 60% (respectively) in the activity level in the future scenarios.

5.1.5.2 Emissions

The only relevant emissions in this SNAP are the emissions of VOC (*Figure 29)* since the emissions of NOx, SO_2 and PM2.5 do not present changings throughout the three scenarios and it does not present emissions for NH_3. The emissions of NOx and SO_2 are only associated with sector CON_LOSS and the emissions of PM2.5 are only associated with associated with sector STH_COAL.

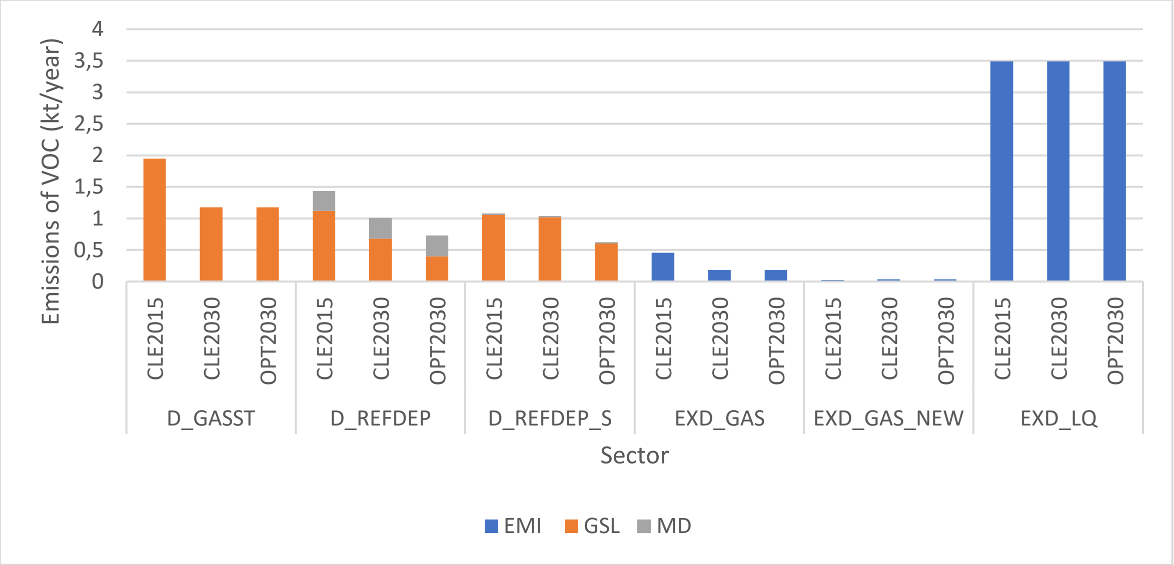

Figure 29: SNAP5 emissions of VOC (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

Sector EXD_LQ is the major contributor for the emissions of VOC associated with its high activity level, although, there is any change in the emission levels throughout the three scenarios, behaviour that corresponds also to the activity level results.

Sectors D_GASST, D_REFDEP and EXD_GAS follow the behaviour of the activity level, experimenting a decrease in the emissions in the future scenarios.

Sector D_REFDEP_S although presenting a decrease in the emissions in scenario OPT2030, it cannot be associated with the activity level, since it remains constant throughout the three scenarios. This results by the fact that in activity GSL the technology NOC_VOC is substituted by internal floating covers or secondary seals (IFC) technology.

5.1.5.3 Cost Results

The cost in this SNAP is associated with sectors D_GASST, D_REFDEP and STH_COAL, as it is possible to conclude trough Figure *30*.

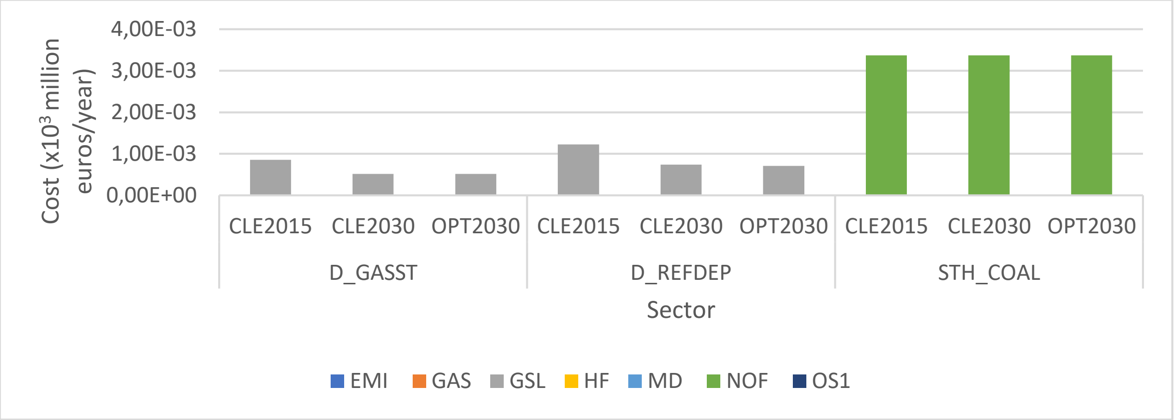

Figure 30 SNAP5 emission control costs (in m€/year) per sector for CLE2015, CLE2030 and OPT2030.

Sector STH_COAL is the one with highest cost associated, that, following the behaviour of the activity level, remains constant throughout the three scenarios.

Consequently, the reduction in the cost in the future scenarios is related with sectors D_GASST and D_REFDEP, following the behaviour of activity level that decreases in scenarios CLE2030 and OPT2030.

The decrease in the cost associated with sector D_GASST it is related to its decrease in the activity level and, in sector D_REFDEP it is related with the implementation of technology IFC, which presents a negative cost, meaning a saving, resulting in the decrease on the overall cost.

5.1.5.4 Discussion of SNAP 5 results

The sectors with major influence in this SNAP are D_GASST, D_REFDEP and EXD_GAS for which decreases in the activity level, results in decreases in emissions and costs of future scenarios. D_REFDEP_S, although not experiment any change in the activity level, suffers a decrease in the emissions of VOC in the optimum scenario.

Regarding technologies, the gasoline storage and distribution sectors (D_REFDEP and D_REFDEP_S) verified the addition of technology IFC in activity GSL. Internal floating covers or secondary seals are required in the directive 94/63/EC on the control of VOC emissions resulting from the storage of petrol and distribution from terminals to service stations, issued the minimum requirements for emission control of gasoline storage. Storage installations shall be designed and operated in accordance with the technical provisions of Annex I of the referred directive, which are designed to reduce the total annual loss of petrol (EC, 1994).

5.1.6 Use of solvents and other products (SNAP 6)

The results obtained for the activity level, emissions and costs of SNAP 6 are now presented and discussed. This SNAP only presents emissions of VOC.

5.1.6.1 Activity Level

In the Figure 31 the activity level results for SNAP 6 is presented, where, again, the index analysis was applied to study the variation of the future scenarios considering the scenario CLE2015 as 100%. The units associated with the results for each activity are listed in the Table *4*. .

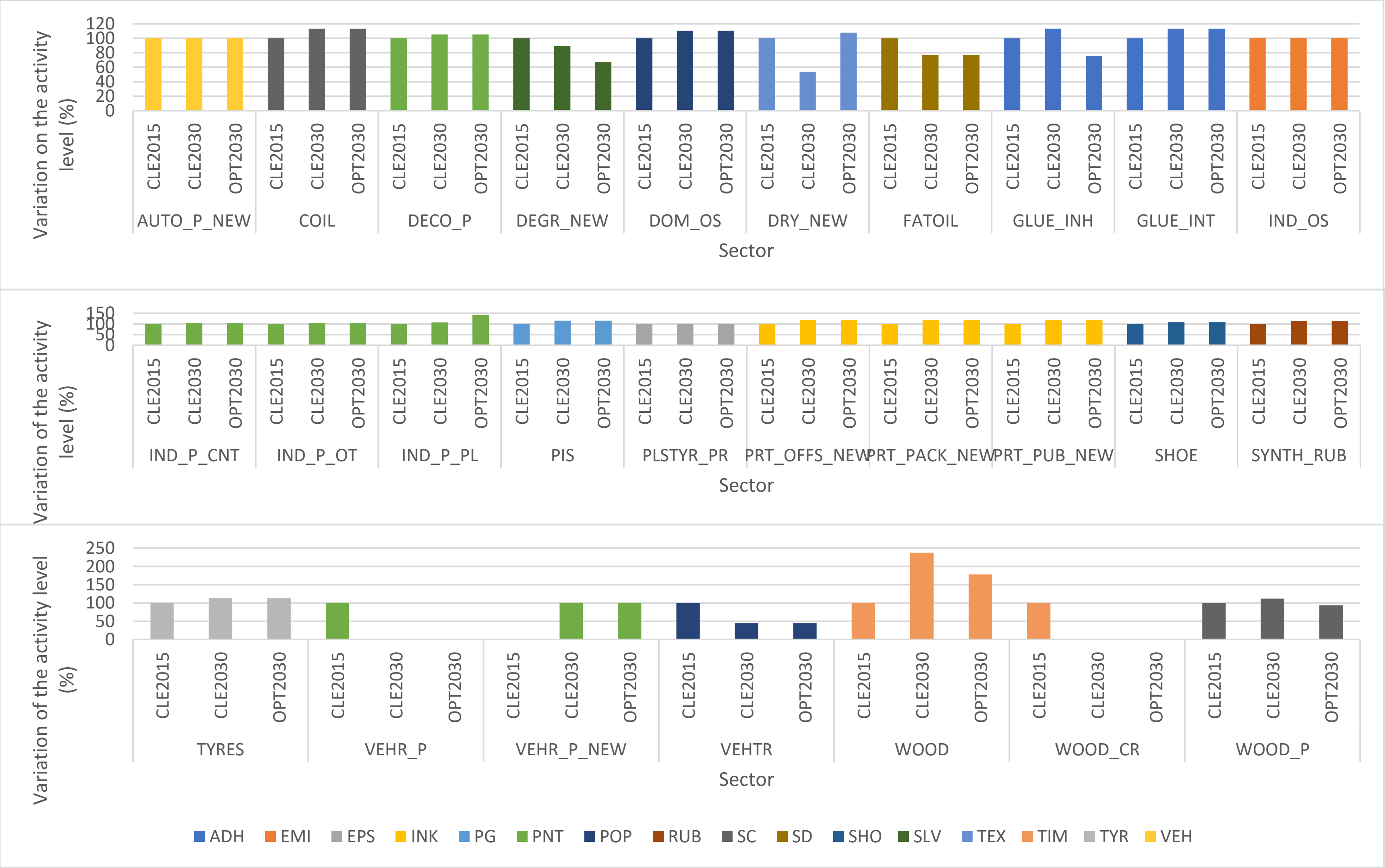

Figure 31: SNAP6 activity levels variations (%) per sector for CLE2015, CLE2030 and OPT2030.

Table 4: Units for the Activities of the SNAP 6.

Activity	Unit	Sector
ADH	kt	GLUE_INH
		GLUE_INT
EMI	kt VOC	IND_OS
EPS	kt	IND_OS
INK	kt INK	PRT_OFFS_NEW
		PRT_PACK_NEW
		PRT_PUB_NEW
PG	kt PG	PIS
PNT	kt	DECO_P
		IND_P_CNT
		IND_P_OT
		IND_P_PL
POP	M people	DOM_OS
		VEHTR
RUB	kt	SYNTH_RUB
SC	mln m2	COIL
		WOOD_P
SD	kt	FATOIL
SHO	mln pairs	SHOE
SLV	kt SLV	DEGR_NEW
TEX	kt TEX	DRY_NEW
TIM	mln m3	WOOD
TYR	kt	TYRES
VEH	kveh	AUTO_P_NEW

This SNAP includes several different sectors. In degreasing (new installations) (DGR_NEW), high performance of industrial application of adhesives (GLUE_INH), (de)waxing and underbody treatment of vehicles (VEHTR) and wood coating (WOOD_P) sectors, decreases in the future scenarios are verified. In sector DGR_NEW there is a decrease in 11% and 33%, in the activity level of scenarios CLE2030 and OPT2030, related with the decrease in the paint use (PNT). In the sector GLUE_INH, although an increase (13%) in scenario CLE3030 is verified, scenario OPT2030 implies a decrease in 75% in the activity level of scenario OPT2030, related with activity POP (population). In the sector VEHTR, there is a decrease in 55% in the future emissions related with the decrease in the activity level of POP. In the sector WOOD_P, although an increase in 12% in the activity level of scenario CLE2030 is verified, the optimum scenario simulates a decrease in 7% in the activity level. These variations are linked to coated surface (SC) activity.

In the sectors coil coating (COIL), domestic use of solvents other than paint (DOM_OS), dry cleaning (new installations) (DRY_NEW), industrial paint use (plastic parts) (IND_P_PL), products incorporating solvents (PIS), new offset printing (PRT_OFFS_NEW) new installations of flexography and rotogravure packaging (PRT_PACK_NEW) and new rotogravure in publication (PRT_PUB_NEW) there is an increase in the activity level in the future scenarios. In the sector COIL the increase (13%) in the activity level in the future scenarios is related with the activity SC. In the sector DOM_OS the increase (10%) in the activity level in the future scenarios is related with activity POP. Regarding sector DRY_NEW, although a decrease (46%) in the activity level in scenario CLE2030, scenario OPT2030 implies an increase (8%). This sector is related with textiles (clothing) activity (TEX). In the sector IND_P_PL the increase in 7% in scenario CLE2030 and 42% in scenario OPT2030 in the activity level is related with activity PNT. In the sector PIS the increase (15%) in the activity level in the future scenarios is related with paint and glue produced (PG). The increase in the activity level of sectors PRT_OFFS_NEW (18%), PRT_PACK_NEW (18%) and PRT_PUB_NEW (18%) are related with activity INK (Printing inks).

Vehicle refinishing (VEHR_P) and wood preservation (creosote) (WOOD_CR) sectors are not presented in future scenarios. Sector VEHR_P is substituted by new installations of vehicle refinishing (VEHR_P_NEW) in the future scenarios.

5.1.6.2 Emissions

In the Figure 32 the emissions of VOC for SNAP 6 are displayed.

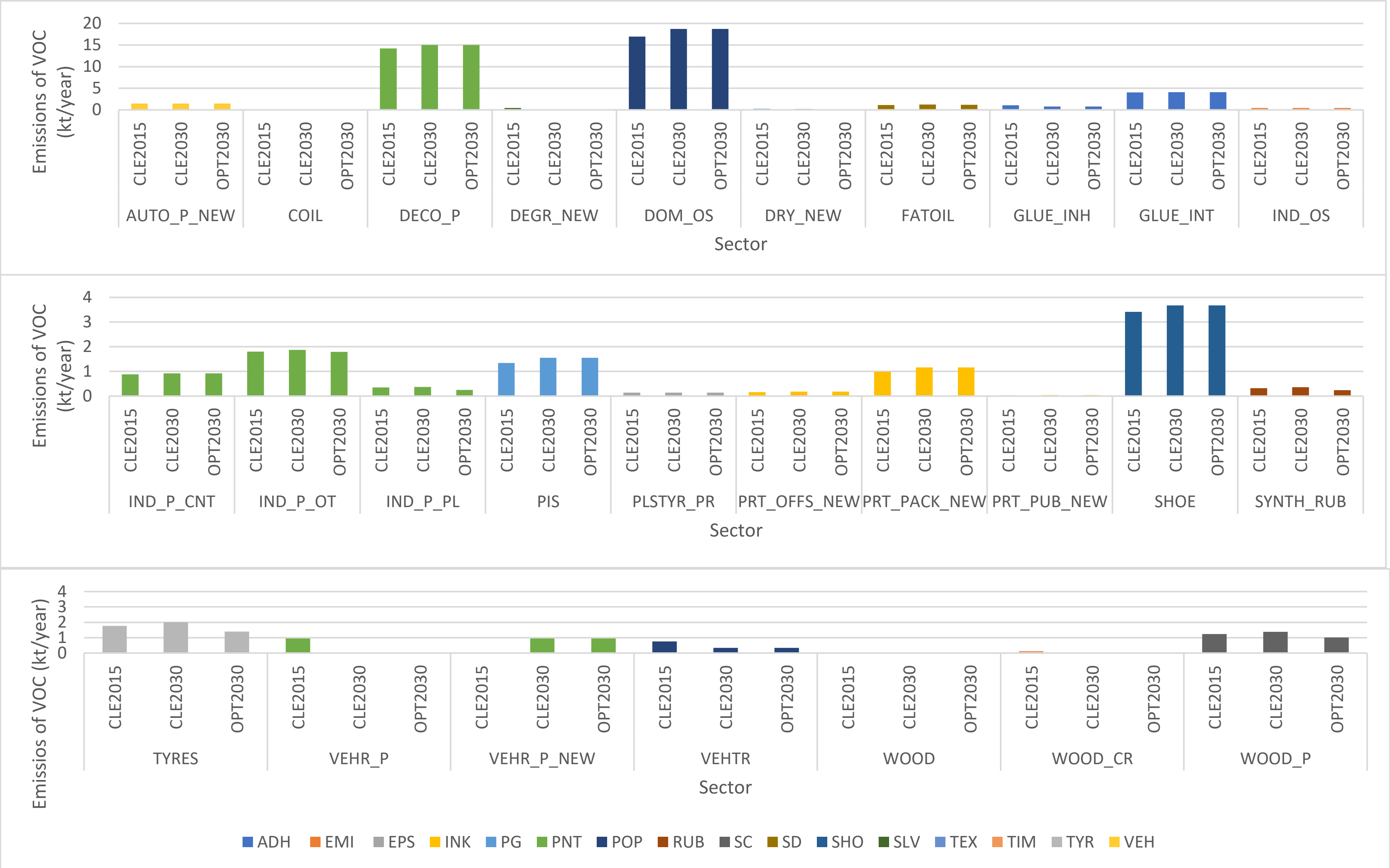

Figure 32: SNAP6 emissions of VOC (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

In general, although there are no relevant changes in the emissions of VOC in the future scenarios, a tendency to an increase is verified in most of the sectors. Sectors DECO_P and DOM_OS are the ones with highest emissions of VOC, experimenting an increase in 5% (DECO_P) and 10% (DOM_OS) in the future scenarios, related to the increase in the activity level.

5.1.6.3 Cost

The results of the costs obtained in this SNAP are displayed in the Figure 33 and Figure *34*.

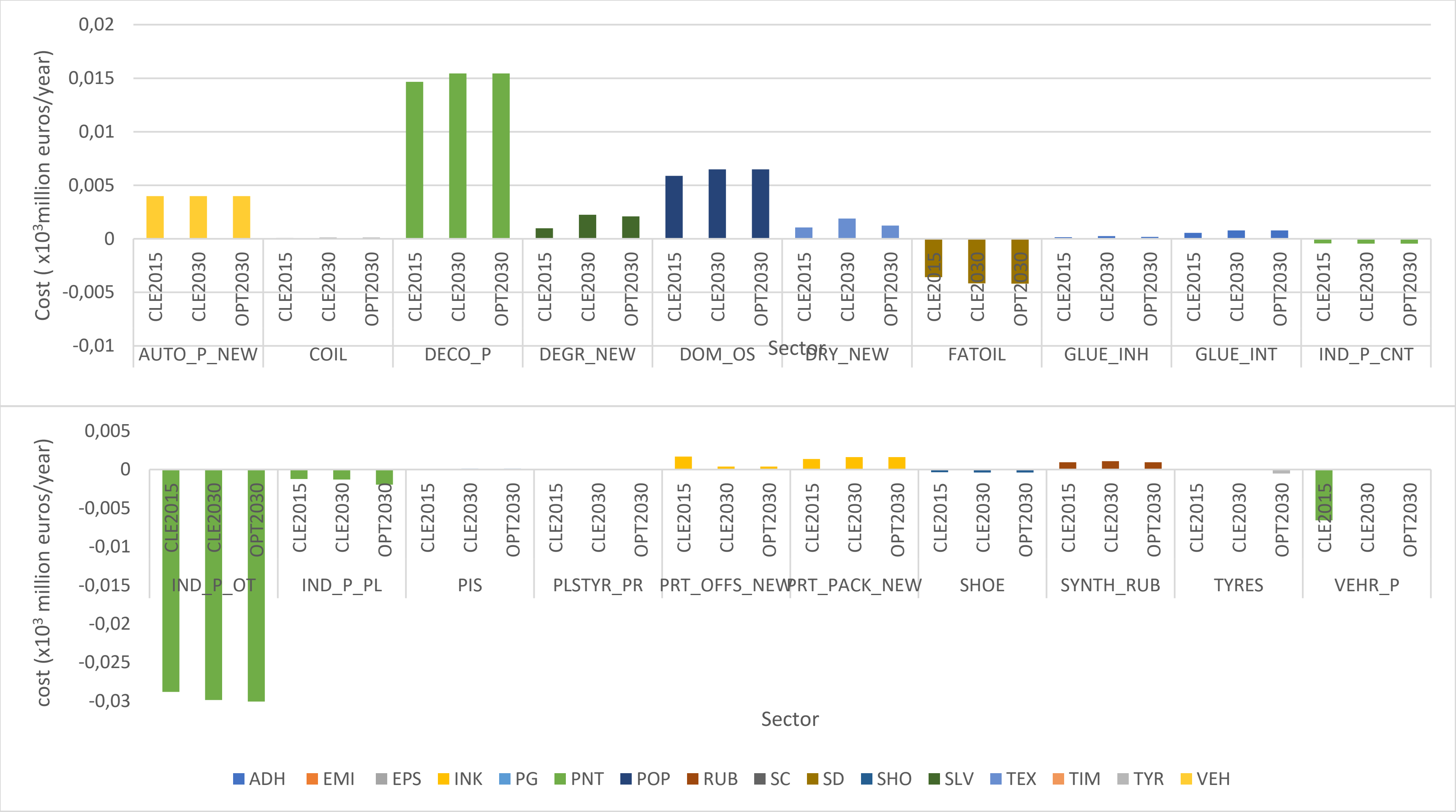

Figure 33: SNAP6 emission control costs (in m€/year) per sector for CLE2015, CLE2030 and OPT2030.

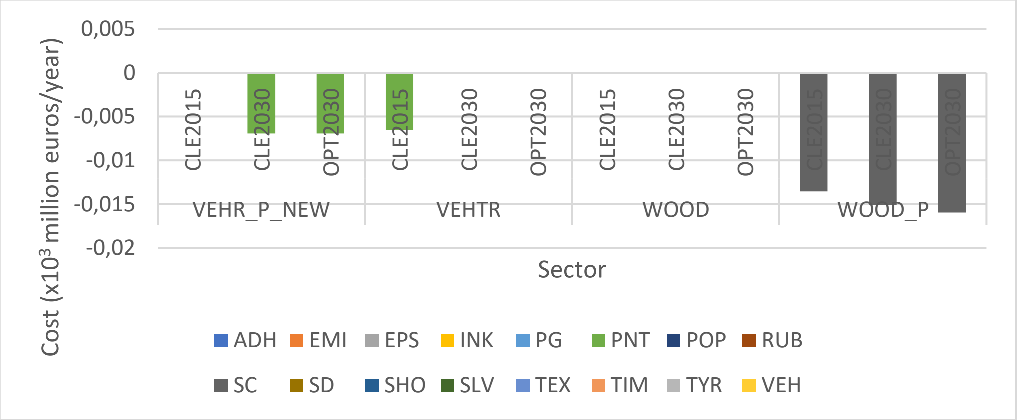

Figure 34: SNAP6 emission control costs (in m€/year) per sector for CLE2015, CLE2030 and OPT2030.

The changings in the costs, as well as was verified in the emissions results, are not significant overall, remaining almost constant throughout the three scenarios.

Sector DECO_P and DOM_OS are the sectors for which higher costs are associated. In the sector DECO_P there is an increase in 5% and in sector DOM_OS an increase in 10% in the future costs.

What is evident in this SNAP is the number of sectors with negative costs. Fat and oil extraction (seeds) (FATOIL), other industrial paint use (IND_P_OT), industrial paint use of plastic parts (IN_P_PL), VEHR_P, VEHR_NEW and WOOD_P, represent the sectors for which savings instead of extra costs are registered.

5.1.6.4 Discussion of the results of SNAP 6

Sector DECO_P and DOM_OS are the sectors for with highest activity level and emission control cost.

The increase in the activity level, emissions and costs in the future scenarios of sector DECO_P is only associated with activity PNT and technology SED (simulation of changes in paint formulation and application patterns). SED technology implies simulations of changes in paint formulations and application patterns in order to comply with the EU General Product Safety Directive (EC, 2001). In order to comply with this directive, a product need to meet all statutory safety requirements under the European and national law.

Regarding sector DOM_OS, for which the activity associated is POP, the increase in the activity level, emissions and costs in the future scenarios is only associated to the increase in the activity level, since the percentage of applications of its technologies (NOC_VOC and REF1) remains constant throughout the three scenarios. The costs in this sector are only associated with technology REF1 (reformulation of products), the one with highest application (75%) in the sector.

In the sector FATOIL, it is possible to verify that the increases in the saving are associated with technology SHM+ACAN. The Schumacher-type Desolventizer/Toaster/dryer/Cooler was created to reduce energy use, being nowadays widely accepted. To the SHM+ACAN technology, it is added a new hexane recovery section and process optimization. The oil removed from the oilseed flakes, leave the extractor with approximately 30% solvent content. Schumacher Desolventizer/Toaster (DT) allows removing the solvent from the flakes. (Crwon Iron, 2020)

In the sector IND_P_OT the increase in the savings is related with the increase in the activity level. This sector, for which only activity PNT is associated, has its savings mainly associated with technology POWDER. Powder coating system technology can achieve nearly 100% use by the recycling of powder coating overspray. This technology is ready to use not requiring stirring, mixing or thinning as it may be with liquid paints. The ease of use of powder, gives lower reject rate compared with wet painting as well as rejects caused by damage after coating are also reduced, due to the toughness of powder coating. An increase in the application of this technology, will result in the increase in the savings (European Council of the Paint Printing Ink and Artists Colours Industry (CEPE), 2020).

In the sector IND_P_PL, also only associated with activity PNT the technologies responsible for the savings are CSBP, WBP and TSBP_IA. These technologies are associated with savings since they have high efficiency application.

Sector VEHR_P is substituted by sector VEHR_P_NEW in the future scenarios. The simulations in sector VEHR_P in scenario CLE2015 and the simulations of sector VEHR_P_NEW in scenarios CLE2030 and OPT2030 are constant and only associated with activity PNT and technology HAMP_SUB1 (primary measures and 25% of high solids and water-based paints). High solids paints, includes more than 60% of solids. Increase the percentage of solids within a paint, means decrease the percentage of solvent content (Mariz et al., 2010). Since the higher the percentage of solids, the higher the area covered, opting for these paints means increasing the savings. Water-based paints are an inexpensive safe and nontoxic technology that reduces or eliminates volatile organic solvents, being a good option against solved-based paints (Lucier & Hook, 1998).

In the sector WOOD_P the only activity associated is SC. In this sector the most relevant technologies, and the ones that mostly contribute to the increase in the savings are VHSS+PRM and HSS+PRM technologies with very high and high (respectively) solids systems, low solvent content and high efficiency. The advantages of these technologies were already mentioned above.

This SNAP does not present relevant changes in the future, related with the fact that in the past this sector has already been forced to implement changings, as it is possible to verify through the technologies applied in the various sector, a lot of them corresponding to saving instead of extra costs.

Fifty years ago, almost all paints were solvent-based, due to its easy application, drying and the formation of a durable regular paint film. Due to its high levels of VOCs emissions, stricter environmental regulations forced to the application of alternative solutions, resulting in the increase on water-based paints applications. The increase on strict environmental and safety regulations lead to the increase on the research targeted to improve durability and application of water-based coating and, nowadays, it is equal or superior to their solvent-based counterparts, in different ways. Their excellent durability, quick dry time and low emissions as well as the low costs, make it an excellent option (Lucier & Hook, 1998).

5.1.7 Road Transport (SNAP 7)

This SNAP is an important emissions' source of NO_x and VOC, being the other emissions simulated for this SNAP irrelevant and consequently not presented and discussed.

5.1.7.1 Activity Level

The results of the activity level (Figure *35* and Figure 36) are presented in different units (PJ/year and Gvkm/year).

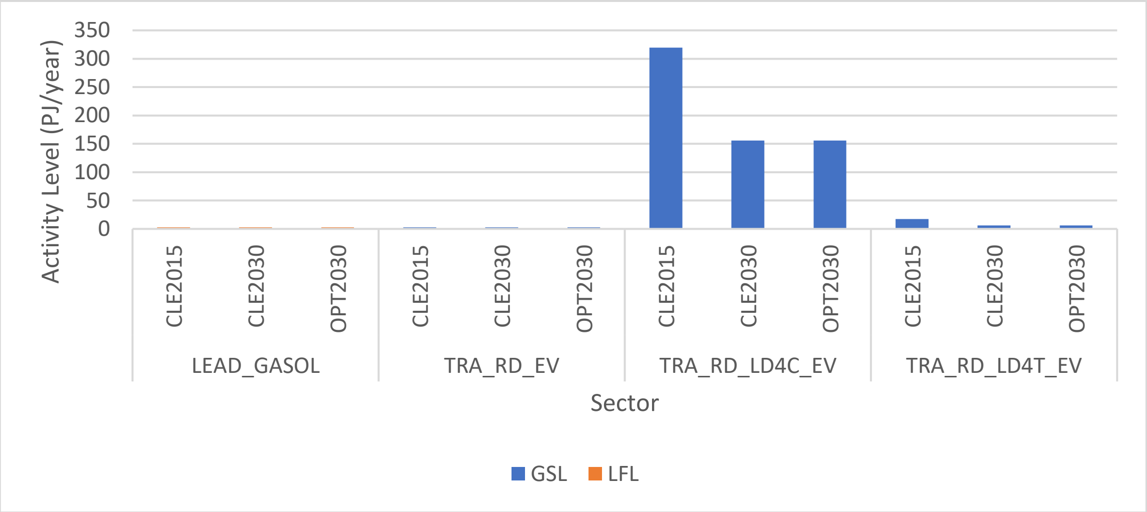

Figure 35 SNAP 7 activity levels (in PJ/year) per sector for CLE2015, CLE2030 and OPT2030.

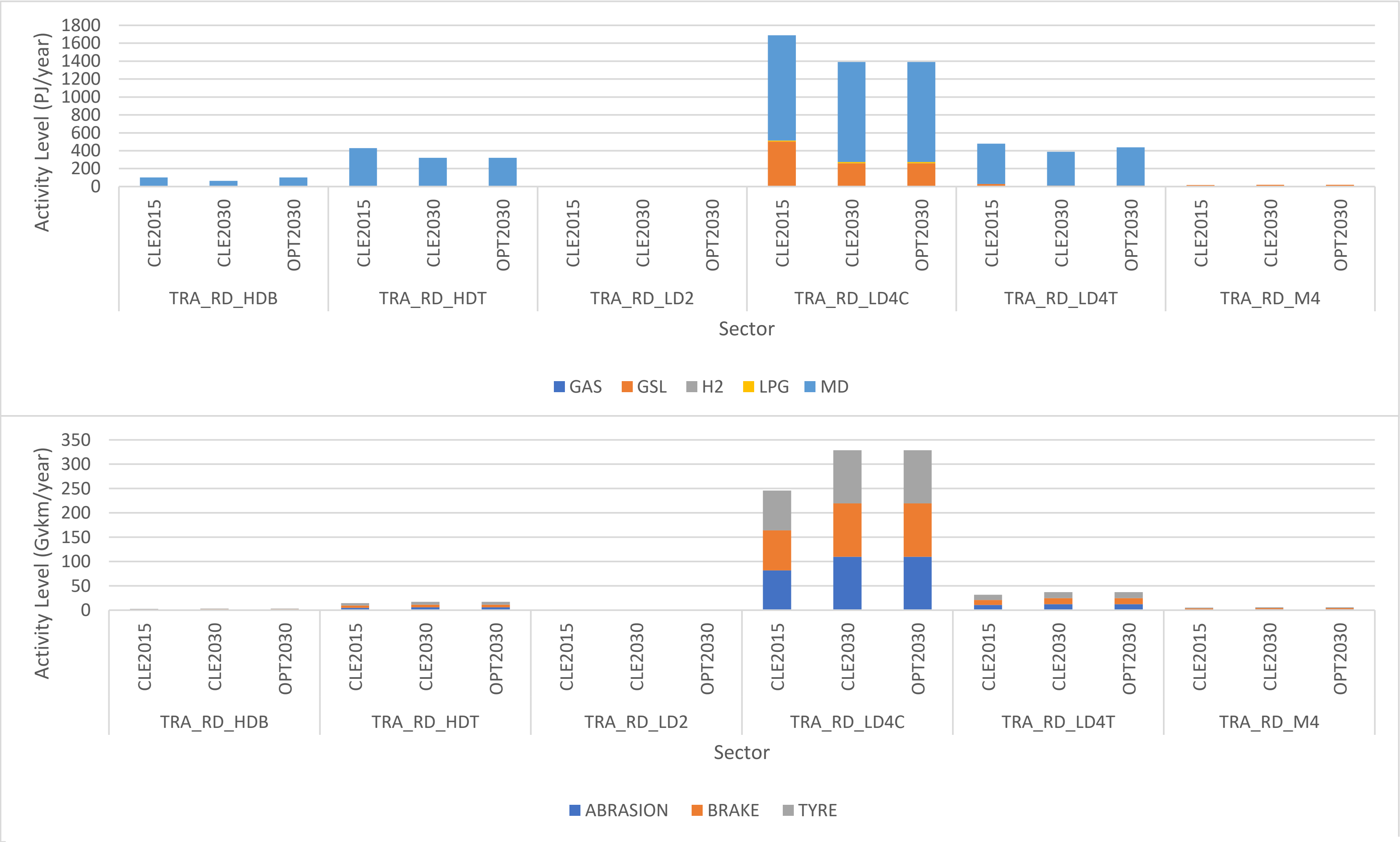

Figure 36: SNAP 7 activity levels (in PJ/year and Gkm/year) per sector for CLE2015, CLE2030 and OPT2030

Regarding activity level, evaporative emissions from cars (TRA_RD_LD4C_EV), heavy duty vehicles (TRA_RD_HDT), cars (TRA_RD_LD4C) and light duty vehicles (TRA_RD_LD4T) sectors are the most relevant.

In the sector TRA_RD_LD4C_EV there is a decrease in 51% in the activity level of the future scenarios, mainly related with the decrease in GSL consumption. Regarding sector TRA_RD_HDT, the decrease is in 25% in the future scenarios, related with the decrease in MD consumption.

In the sector TRA_RD_LD4C the activities LPG, ABRASION, BRAKE and TYRE, suffer an increase in 67% in the activity level of the future scenarios. In this sector is verified a decrease on the consumption of GSL

For sector TRA_RD_LD4T, although the differences throughout the three scenarios are not significative, it is verified a decrease in the activity level in scenario CLE2030 (19%) due to the decrease in GSL consumption and an increase (12%) in scenario OPT2030 due to the increase in MD consumption.

5.1.7.2 Emissions

In this study it is possible to verify that the emissions, presented in *Figure 37* (NOx) and *Figure 38* (VOC) are the most relevant in this SNAP. The results are presented in kt/year for each sector and scenario.

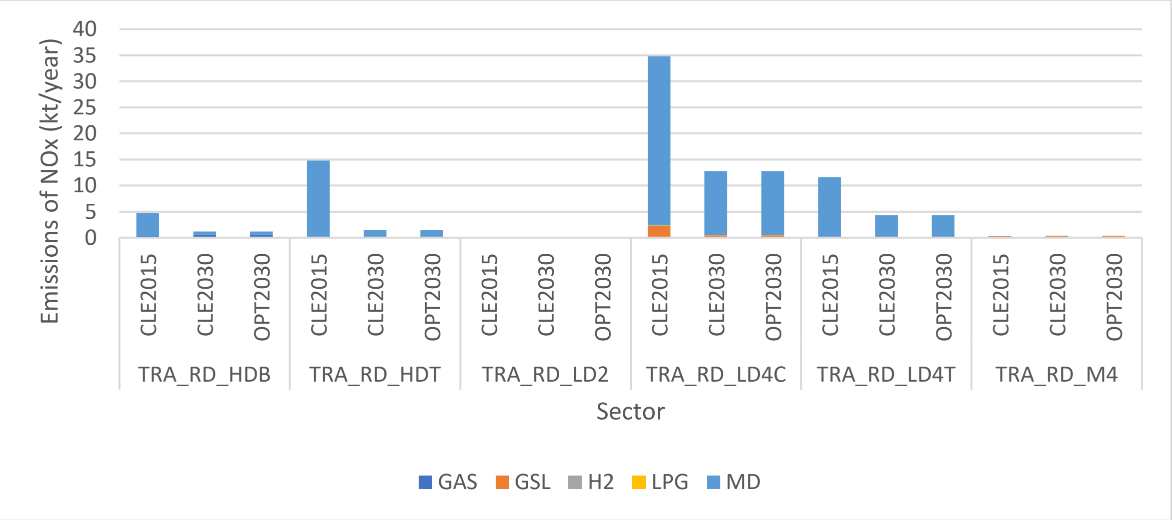

Figure 37: SNAP7 emissions of NO_x (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

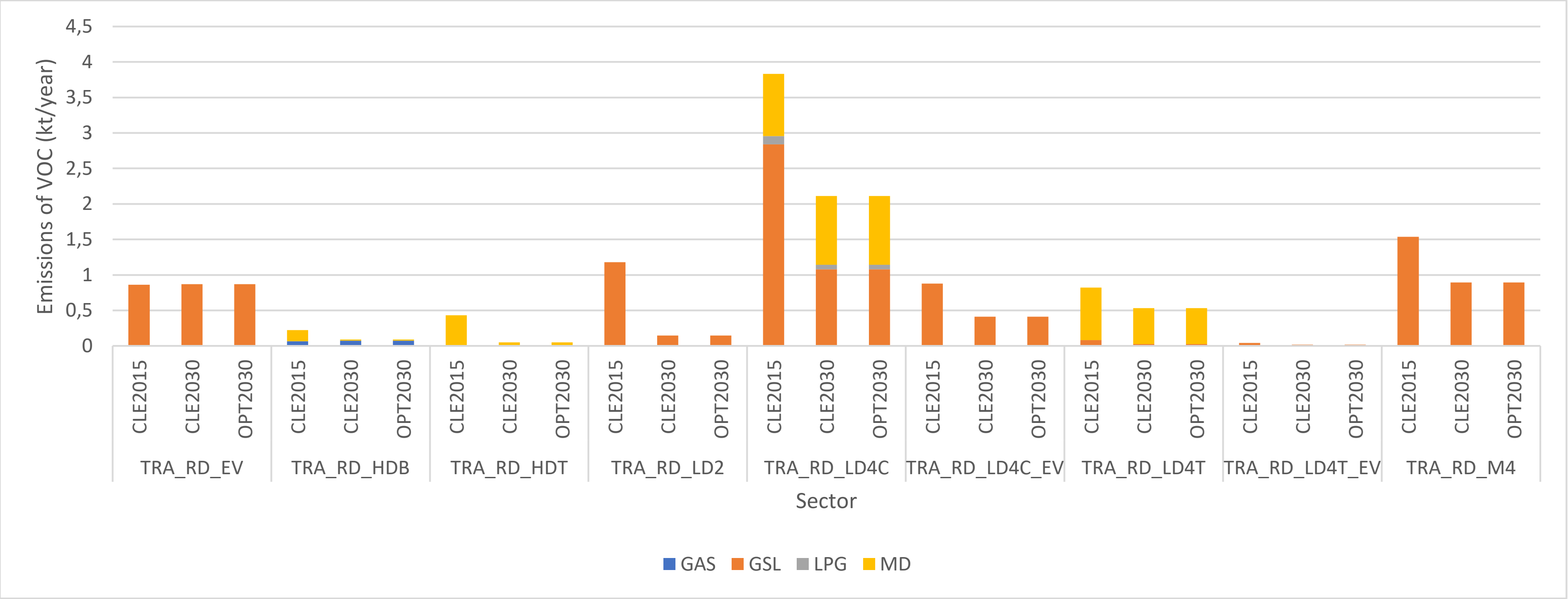

Figure 38: SNAP7 emissions of VOC (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

Regarding NOx, the emissions show a tendency to decrease in the future scenarios, mainly related with sectors TRA_RD_HDT, TRA_RD_LD4T and TRA_RD_LD4C. In the sector TRA_RD_HDT there is a decrease in 89% in the future NO_x emissions mainly related with activity MD. The different EURO standards for heavy duty diesel vehicles (HDEUI, HDEUII and HDEUIII), the main responsible for the decrease in the emissions in the future scenarios, justifying, together with the decrease in the activity level, the decrease in the emissions. With the absence of HADEUI, HADEUII and HDEUIII technologies in the future scenarios the percentage of application of HDEUIV, HDEUV and HDEUVI (technologies with lower emission factors) increases. In the sector TRA_RD_LD4T there is a decrease in 35% in the future NO_x emissions, related with the decrease in MD consumption and with the fact that the technologies MDEUI, MDEUII and MDEUIII, (euro standards for light duty and passenger cars) technologies are only present in scenario CLE2015. It is possible to verify that the sector TRA_RD_LD4C is the one that most contribute to the decrease in the emissions of NO_x, corresponding to a decrease in 63%. This decrease is mainly associated with activity MD. In the future scenarios, the percentage of application of technology MDEUVI increases significantly resulting in the decrease in the application of technologies MDEUI (not presented in the future scenarios), MDEUII, MDEUIII, MDEUIV and MDEUV, which have higher emissions factors for NO_x.

Respecting VOC emissions, they also decrease in the future scenarios. Sector TRA_RD_LD4C not only is the main responsible for the emissions of VOC, but also the one that most contributes for its reduction, with a decrease in 45% in the future emissions. This decrease is mainly related with activity GSL. Once again, it is verified an increase in the application of technology LFEUVI and a decrease on the application of technologies LFEUII, LFEUIII LVEUIV and LFEUV (euro standards for light-duty, spark ignition engines) technologies with higher emissions factors for VOC. The decrease on the emissions is also related with the decrease in the activity level.

This SNAP presents emissions for NH_3, PM2.5 and SO_2, although, as the results are not relevant, they are not discussed.

5.1.7.3 Cost Results

Regarding the cost results for SNAP 7, mopeds (TRA_RD_LD2) and combustion in fuel conversion (TRA_RM4) sectors present costs, although not relevant comparing to the other sectors.

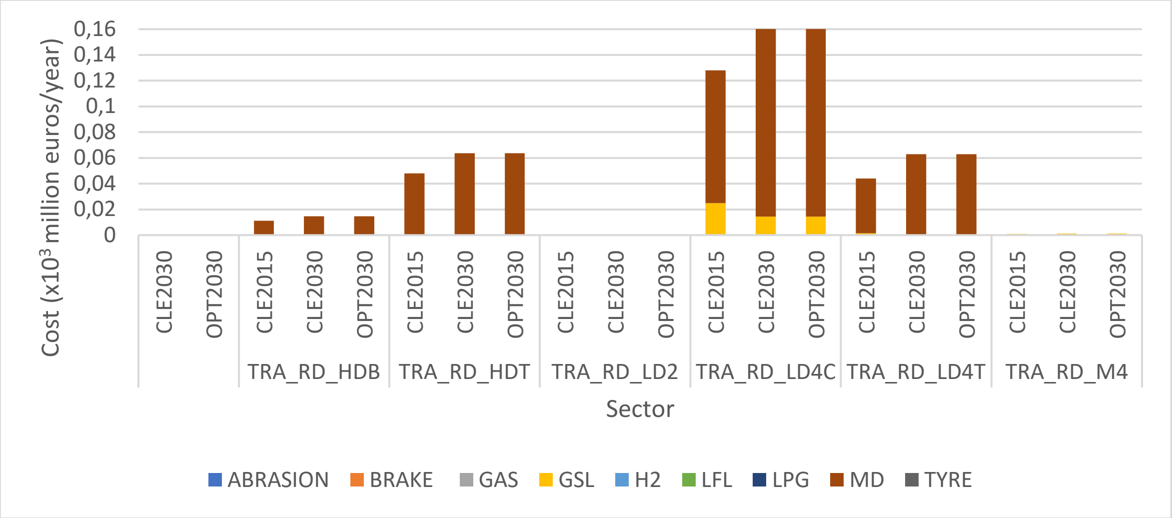

Figure 39: SNAP7 emission control costs (in m€/year) per sector for CLE2015, CLE2030 and OPT2030.

In a general way it is possible to verify that the increase in the cost in the future scenarios is associated with sectors TRA_RD_HDT, TRA_RD_LD4C and TRA_RD_LD4T. Sectors TRA_RD_HDT, TRA_RD_LD4C and TRA_RD_LD4T, the cost in the future scenarios is constant, facing an increase in 32 % (TRA_RD_HDT), 26% (TRA_RD_LD4C) and 43% (TRA_RD_LD4T). The increase in the costs not only is associated with increases in the activity level but also with the increase in the application of higher demanding (regarding reduction impositions) technologies.

5.1.7.4 Discussion of the results of SNAP 7

Despite the growing of the transport sector, the stricter regulations in diesel vehicles emissions, limit the growth of these emissions, resulting in the stabilisation and even decline of the transport emissions growth. In this SNAP it is clear the influence of European emissions standards for the heavy-duty vehicles, light-duty vehicles and passenger cars. The European emissions standards define the acceptable limits for exhaust emissions of new vehicles sold in European Union and European Economic Area. The number included in the acronym identifies the level of demand, meaning that, the higher the number, the less polluting the car is. So that, is understandable that the application of these technologies results in the decrease on the emissions. Every time the standard is updated the manufactures must discontinue all the vehicles manufactured in accordance with the previous standards. Since the first norm established by EU (1998), models sold in the Member States have been forced to meet the imposed targets, which vary according to the type of engine and fuel used and market.

5.1.8 Other mobile sources and machinery (SNAP 8)

In order to understand the simulations performed for SNAP 8, in this point they are presented and discussed.

5.1.8.1 Activity Level

The activity level results obtained in this scenario are presented in Figure 40.

Other transport in agriculture (TRA_OT_AGR) and air traffic (TRA_OT_AIR) are the sectors with highest activity level, and also the sectors for which more relevant changes in the future scenarios are registered. Sector TRA_OT_AGR has a decrease in 42% in the activity level of the future scenarios related with the decrease in MD consumption. Sector TRA_OT_AIR presents an opposite behaviour, registering an increase in 12% in the activity level of the future scenarios associated with increase in GSL consumption.

Construction machinery (TRA_OT_CNS) sector, is also an important sector in the reduction of the activity level in future scenarios, mainly associated with activity MD. In this sector there is a decrease in 89% in scenario CLE2030 and in 97% in scenario OPT2030, regarding the activity level.

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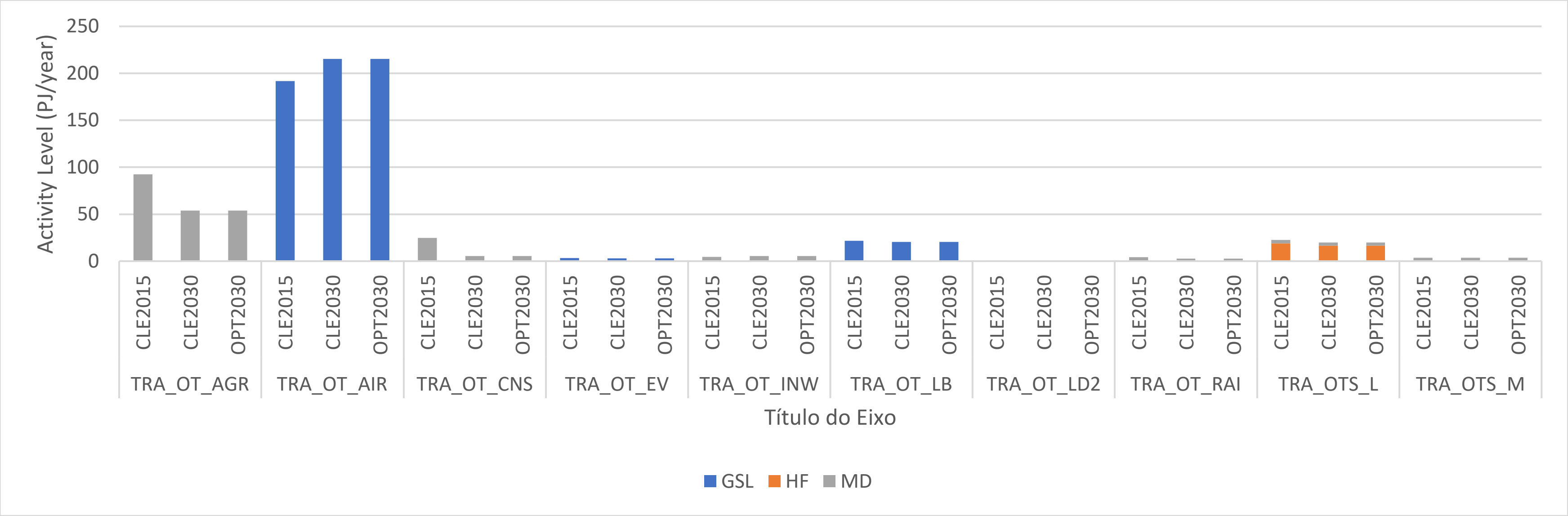

Figure 40: SNAP8 activity levels (in PJ/year) per sector for CLE2015, CLE2030 and OPT2030.

5.1.8.2 Emissions

Analysing Figure 41, Figure 42 and Figure 43 it is possible to identify the sectors that most contribute to the emissions.

The decreases in NOx emissions verified in this SNAP are mainly related with sector TRA_OT_AGR, which verifies an increase in 30% in the future. The same happen regarding pollutant PM2.5, which has a significant decrease (81%) in the future scenarios, in this sector.

The emissions of VOC, also reveal a significant decrease in the future scenarios, mainly associated with sectors TRA_OT_AGR (41%), TRA_OT_CNS (50%), TRA_OT_EV (evaporative emissions from gasoline vehicles) (5%), TRA_OT_LB (sources with 4-stroke engines including military, households, etc.) (75%) and TRA_OT_LD2 (mopeds) (69%).

In the sector TRA_OT_AIR there is an increase in 12% in the emissions of VOC related with the increase in GSL consumption.

The sector TRA_OT_AGR is the one that stands what, with highest changes in the emission trends. This sector represents a significant decrease in the emissions o NOx,, PM2.5 and VOC, mainly related with de elimination of no control technologies (NOC_NOx, NOC_PM2.5 and NOC_VOC) in the future scenarios and the implementation of technologies CAGEUIV, CAGEUV (EURO standards technologies for off road high duty vehicles in construction and agriculture).

There are emissions associated for NH_3 and SO_2, although not significant.

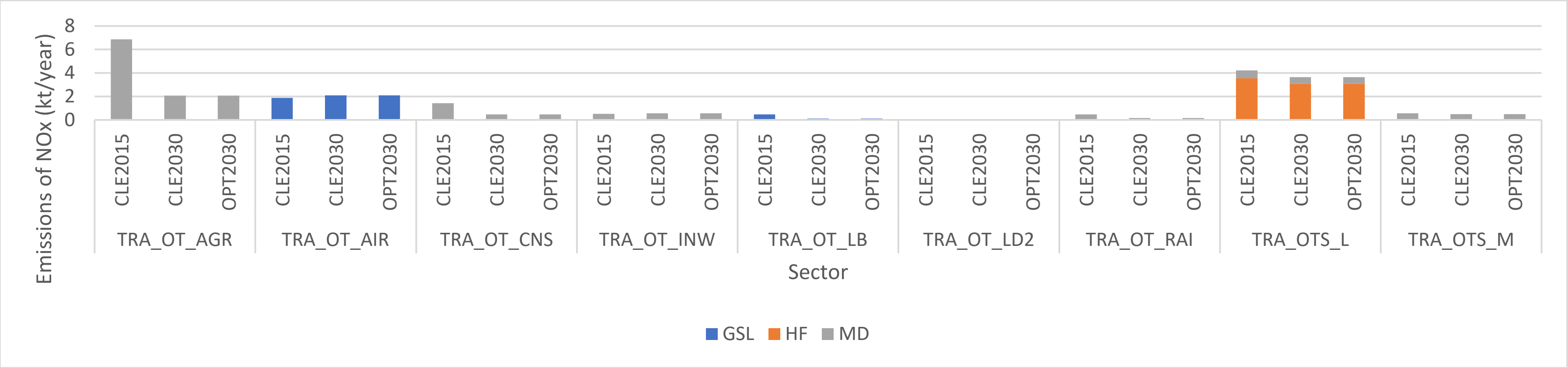

Figure 41: SNAP8 emissions of NO_x (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

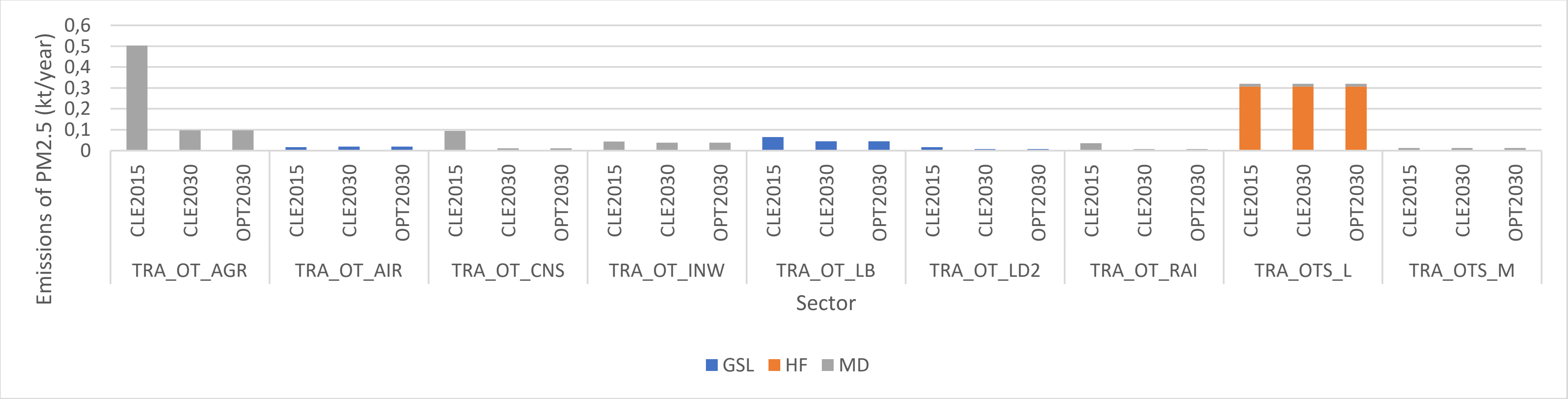

Figure 42: SNAP8 emissions of PM2.5 (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

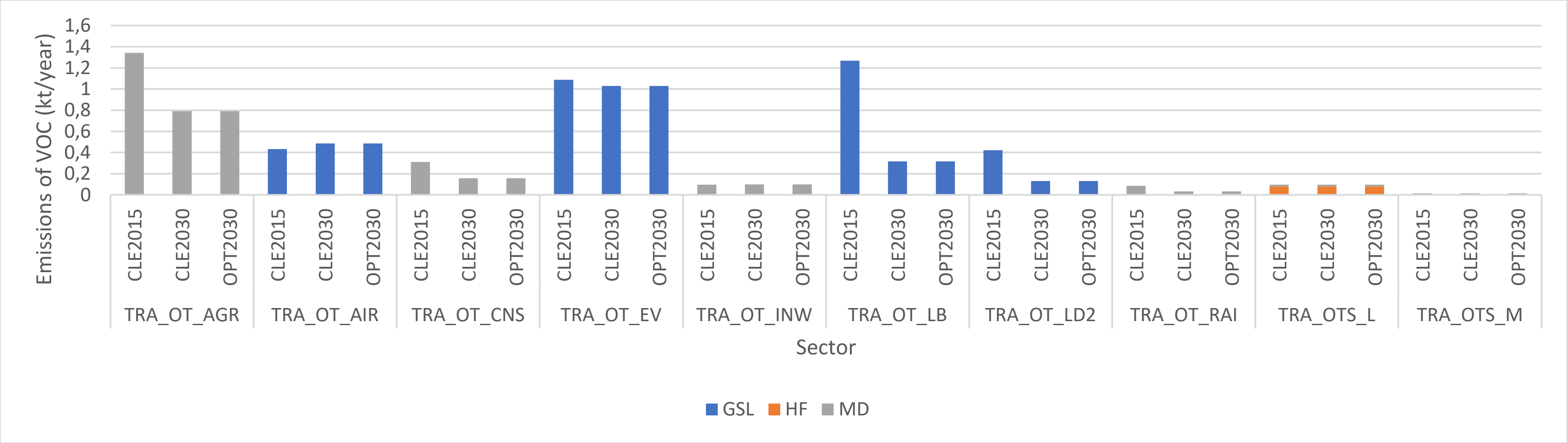

Figure 43: SNAP8 emissions of VOC (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

5.1.8.3 Cost

In the *Figure 44*, the costs for SNAP 8 are presented and, although in general it does not suffer significant changes, it is possible to verify an increase in the future scenarios.

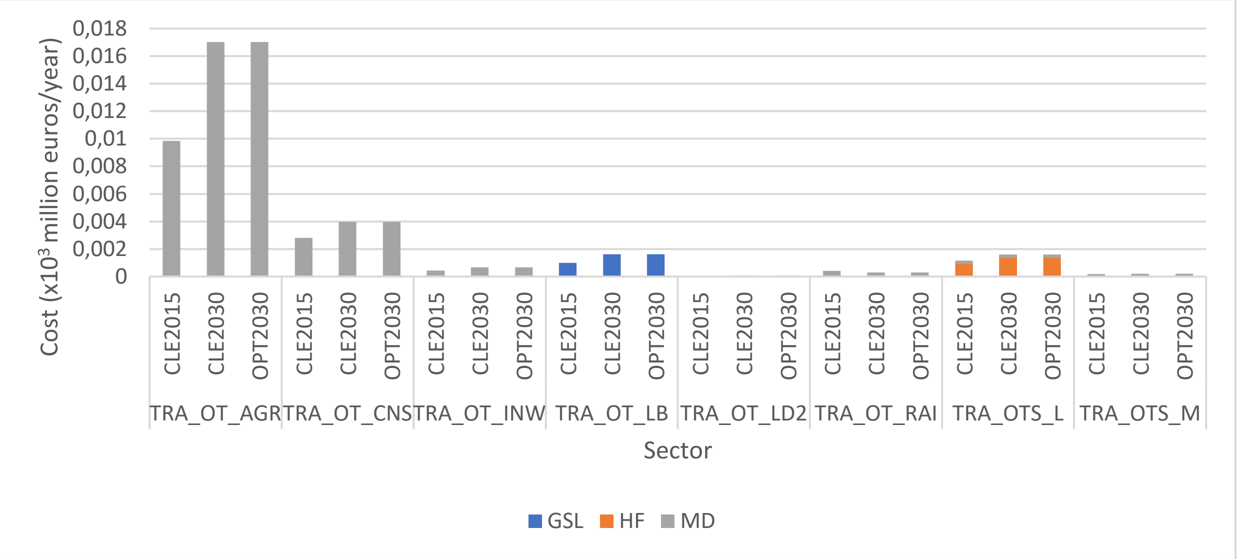

Figure 44: SNAP8 emission control costs (in m€/year) per sector for CLE2015, CLE2030 and OPT2030.

Sector TRA_OT_AGR stands out from all the scenarios, being the one with highest costs associated, facing an increase in 73% in the future scenarios, mainly related with the implementation of new technologies.

5.1.8.4 Discussion of the results of SNAP 8

This SNAP, covers a very wide variety of machinery typically used off the road in many ways. It does not present significant changings in an over all, although it is possible to identify sector TRA_OT_AGR, which represents off road, agriculture and forestry mobile sources, as the one for which more significant changes are identified. It verifies a decrease in the future emissions due to the application of technologies CAGEUIV and CAGEUV.

In this SNAP it is clear the influence of European emissions standards for vehicles in construction, agriculture, train, inland waterways, equivalent to high duty vehicles standards. Following the same logic, the higher the number in the code, the higher the removal efficiency, so that, it is possible to verify that in the future scenarios the application of technologies with higher numbers (IV, V and VI) is significant higher.

In an overall it is verified a decrease in the consumption of diesel mainly associated with agriculture sector and an increase in the consumption of gasoline mainly associated with air traffic.

5.1.9 Waste treatment and disposal (SNAP 9)

This SNAP cover the waste treatment and disposal, including batteries, electrical equipment, incineration, landfill, lighting, measurement and control equipment, offshore flaring, refineries (flares), regeneration of activated carbon and sewage sludge disposal.

The simulations for this SNAP do not expect significant changings in the future, being the activity level and consequently, the emissions constant in the three scenarios. In this SNAP there are no NOx and SO_2 emissions. Any control cost is also registered in this SNAP. The results obtained shows that this SNAP is not relevant for this study.

5.1.10 Agriculture (SNAP 10)

In this point there will be shown the results of activity level, emissions and costs, obtained for this SNAP. The NH_3 emissions are the only relevant, so that, the only presented and discussed.

5.1.10.1 Activity Level

In the *Figure 45* it is possible to verify the emission variation for SNAP 10.

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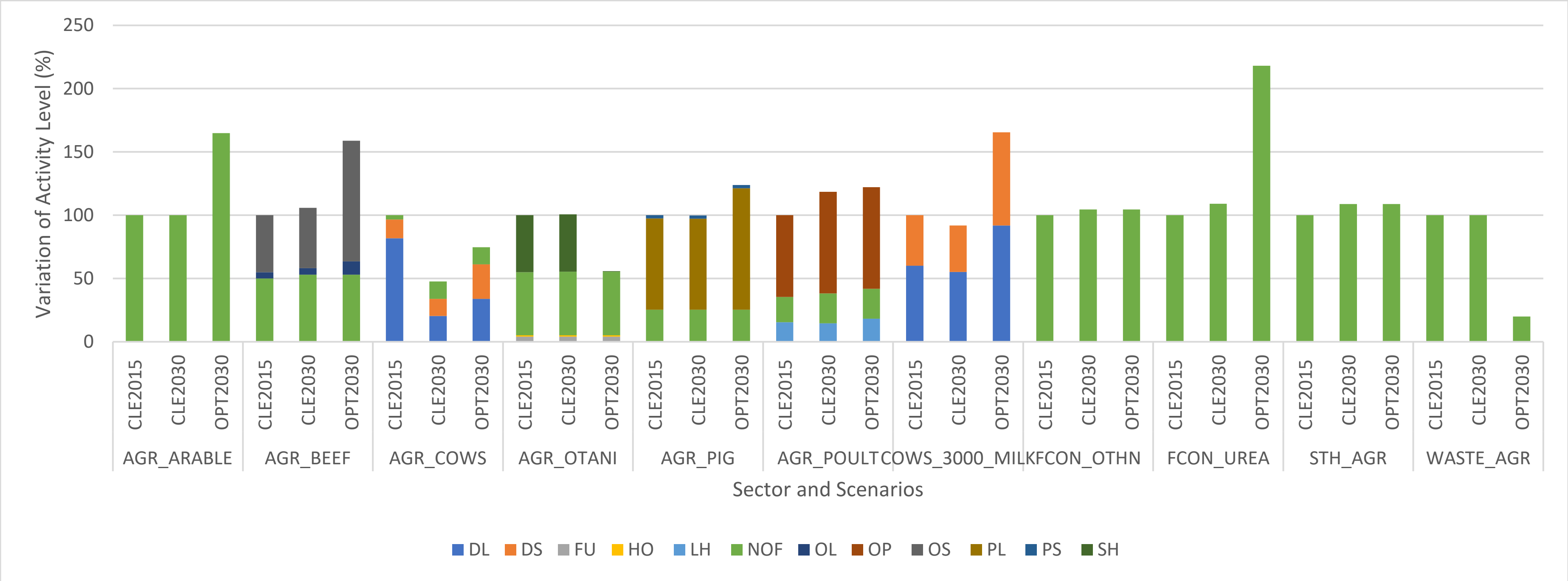

Figure 45: SNAP 10 variation on the activity levels (in %) per sector for CLE2015, CLE2030 and OPT2030

Table 5 Units for the activity level results of SNAP 10

Activity	Unit	Sector
DL	M animals	AGR_COWS
	kt milk	COWS_3000_MILK
DS	M animals	AGR_COWS
	kt milk	COWS_3000_MILK
FU	M animals	AGR_OTANI
HO	M animals	AGR_OTANI
LH	M animals	AGR_POULT
NOF	M ha	AGR_ARABLE
	M animals	AGR_BEEF
		AGR_COWS
		AGR_OTANI
		AGR_PIG
		AGR_POULT
	kt N	FCON_OTHN
		FCON_UREA
	Mt	STH_AGR
		WASTE_AGR
OL	M animals	AGR_BEEF
OP	M animals	AGR_POULT
		AGR_POULT
		AGR_POULT
		AGR_POULT
OS	M animals	AGR_BEEF
PL	M animals	AGR_PIG
		AGR_PIG
		AGR_PIG
PS	M animals	AGR_PIG
		AGR_PIG
SH	M animals	AGR_OTANI
NOF	Mt	WASTE_AGR

Sectors dairy cattle (AGR_COWS), other livestock (sheep, horses) (AGR_OTANI) and agricultural waste burning (WASTE_AGR), presents decreases in the activity level in the future scenarios. The decreases in 52% (CLE2030) and 25% (OPT2030) in the activity level of sector AGR_COWS is related with the decrease in the activity level of activity NOF. The increase in 44% in the activity level in scenario OPT2030 in sector AGR_OTANI is related with the decrease in activity SH (sheep and goats). In the sector WASTE_AGR there is a decrease in 80% in the activity level of the optimum scenario related with the decrease in activity NOF.

The sectors for which increases in the activity level are registered are: ploughing, tilling, harvesting (AGR_ARABLE), other cattle (AGR_BEEF), pig-livestock (AGR_PIG), poultry (AGR_POULT), milk yield over 3000 kg/animal threshold (COWS_3000_MILK), mineral nitrogen fertilizers use excluding urea (FCON_OTHN), urea application (FCON_UREA) and storage and handling of agricultural crops (STH_AGR). Sectors AGR_ARABLE and FCON_UREA, experiment a significant increase in scenario OPT2030, related to the increase in the activity level of activity NOF. Sector AGR_BEEF, AGR_PIG and COWS_3000_MILK are the sectors for which the most relevant increase in the optimum scenario is registered. In sector AGR_BEEF there is an increase in 6% (CLE2030) and 95% (OPT2030) in the activity level, mainly related with the increase in the use of solid systems (OS). Regarding sector AGR_BEEF the increase in 23% in the future scenarios is related with the decrease in the use of liquid systems (PL). The increase in 66% in the activity level of sector COWS_3000_MILK is related with the in increase in the use of solid and liquid systems (DL and DS).

5.1.10.2 Emissions Results

In this SNAP, the most important pollutant is NH_3 (Figure 46).

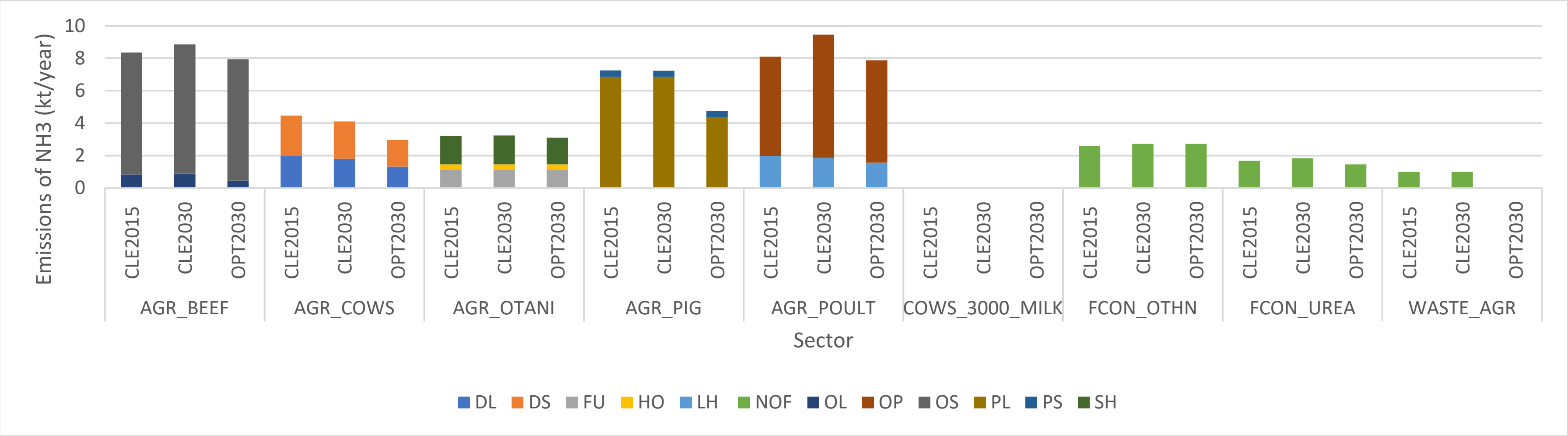

Figure 46: SNAP 10 emissions of NH_3 (in kt/year) per sector for CLE2015, CLE2030 and OPT2030.

Sectors AGR_BEEF and AGR_POULT are the sectors responsible for the increase in the emissions of NH_3 in scenario CLE2030.

In sector AGR_BEEF, the increase in the emissions of NH_3 in scenario CLE2030 corresponds to 6%, related to the increase in the activity level. Since the activity level of OS is much higher than the activity level of OL, this activity is the highest source of NH_3 in this sector. In the optimum scenario it is verified a decrease (in 5%) in the emissions due to the addition of low ammonia application with a high efficiency (LNA_high) technology.

In the sector AGR_POULT the reason of the increase in 18% in the NH_3 emissions in scenario CLE2030 is related with the increase in the activity level. The increase in the use of low nitrogen feed (LNF), low ammonia in combination with low emission housing (LNF_SA_LNA), low emission housing and manure application (SA_LNA), use of LNF and (CS) low ammonia application (LNA) in the covered outdoor storage of the manure (LNF_CS_LNA) and use of LNF in combination with LNA (LNF_LNA) results in the decrease in the emissions of NH_3 in scenario OPT2030.

These sectors together with sectors AGR_COWS, AGR_PIG and WASTE_AGR, suffer a decrease in the emissions in the optimum scenario. In the sector AGR_COWS the decrease in the emissions from scenario CLE2015 to scenario CLE2030 (8%) is related with the decrease in the activity level of DL. From these scenarios to scenario OPT2030, although it is verified an increase in the activity level, lot of changes on the abatement technologies are presented, resulting in the decrease of the emissions (in 34%). The increase in the use of low efficient (LNA_low) and high efficient LNA (LNA_high), LNF, combination of LNF and CS (LNF_CS) and LNF_LNA results in the decrease of NH_3 emissions. In the sector AGR_PIG there is a decrease in 34% in the NH_3 emissions in the optimum scenario also due to the increase in the use of LNF, LNF_LNA, LNF_SA_LNA and SA_LNA. The sector WASTE_AGR does not present emissions in the scenario OPT2030 related with the ban on open burning (BAN).

5.1.10.3 Cost Results

The cost associated with SNAP 10 (*Figure 47*) slightly increases in the future scenarios being sectors AGR_PIG and AGR_POULT the ones with highest costs. The increase is not only associated with the increase in the activity level but also with the addition of new technologies. The optimum scenario is the one for which the highest costs are experimented.

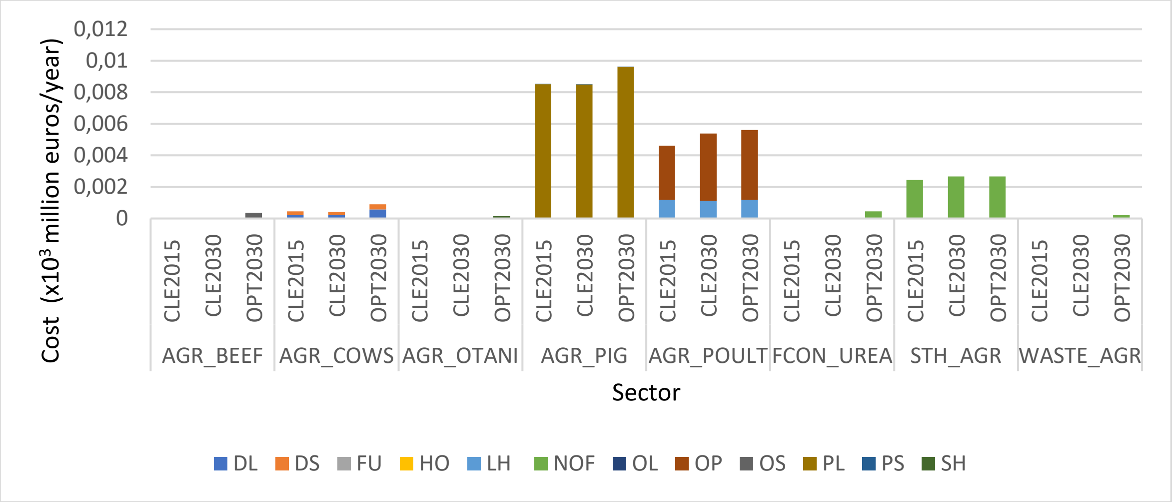

Figure 47: SNAP10 emission control costs (in m€/year) per sector for CLE2015, CLE2030 and OPT2030.

5.1.10.4 Discussion of the results of SNAP 10

The results show that dairy and other cattle, pig production and poultry (are the largest sources of NH_3 emissions.

The NH_3 abatement technologies are mainly divided into feeding strategies and housing strategies. Feeding strategies aims to implement low nitrogen content in order to reduce the NH_3 emissions. Animal faeces and urine extracted by livestock results in gaseous N losses. So that, changings in the animal feed influences the composition of the faeces and urine, being a widely used strategy to reduce NH_3 emissions. Low emissions housing implies techniques to reduce NH_3 emissions. Some examples of techniques that help in reducing NH_3 in cattle housing are: decrease the surface area fouled by manure; absorption or adsorption by bedding (e.g. straw); fast removal of urine and rapid separation of faeces and urine; decreasing the velocity and temperature of the air above the manure (except when it is being dried); reducing the temperature of the manure; decreasing the soiled areas in houses and hard standings by increased grazing or removing NH_3 from the air trough forced ventilation in combination with air scrubbers (Council, 2014)

The model projects the elimination of open burn in the optimum scenario. Burning crop residues is mainly used to clean land rapidly and in an inexpensive way. Legislation within the EU has largely outlawed the practice of field burning agricultural wastes (European Environment Agency (EEA), 2013). The main mitigation measure to control emissions from the open burning of agricultural residues is to ban the practice, as suggested in the United Nations Environmental Programme in industrialised countries (United Nations (UN), 2011).

5.1.11 Main outcomes of the national totals' analysis

For a global assessment of the results of GAINS scenarios by SNAP sector, the differences throughout the three scenarios, in terms of totals were analysed (*Table 6*). Regarding scenario CLE2030, NOx is the pollutant that is closer to the NEC target. For the other pollutants relevant additional emission control measures are required achieving the NEC targets in scenario OPT2030. As expected, the extra effort taken by scenario OPT2030, results in higher emission control costs.

Table 6 Emission and costs results in terms of totals for each scenario and pollutant

	NH_3 (kt)	**NOx (kt)**	**PM2.5(kt)**	**SO_2 (kt)**	**VOC (kt)**	**Cost (m€)**
CLE2015	50.0	125.7	47.5	45,8	165,6	543
CLE2030	52.6	99.3	36.7	48,7	141,4	509
OPT2030	42.9	94.8	25.9	29,9	130,4	518
Target	42.7	95.2	26.8	30,0	131,8	

Not all the SNAP present relevant changings in the future scenarios, being possible to stand out, in which of them extra effort will need to be more significative in order to reach the targets in a cost-effective way. The Table *7* displays the extra effort implied by scenario OPT2030, meaning, the difference between the results of scenario OPT2030 and scenario CLE2015.

Table 7: Extra effort that should be taken under scenario OPT2030 relative to scenario CLE2030 (OPT2030-CLE2030).

OPT2030-CLE2030						
SNAP	NH_3 (kt)	NOx (kt)	PM2.5(kt)	SO_2 (kt)	VOC (kt)	Cost (m€)
1	0.00	-0.01	0.00	-8.02	-0.01	3.49
2	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	-1.03	0.00	-2.09	0.00	1.58
4	0.00	-1.59	-8.90	-8.59	-6.53	4.48
5	0.00	000	0.00	0.00	-0.69	-0.03
6	0.00	0,00	0.00	0.00	-1.42	-3.31
7	0.00	0.00	0.00	0.00	0.00	0,00
8	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00
10	-9.71	-1.93	-1.92	-0.08	-2.31	2.99
Total	-9.71	-4.55	-10.82	-18.77	-10.97	9.19

SNAP 1 has relevant emissions of NOx and SO_2 being verified a reduction in the emissions in the future scenarios. Scenario OPT2030 is the one associated with the lowest emissions although presenting higher cost due to the application of an abatement technology with higher costs associated (LSHF).

The results of SNAP 2 demonstrate that the emissions of NOx, PM2.5 and VOC decrease in the future scenarios. The results obtained are similar for scenarios CLE2030 and OTP2030. The sectors for which a higher cost is associated are the ones that face the main decrease in the emissions, not influencing the overall cost of the future scenarios, which presents a decrease comparing to scenario CLE2015.

The relevant emissions in SNAP 3 are verified for NOx and SO_2.The results obtained for scenario CLE2030 and OPT2030, are practically constant, although the optimum scenario presents lower emissions. Sectors PR_CEM, PR_GLASS and PR_LIME, not only are associated with the increases in the emissions in the future scenarios, but also with the increases in the costs.

In SNAP 4, emissions of PM2.5, SO_2. and VOC, are the most relevant, decreasing throughout the three scenarios. The costs are practically constant throughout the three scenarios although, scenario OPT2030 has associated higher savings. So that, scenario OPT2030 presents the most cost-effective options, reducing the emissions and increasing the savings.

SNAP 5 does not represent significant changes throughout the simulations. The only relevant emissions are for VOC, which present a decrease in the future scenarios. The same behaviour is registered for costs, also decreasing in the future scenarios.

SNAP 6, only presents emissions for VOC. This SNAP does not present relevant changings in the future scenarios, being verified that that a lot of technologies presented in the current legislation are already the best solution in terms of emissions abatement and costs (a lot of them corresponding to savings instead of extra cost). This SNAP was identified as the one which has suffered more changings in the last 50 years, what may justify that no relevant changings are expected in the future scenarios.

SNAP 7 and SNAP 8 presents the same emissions results for scenario CLE2030 and OPT2030. This means that the legislation already implies the application of the best technologies in terms of costs and emissions reduction. So that, scenario OPT2030 did not simulate extra measures in SNAP 7 and SNAP 8 since it would be reflected in higher costs, being preferable to act in other SNAP. Regarding SNAP 7 the emissions of NOx and VOC are the correspondent to the most relevant reduction in the future scenarios, resulting in approximately 25% increase in the costs. The same goes for SNAP 8 for NOx, PM2.5 and VOC. The technologies associated with these SNAP are mainly related with European emissions standards for heavy-duty vehicles, light-duty vehicles and passenger cars. The technologies applied in the future scenarios have higher demand, what results in higher cost associated. Although representing more costs, these technologies have to be implemented being efficient in the reduction of the emissions.

SNAP 9 does not represent significant results for this study. The results are practically constant throughout the three scenarios not being verified changes. In this SNAP it is not registered any extra cost.

In SNAP 10 the most relevant emissions are for NH_3. Scenario OPT2030 is the one that presents the lowest emissions and, although it is verified an increase in the cost, it just corresponds to an increase in 6% comparing to the cost of the scenario CLE2015. The increase in the cost is not only related with the increase in the activity level, but also with the introduction of new technologies for which higher unit costs are associated. Scenario CLE2030, although having lower costs, shows a tendency to an increase in NH_3 emissions, that need to be reverted by additional measures. So that, even with higher cost, scenario OPT2030 represents good options for emissions reduction.

5.2 Emission and costs-spatial variability

EESIP-Air produces spatially distributed results in the predefined grid over Portugal, at 5 x 5 km^2 horizontal resolution, allowing to understand in which parts of the country the emission reduction measures will have to be bigger in order to achieve the targets at least cost. The analysis of results is based on the spatial distribution of emission totals, to identify the regions of Portugal where emissions are more relevant, and for specific SNAPs to evaluate the differences between each scenario. When relevant, SNAP results are analysed. The SNAP presented were selected according to their relevance regarding the different pollutants' emissions. For a global assessment of the scenarios, the spatial variation of costs was also analysed.

5.2.1 Emissions of NOx

NOx emissions are, as can be observed in Figure *48*a, mainly related to the urban centers of Porto and Lisbon. Also, some disperse higher emission values are verified, corresponding to industrial areas.

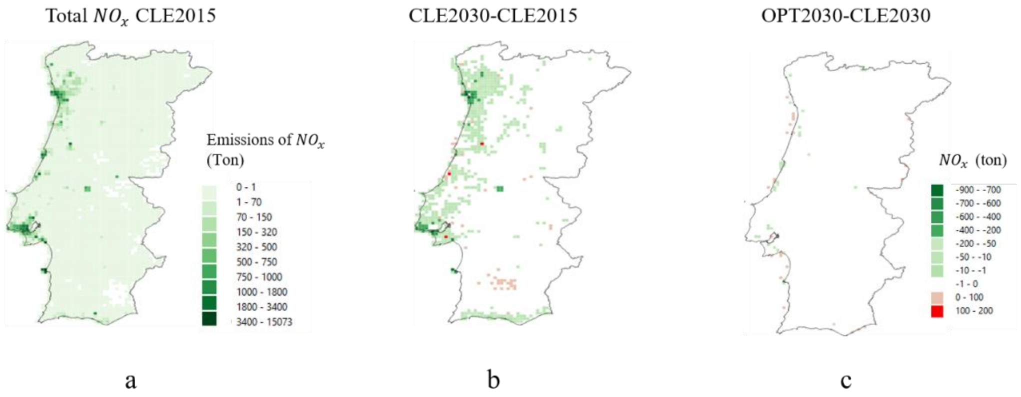

Figure 48: NOx emissions (in t/year) total in scenario CLE2015 (a), and differences between scenario CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

This spatial variability is expected because, as previously mentioned, the emissions of NOx are closely related to population density, being mainly associated with road transport and industrial combustion activities.

The tendency in 2030 is towards a reduction in NOx emissions in these urban areas (see Figure *48*b), while the OPT2030 scenario does not bring any remarkable additional reduction in NOx emissions (OPT32030-CLE2030 is almost zero) besides in some industrial areas (see: Figure *48*c). It can be concluded that for NOx, the CLE2030 will attain a NOx emission reduction very close to the NEC target.

5.2.2 Emissions of NH_3

Regarding NH_3 emissions, the highest are mainly located in the west coast of Portugal, as verified in Figure *49*a.

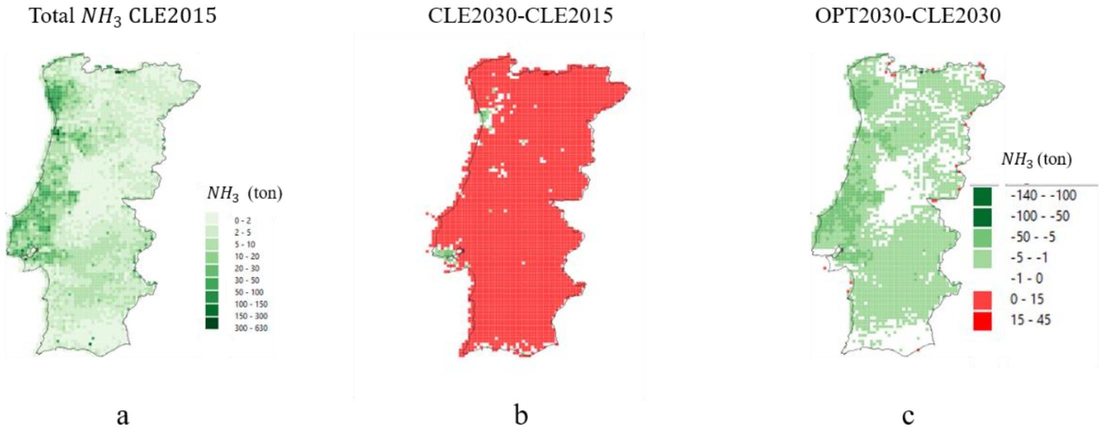

Figure 49: NH_3 emissions (in t/year) total in scenario CLE2015 (a), and differences between scenario CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

Moreover, it is also possible to stand out Alentejo and Trás-os-Montes regions as areas with considerable levels of NH_3. Since it was verified trough GAINS simulations that Agricultural sector is the main source of emissions of NH_3 and being these areas of intensive agricultural practices, it is again evident the importance of SNAP 10, regarding NH_3 emissions.

Being Portugal a country with intense agricultural practices, SNAP 10 emissions of NH_3 may be spotted in almost all regions of Portugal (Figure *50*).

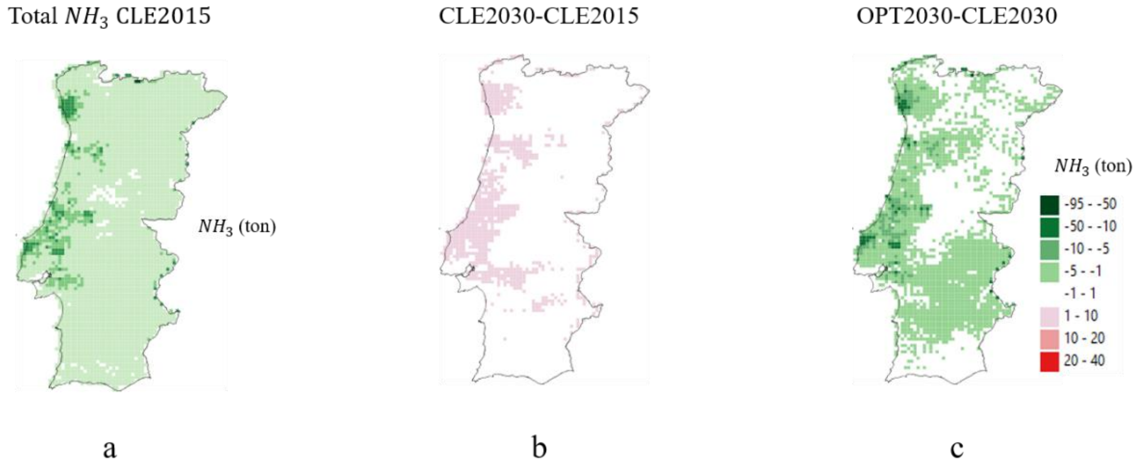

Figure 50: SNAP 10 NH_3 emissions (in t/year) in scenario CLE2015 (a), and differences between scenario CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

Areas in the west coast are identified with higher emissions of NH_3. For those areas increases in the emissions are expected, under scenario CLE2030, as represented in the Figure *50*b. Figure *50*c allows to identify decreases, in Minho, Trás-os-Montes, Beira Litoral, Extremadura and Alentejo, meaning that extra effort will need to be taken in these areas, in order to reverse the increase, as scenario OPT2030 undertakes as additional measures.

5.2.3 Emissions of PM2.5

Emissions of PM2.5 are registered, in general, for all the regions of Portugal, more pronounced in west coast, mainly in the regions of Porto, Aveiro and Lisbon (Figure *51*a). These regions correspond to urban areas, what reinforce the results obtained with GAINS which identify industrial processes sectors as the main source of PM2.5 emissions.

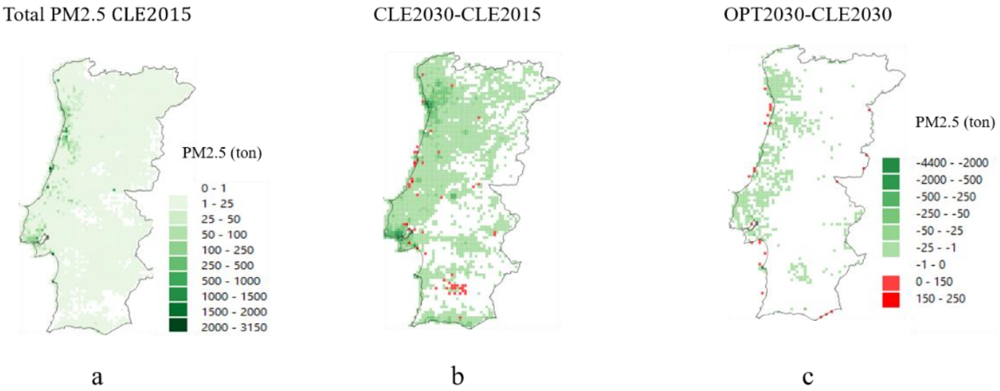

Figure 51: PM2.5 emissions (in t/year) total in scenario CLE2015 (a), and differences between scenario CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

In 2030 the tendency is to a reduction in PM2.5 emissions, although, as explicit in Figure 51b, there is spotted some points of increase, probably representants of industrial areas.

Through the evidences that industrial sectors are the main source of PM2.5, the behaviour of this pollutant in SNAP 3 and 4 (that are simulated together in EESIP-Air) is presented (Figure *52*).

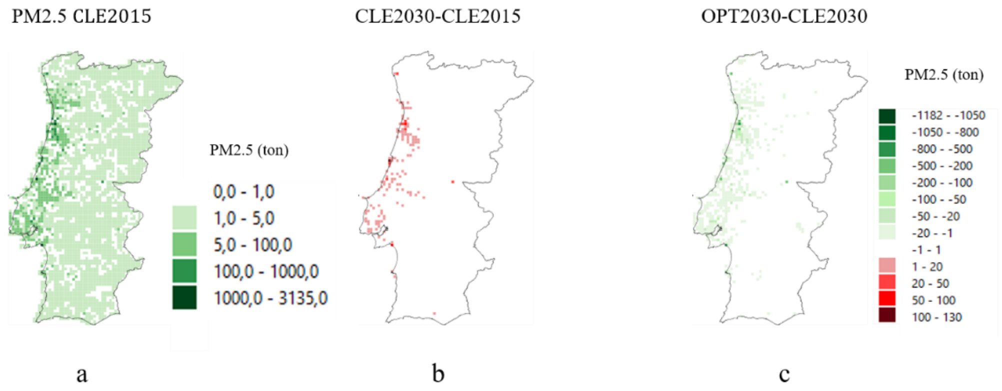

Figure 52: SNAP 3 and 4 PM2.5 emissions (in t/year) in scenario CLE2015 (a), and differences between scenario CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

Analyzing the Figure 52a it is clear that the trend in the emissions of PM2.5 reproduces the behaviour in terms of totals (Figure 51a), identifying the west coast of Portugal as the main contributor to PM2.5 emissions. For that area, increases in the emissions are expected, as shown in Figure 52b.

Regarding the optimum scenario, it reinforces the reduction in the west coast, together with reduction in some spots for which increases in the emissions are expected in 2030 (Figure 51c and Figure 52c). For those areas, extra efforts should be done, in order to achieve the NEC target in the least costive way.

5.2.4 Emissions of SO_2

SO_2 as exposed in Figure 53a. has its emissions mainly related with the west coast with more relevance in the regions of Porto, Aveiro, Coimbra and Lisbon, and also some isolated spots.

Under scenario CLE2030 reductions mainly in region of Porto and Lisbon are identified (Figure 53b), however not enough to comply with the target since the optimum scenario reveals extra effort for all the regions of the west coast identified as the main source of SO_2 (Figure 53c).

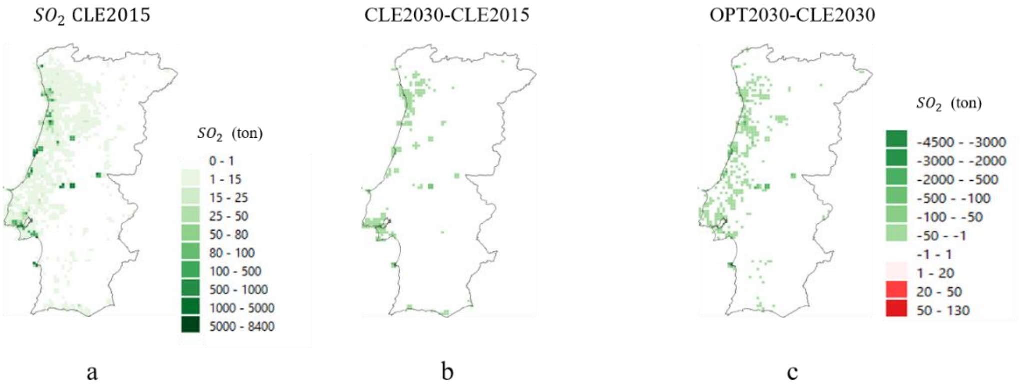

Figure 53: SO_2 emissions (in t/year) total in scenario CLE2015 (a), and differences between scenario CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

Since GAINS identified industrial sectors as important emissions sources of SO_2 and since the areas associated with highest emissions correspond to industrialized areas (urban areas and isolated spots probably associated with industrial plants spread across the country), the behaviour of SNAP 3 and 4 is analyzed (Figure *54*).

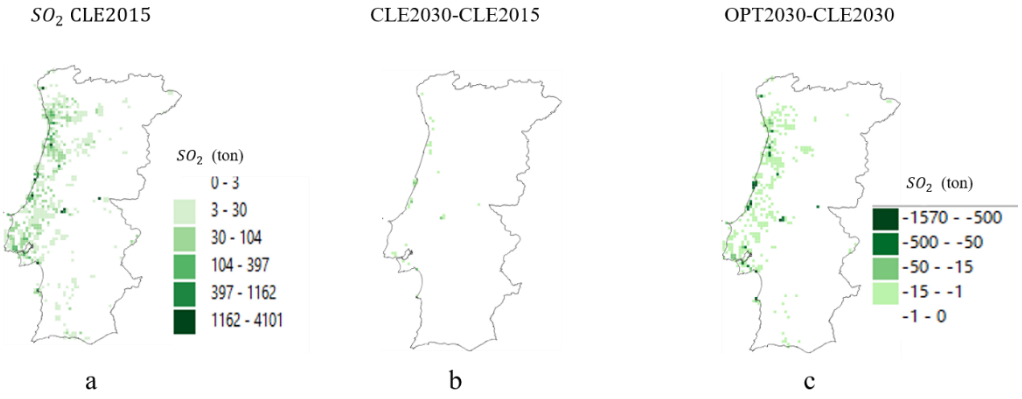

Figure 54: SNAP 10 SO_2 emissions (in t/year) in scenario CLE2015 (a), and differences between scenario CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

In SNAP 3 and 4 the emissions under scenario CLE2030 are very similar to the ones in scenario CLE2015, only being registered some decreasing points in the west coast area (Figure *54*a). This fact, together with the reductions achieved with the OPT2030 scenario (Figure *54*c), highlight that additional measures are required to attain SO_2 target.

5.2.5 Emissions of NMVOC

NMVOC, having as main emissions sources, not only industrial processes sector but also the use of solvents and other products (as shown trough GAINS results), has its emissions mainly associated with urban areas, with a strong incidence in Porto and Lisbon region (Figure 55a).

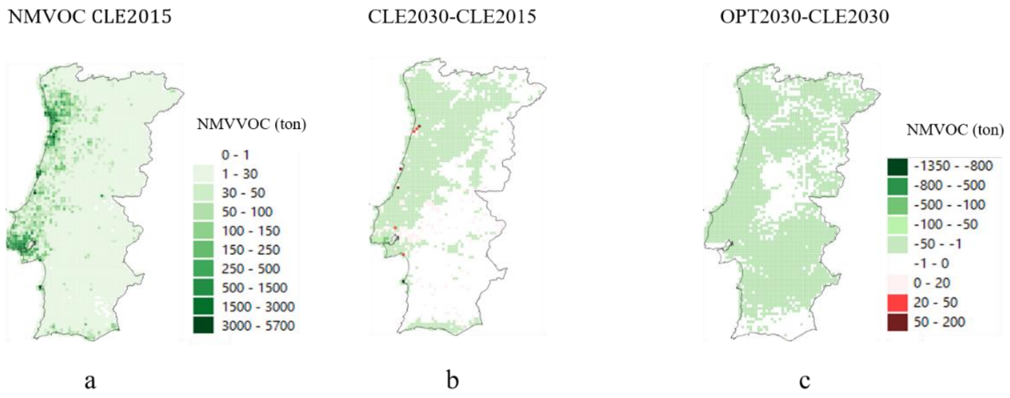

Figure 55: NMVOC emissions (in t/year) total in scenario CLE2015 (a), and differences between scenario CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

Despite being expected a decrease on the emissions of NMVOC with CLE2030, it is yet verified some spots that will face increases, as shown in Figure 55b.

Scenario CLE2030 does not comply with emissions targets, so that, scenario OPT2030 implies some extra effort in order to reach 2030 ceiling. As shown in Figure 55c the solution given by the model implies reductions in almost all regions of Portugal, with high incidence in the west coast, North and Alentejo.

Regarding Industrial sectors (SNAP 3 and 4) behaviour (Figure 56a) it is once again evident that the west coast regions are the main NMVOC emitters.

Figure 56: SNAP 3 and 4 NMVOC emissions (in t/year) in scenario CLE2015 (a), and differences between scenario CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

In these SNAP, it is clear that the emissions of NMVOC, under CLE2030 scenario, will increase in the urban areas of Porto and Lisbon (Figure *56*b). Consequently, scenario OPT2030, will expect extra effort reducing NMVOC emissions in the west coast of Portugal (Figure *56*c).

Regarding solvents and the use of other products (SNAP 6), it is clear that the emissions of NMVOC, under CLE2030 scenario, have a tendency to an increase (*Figure 57*b).

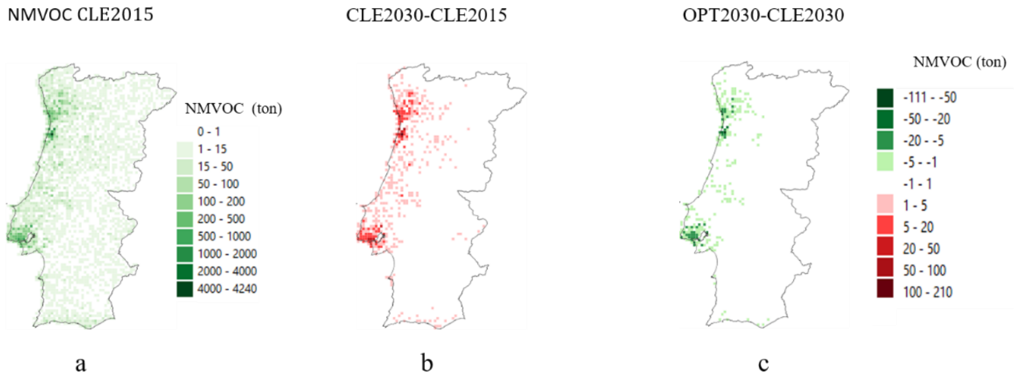

Figure 57: SNAP 6 NMVOC emissions (in t/year) in scenario CLE2015 (a), and differences between scenario CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

The emissions increase in scenario CLE2030 is mainly in the urban areas (*Figure 57*b). In order to reverse this tendency, scenario OPT2030 will imply extra efforts in these regions (*Figure 57*c).

5.2.6 Costs

The areas that were identified in the previous points as the main sources of pollutant emissions (west coast with incidence in urban areas of Porto and Lisbon) are also the areas for which the highest emission reduction costs are observed (see *Figure 58*a).

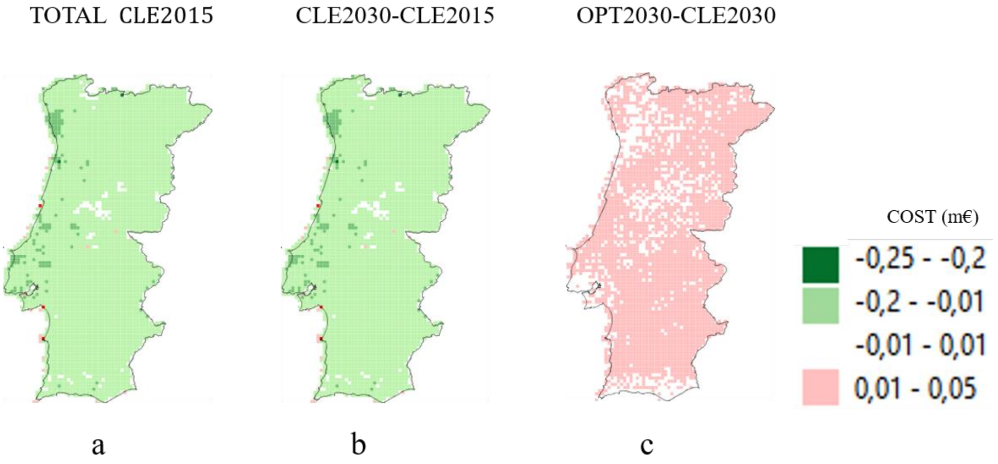

Figure 58: Emission reduction costs (in m€/year) total for scenario CLE2015 (a), and differences between scenario CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

Although for the scenario CLE2030 it is expected that emission reduction costs decrease (see *Figure 58*b), the emissions results for this scenario are not enough to achieve the NEC ceiling by 2030. Hence, extra measures need to be implemented that imply additional costs, under scenario OPT2030 (see *Figure 58*c).

Trough Table *8*, it is easy to identify the SNAP that are more important regarding the costs and which of them will imply higher extra effort to achieve the targets.

Table 8 Cost per SNAP, for each scenario and extra effort considered in scenario OPT2030 (OPT2030-CLE2030)

	cost (m€)	cost (m€)		cost (m€)	
SNAP	CLE2015	CLE2030	CLE2030-CLE2015	OPT2030	OPT2030-CLE2030
1	133.83	31.06	-102.77	34,55	3.49
2	50.13	30.59	-19.54	30,59	0.00
34	116.53	119.66	3.13	125,72	6.06
5	2.08	4.63	2.55	4,60	-0.03
6	-24.38	-23.77	0.61	-27,08	-3.31
7	232.49	304.31	71.82	304,31	0.00
8	15.89	25.45	9.56	25,45	0.00
9	0,00	0.00	0.00	0,00	0.00
10	16.04	16.97	0.93	19,96	2.99
Total	542.62	508.91	-33.71	518,10	9.19

SNAP 1 is identified as a SNAP for which higher extra effort regarding the costs, resultant from interventions in large industrial units. However, the national emission inventory shows a clear reduction of SO_2 emissions, meaning that this effort was already done and GAINS scenarios do not reflect it, needing to be updated. Industrial sectors (SNAP 3 and 4, see: *Figure 59*) are those that will imply higher extra cost, followed by Agricultural sector (SNAP 10 see *Figure 60*).

Regarding SNAP 3 and 4, the west coast area is the one for which higher costs are associated (*Figure 59*a). The emission control cost in these SNAP not only tend to increase in 2030 under scenario CLE2030 (*Figure 59*b) but also under scenario OPT2030 (*Figure 59*c).

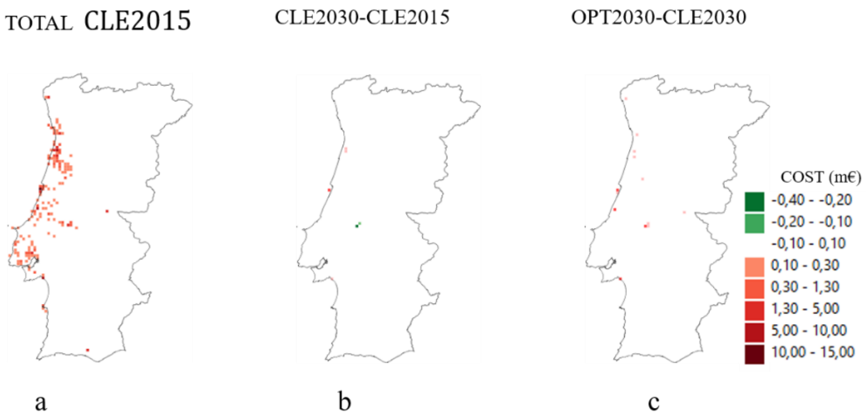

Figure 59: Emission reduction costs for SNAP 3 and 4 (in m€/year) total for scenario CLE2015 (a), and differences between CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

Concerning SNAP 10 it is possible to verify that the costs are related with almost every region of Portugal (Figure *60*a). The increases verified in scenario CLE2030 (Figure *60*b). and OPT2030 (Figure *60*c)., are mainly associated with the west coast area, and Alentejo

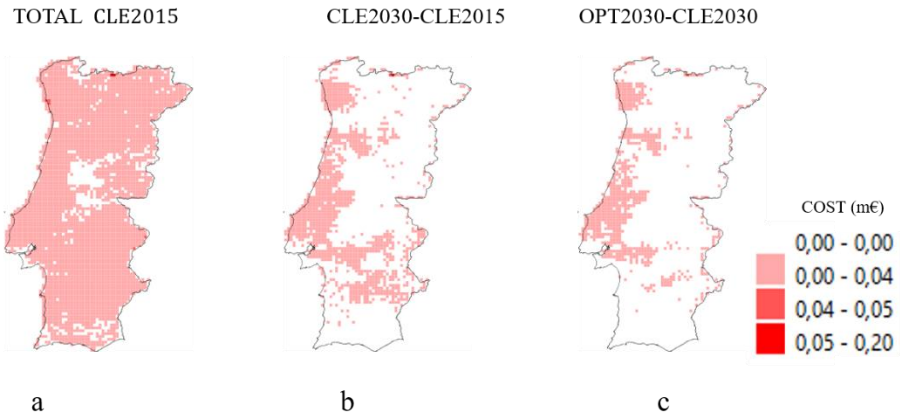

Figure 60: Emission reduction costs for SNAP10 (in m€/year) total for scenario CLE2015 (a), and differences between CLE2030 and CLE2015 (b) and between scenario OPT2030 and CLE2030 (c).

As expected, extra effort to reduce the emissions will imply extra emission control costs, although, the emission cost assumed by scenario OPT2030, is the minimum require to Portugal achieve the 2030 NEC.

6. Conclusions

The topic of emission reduction has been a big concern in Europe as, although the emissions of pollutants have been decreasing, air pollution remains a problem. Hence, in order to limit the negative environmental impacts of acidification, eutrophication and ground-level ozone, the EC adopted the NEC. This Directive was updated in 2016, establishing stricter targets for EU and MS committed to achieve defined ceilings for five main pollutants NOx, SO_2, VOC, NH_3 and PM2.5 (EC,2016).

Since Portugal is a member state of the EU, it needs to fulfil with the NEC Directive. In this context, the current work has addressed the future commitments for the NEC to be attained in 2030, and the emissions projections by activity sector under different scenarios (CLE2015, CLE2030, OPT2030). Since from authorities' point of view, the design of pollution reduction policies is restricted to a limited budget, a cost-effective assessment was performed in order to find out the solution that allow Portugal to achieve the target in 2030, at lowest cost.

The literature review developed in the scope of this dissertation shows a gap regarding studies that consider spatial distribution of emissions and application of abatement technologies. So that, in order to bridge this gap, a spatial distributed assessment on the Portuguese emissions was performed not only allowing the identification of the regions of Portugal that are the main sources of emissions, but also understanding in which part of the country the reductions should be more significant in order to achieve the targets at the lowest cost.

The methodology used allows the identification of the most crucial sector activity categories (following SNAP nomenclature) regarding the emissions and the identification of the cheapest technologies that will enable the achievement of the targets, through the GAINS model database in activity level, emissions and costs by technology; and the identification of the areas of Portugal for which those measures should be applied to achieve the target in a cost-effective way, by the EESIP-Air model application using spatially distributed emission data taken from EMEP.

The first scenario (CLE2015) is performed in GAINS model as a projection, although, it corresponds to the situation of the year 2015 (baseline) regarding emissions and costs. The second scenario (CLE2030) corresponds to the projections regarding emissions and costs to the year 2030, assuming that only the legislation in force is applicable (not considering any extra effort). Regarding the 2030 NEC agreed for Portugal, projections show that the policy regulations in place will not be sufficient to attain the respective ceiling and, consequently, additional measures will need to be implemented. So, a third scenario was created (OPT2030) to project the achievement of the targets in the most cost-effective way, meaning, with the lowest extra emission control cost possible.

Regarding NOx, the transport sector (SNAP 7 and 8) is identified as the main source of emissions, with a relevant contribution from the industrial sector (SNAP 3) as well. Consequently, urban areas are the regions for which main emissions are registered, and, thus, the ones for which mainly changings are expected in the future. Since the scenario CLE2030 is really closed to the target and scenario OPT2030 does not bring any remarkable additional reduction for NOx, it is possible to conclude that the European emission standards which define the acceptable limits for exhaust emissions of new vehicles sold in EU, have been successful regarding emission reductions.

Concerning NH_3, the projections corroborate with past emission indications, showing that agriculture sector (SNAP 10) is the main emission source, something that is reinforced by the spatial distribution of the emission that show high values for areas with intensive agricultural practices. Since the projections indicate a tendency to an increase in scenario CLE2030, extra measures should be applied into the areas with higher emissions (west coast, Alentejo and Trás-os-Montes). These extra efforts can be translated into additional measures in feeding, housing and open burning, as demonstrated trough GAINS. The introduction of low nitrogen feeding, low emission housing techniques and the ban of opening burning techniques, will lead to the achievement of NEC target, cost-effectively.

PM2.5 has industrial processes as the main emission source of emissions (SNAP 4). This SNAP verified increases on the emissions in the west coast area so that, extra emission reduction measures should be applied in this area. The abatement technologies performed by GAINS regarding PM2.5 in industry are replacement of cyclones by high efficiency dedusters and electrostatic precipitators. The full application of these measures is not always considered since it has a high impact on the costs.

The industrial sector is also the main source of SO_2 emissions, with higher emissions in the west coast. The decrease in these areas can be achieved by the injection of limestone into boilers (allowing the reaction with the SO_2) and use of low Sulphur fuel oil.

NMVOC is mainly emitted by industrial activities (SNAP3 and 4), the contribution of solvent and products use sector (SNAP 6) is also an important source. Both sectors verify increases in the emissions in scenario CLE2030 allocated to the west coast area, so that, the areas for which, extra effort should be made to achieve the targets. The reduction in NMVOC emission in industry is reached by the efficient leak detention and consequent modification or replacement of leaking equipment. Regarding the NMVOC emissions from solvents, the implementation of Schumacher-type Desolventizer/Toaster/Dryer/Cooler, which allows the elimination of the solvent, the of powder coating, the use of high solids paints (increases the quantity of solvent) and the use of water based paints, result in the decreases in the emissions.

Overall, scenario OPT2030 presented the best solutions to achieve the NEC targets (43 kt/year for NH_3, 95 kt/year for NOx, 27 kt/year for PM2.5, 30 kt/year for SO_2 and 132 kt/year for VOC) allowing the reduction of the emissions in 14% (NH_3), 25% (NOx), 45% (PM2.5), 35% (SO_2), and 21% (NMVOC) comparing with the scenario CLE2015.

Regarding the emission control cost, CLE2015 represented for Portugal a total of 543 m€/year and the future scenarios are projected to cost a total of 509 m€/year (CLE2030), and 518 m€/year (OPT2030). The optimum scenario implies an increase in 2% relative to the cost for scenario CLE2030, representing the extra effort that Portugal will need to take to achieve the ceilings; however, the minimum required to achieve the NEC targets.

Integrated strategies should be designed and implemented to fulfil the NEC and, the studies as the one performed in this dissertation provide essential information to support and define such strategies.

The objectives of this dissertation were achieved; however, further work can be developed.

Several technologies were provided that may help achieving the NEC. However, non-technical measures are still not considered because it is very complex to estimate associated costs and removal efficiencies. This is a problem identified systematically, withing Integrated Assessment studies, that will need to be solved in future, since the potential of these measures is being ignored.

The goal of this dissertation was to achieve reductions in the pollutants that are required by NEC directive at the lowest costs. Although, as it is known, there are other pollutants that can be harmful to the environment so, a study about which measures would need to be applied to reduce their emissions, as well as the economic impact of those measures, would be interesting and useful.

In this study, only three scenarios were used, since they were considered enough to achieve the specific goals of this dissertation. However, it would be interesting to go a little further and project more ambitious scenarios, as for example, a maximum technical feasible emissions reduction scenario, allowing to understand the impacts in the costs that higher reductions (beyond the targets) would bring.

This dissertation provides essential information to support and define, strategies that fulfil the NEC (consult annex 4 for the sum-up of the main strategies). So that, since Portugal is not the only MS that needs to achieve NEC targets, and since the methodology applied in this dissertation proved to be useful in the provision of support information to emission reductions strategies definition, it can be replicated to other European countries. A comparison of the technical measures selected under the same scenarios for different countries would also be interesting.

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Annexes

Annex 1: Description of sectors presented in GAINS

Abbreviation	Description
AGR_ARABLE	Ploughing, tilling, harvesting
AGR_BEEF	Other cattle
AGR_COWS	Dairy cattle
AGR_OTANI	Other livestock (sheep, horses)
AGR_PIG	Pigs
AGR_POULT	Poultry
AUTO_P_NEW	ehicles manufacturing (new plants)
COIL	Coil coating
COWS_3000_MILK	Milk yield over 3000 kg/animal treshold
D_GASST	Gasoline distribution - service stations
D_REFDEP	Gasoline storage & distribution (excl. gasoline stations)
D_REFDEP_S	Gasoline storage & distribution (excl. transport sector)
DEGR_NEW	Degreasing (new installations)
DOM_OS	Domestic use of solvents (other than paint)
DRY_NEW	Dry cleaning (new installations)
EXD_GAS	Production & distribution of natural gas
EXD_GAS_NEW	Production & distribution of natural gas - new mains
EXD_LQ	Extraction of oil (incl delivery to terminals)
FATOIL	Fat and oil extraction (seeds)
FCON_OTHN	Mineral N fertilizers use (excl. urea)
FCON_UREA	Urea application (incl. ABC)
GLUE_INH	Industrial application of adhesives (high performance)
IND_P_OT	Industrial paint use (other)
IND_P_PL	Industrial paint use (plastic parts)
OTH_NH3_EMISS	Other NH3 emissions
PIS	Products incorporating solvents
PR_CAST_F	Cast iron (grey iron foundries) (fugitive)
PR_CEM	Cement and lime
PR_EARC	Electric arc furnace
PR_FERT	Fertilizer production
PR_GLASS	Glass production (flat, blown, container glass)
PR_OT_NFME	Non-ferrous metals
PR_OTHER	Production of glass fiber, gypsum, PVC, other
PR_PULP	Paper pulp mills
PR_REF	Petroleum refineries
PR_SMIND_F	Small industrial and business facilities - fugitive
PR_SUAC	Sulfuric acid
PRT_OFFS_NEW	Offset printing (new)
PRT_PACK_NEW	Flexography & rotogravure - packaging (new inst.)
PRT_PUB_NEW	Rotogravure in publication (new)
PVC_PR	Rotogravure in publication (new)
RES_BBQ	Meat frying, food preparation, BBQ
RES_CIGAR	Cigarette smoking
RES_CREM	Share of population cremated annually
RES_FIREW	Fireworks
STCRACK_PR	Steam cracking (ethylene & propylene production)
STH_AGR	Storage & handling of agricultural crops
STH_COAL	Storage & handling of coal
TRA_OT_AGR	Other transport: agriculture (exhaust)

TRA_OT_AIR	Other transport: air traffic
TRA_OT_CNS	Other transport: construction machinery (exhaust)
TRA_OT_EV	Evaporative emissions from gasoline vehicles
TRA_OT_LB	Other transport: other off-road, 4-stroke (military, households, etc.)
TRA_RD_HDT	Heavy duty vehicles
TRA_RD_LD2	Mopeds
TRA_RD_LD4C	Cars
TRA_RD_LD4C_EV	Cars - evaporative
TRA_RD_LD4T	Light duty vehicles
TRA_RD_M4	Fuel conversion- combustion
VEHR_P	Vehicle refinishing
VEHR_P_NEW	Vehicle refinishing (new installations)
VEHTR	(De)Waxing and underbody treatment of vehicles
WASTE_AGR	Agricultural waste burning
WASTE_VOC	Waste treatment and disposal
WOOD_CR	Wood preservation (creosote)
WOOD_P	Wood coating

Annex 2: Description of Activities presented in GAINS

Abbreviation	Description
ABRASION	Road abrasion
ADH	Adhesives
BRAKE	Brake wear
CRU	Crude oil
DC	Derived coal (coke, briquettes)
DL	Dairy cows - liquid systems
DS	Dairy cows - solid systems
EMI	Emissions of NMVOC
EP	Ethylene and Propylene
EPS	Expandable polystyrene beads consumption
FU	Fur animals
FWD	Fuelwood
GAS	Gaseous fuel
GSL	Gasoline
H2	Hard coal, high quality
HC1	Heavy fuel oil
HF	Havy fuel oil
HO	Horses
INK	Printing inks
LFL	Liquefied petroleum gas
LH	Laying hens
LPG	Liquefied petroleum gas
MD	Diesel
NOF	No fuel use
NOF	No fuel use
OL	Other cattle - liquid systems
OP	Other poultry
OS	Other cattle - solid systems
OS1	biomass fuels
OS2	Other biomass and waste fuels
PG	Paint and glue produced
PL	Pigs - liquid systems
PNT	Paint use
POP	Population
PS	Pigs - solid systems
PVC	Renewable energy other than biomass
REN	Renewable energy other than biomass
RUB	Synthetic rubber
SC	Coated surface
SD	Seeds
SH	Sheep and goats
SHO	Shoes
SLV	Solvent use
TEX	Textiles (clothing)
TIM	Wood treated
TYR	Tyres
TYRE	Tyre wear
VEH	Vehicles

Annex 3: Description of Technologies presented in GAINS

Abbreviation	Description
A_INC	Adsorption, incineration
ACA	Activated carbon adsorption
BAN	Ban on open burning
BEMT	Basic emissions management techniques
CAGEUI	Constr. & agric., off-road -1998, as EUROI for HDV
CAGEUII	Constr. & agric., off-road -2000/02, as EUROII for HDV
CAGEUIII	Constr. & agric., off-road; as EUROIII for HDV
CAGEUIV	Constr. & agric., off-road; as EUROIV for HDV
CAGEUV	Constr. & agric., off-road; as EUROV for HDV
CLSD_A3	Closed (sealed) degreaser: use of A3 solvents
CLSD_CL	Closed (sealed) degreaser: use of chlorinated solvents
COLD	Cold cleaner
CS	Covered outdoor storage of manure; mean efficiency
CS_high	Covered outdoor storage of manure; high efficiency
CSBP	Use of current standard solvent based paints (60% solvent content) and application efficiency 65%
DL	Dairy cows - liquid systems
DS	Dairy cows - solid systems
EMU	Emulsions, water-based dispersion paints
ESP1	Electrostatic precipitator: 1 field
ESP2	Electrostatic precipitator: 2 fields
FP_IMP	Improved fireplace
FP_IMP	Improved Fireplaces
FP_NEW	New fireplace
FP_NEW	New fireplaces
GHDOM	Good housekeeping: domestic oil boilers
GHIND	Good housekeeping: industrial oil boilers
HAMP+SUB1	Primary measures and 25% of high solids and water based paints
HDEUI	EURO I - 1992, heavy duty diesel vehicles
HDEUII	EURO II - 1996, heavy duty diesel vehicles
HDEUIII	EURO III - 2000, heavy duty diesel vehicles
HDEUIV	EURO IV - 2005, heavy duty diesel vehicles
HDEUV	EURO V - 2008, heavy duty diesel vehicles
HDEUVI	EURO VI, heavy duty diesel vehicles, post-2008
HDSEI	Duty, spark ignition engines, stage 1
HDSEII	Duty, spark ignition engines, stage 2
HDSEIII	Duty, spark ignition engines, stage 3
HOTM	Hot melts or UV cross-linking acrylates or electron beam curing systems (solids content 100%)
HSS	High solids coating systems (20% solvent content), application process with an efficiency of 35%
HSS+PRM	High solids coating systems (20% solvent content), application process with an efficiency of 75%
IFC	internal floating covers or secondary seals
IFC+ST_IAS	IFC and Stage IA (single stage) controls
IN_ESP1	Electrostatic precipitator: 1 field
IN_ESP2	Electrostatic precipitator: 2 fields
IN_HED	High efficiency deduster
INC	Incineration
IOGCM	Combustion modification on oil and gas industrial boilers and furnaces
IOGCM	Combustion modification on oil and gas industrial boilers and furnaces
ISBP	Use of improved solvent based paints (55%), application efficiency as above
ISFCM	Combustion modification on solid fuels fired industrial boilers and furnaces
IWFGD	Industry - wet flue gases desulphurisation
LDAR_I	Leak detection and repair program, stage I
LDAR_II	Leak detection and repair program, stage II
LDAR_IV	Leak detection and repair program, stage IV
LFEUI	EURO I, Light-duty, spark ignition engines: 4-stroke, not DI
LFEUI	EURO I, L. Duty, spark ignition engines: 4-stroke, not DI
LFEUII	EURO II, Light-duty, spark ignition engines: 4-stroke, not DI
LFEUII	EURO II, L. Duty, spark ignition engines: 4-stroke, not DI
LFEUIII	EURO III, L. Duty, spark ignition engines: 4-stroke, not DI
LFEUIV	EURO IV, Light-duty, spark ignition engines: 4-stroke, not DI
LFEUV	EURO V, Light-duty, spark ignition engines: 4-stroke, not DI
LFEUVI	EURO VI, Light-duty, spark ignition engines: 4-stroke, not DI
LINJ	In-furnace control - limestone injection
LNA	Low ammonia application; mean efficiency
LNA	Low amonia aplication

LNA_high	Low ammonia application; high efficiency
LNA_low	Low ammonia application; low efficiency
LNF	Low Nitrogen Feed
LNF_CS	Combination of LNF_CS
LNF_CS_LNA	Combination of LNF_CS_LNA
LNF_LNA	Combination of LNF_LNA
LNF_LNA_high	Combination of LNF_LNA_high
LNF_SA	Combination of LNF_SA
LNF_SA_LNA	Combination of LNF_SA_LNA
LSCO	Low sulphur coal (0.6 %S)
LSGSL	Low sulphur gasoline (0.001 %S)
LSGSL	Low sulphur gasoline
LSHF	Low sulphur fuel oil (0.6 %S)
LSHF	Low sulphur fuel oil
LSMD1	Low sulphur diesel oil - stage 1 (0.2 % S)
LSMD1	EURO I, L. Duty, spark ignition engines: 4-stroke, not DI
LSMD2	Low sulphur diesel oil - stage 2 (0.2 % S)
LSMD2	EURO II, L. Duty, spark ignition engines: 4-stroke, not DI
LSMD3	Low sulphur diesel oil - stage 3 (0.001 % S)
LSMD3	Low sulphur diesel oil - stage 3 (0.001% S)
LSS+PRM	Low solids systems (80% solvent content) and application process with an efficiency of 75% (electrostatic, roller coating, curtain coating, dipping)
LSS+PRM+INC	Combination of the above options
MB_CYC	Cyclone
MDEUI	EURO I - 1992/94, diesel light duty and passenger cars
MDEUII	EURO II - 1996, diesel light duty and passenger cars
MDEUIII	EURO III - 2000, diesel light duty and passenger cars
MDEUIV	EURO IV - 2005, diesel light duty and passenger cars
MDEUV	EURO V - diesel l. duty and pass. cars, post-2005, St.1
MDEUVI	EURO VI - diesel l. duty and pass. cars - post 2005, St.2
MINE_GP	Good practice in mining industry
MMO2I	Motorcycles and mopeds 2-stroke, stage 1 NOX
MMO2I	Motorcycles and mopeds 2-stroke, stage 1
MMO2II	Motorcycles and mopeds 2-stroke, stage 2 NOX
MMO2II	Motorcycles and mopeds 2-stroke, stage 2
MMO2III	Motorcycles and mopeds 2-stroke, stage 3 NOX
MOT4I	Motorcycles 4-stroke, stage 1 NOX
MOT4II	Motorcycles 4-stroke, stage 2 NOX
MOT4III	Motorcycles 4-stroke, stage 3
NCCM	New generation closed circuit machine
NOC_NH3	No control of NH3
NOC_NH3	No control of NH3
NOC_NOX	No control of NOX
NOC_NOX	No control of NOx
NOC_PM_2_5	No control of PM2,5
NOC_PM_2_5	No control of PM2,5
NOC_SO2	No control SO2
NOC_SO2	No control of SO2
NOC_VOC	No control VOC
NOC_VOC	No control of VOc

OPTPR	Process optimization
OS	Other cattle - solid systems
PB+REC	6% Pentane expandable beads (85%) and recycled EPS waste (15%)
PHCCM	Combustion modification on existing hard coal power plants
PHCCSC	Combustion modification and selective catalytic reduction on existing hard coal power plants
PHCSCR	Selective catalytic reduction on new hard coal power plants
PL	Pigs-Liquis Systems
POGCM	Combustion modification on existing oil and gas power plants
POGCSC	Combustion modification and selective catalytic reduction on existing oil and gas power plants
POWDER	Powder coating system (solvent free)
PR_CYC	Cyclone
PR_ESP1	Electrostatic precipitator: 1 field
PR_ESP2	Electrostatic precipitator: 2 fields
PR_HED	High efficiency deduster
PRF_GP1	Good practice: ind.process - stage 1 (fugitive)
PRNOX1	Stage 1 - Process NOx control
PRNOX2	Stage 2 - Process NOx control
PRWFGD	Wet flue gases desulphurisation (retrofitted)
PWFGD	Wet flue gases desulphurisation
REF1	Reformulation of products (stage 1 - see BIPRO, 2002 study; researched options)
SA	Low emission housing
SA_LNA	Low emission housing and manure application
SED	Simulation of changes in paint formulation and application patterns in order to comply with the EU Product Directive
SH	Sheep and goats
SHB_IMP_B	Biomass single house boiler improved
SHM+ACA	Schumacher type desolventiser-toaster-dryer-cooler plus an old hexane recovery section
SHM+ACAN	Schumacher type desolventiser-toaster-dryer-cooler plus a new hexane recovery section and process optimization
SO2PR1	Stage 1 - Process SO2 control
SO2PR2	Stage 2 - Process SO2 control
SO2PR3	Stage 3 - Process SO2 control
SPRM	Good housekeeping and substitution (60% solvent based and 40% water based adhesives)
ST_IB	Stage IB controls at service stations
STH_GP	Good practice: storage and handling
STH_GP	Good practice: storage and handling
STLHCM	Combustion modification: ships (large vessels-fuel oil)
STLMCM	St control of STLMCM
STMCM	St control of STMCm
STRIP	Combination of STRIP
STV_BRIQ	Briquette stove
STV_IMP_B	Improved stove - biomass
STV_IMP_C	Improved stove - coal
STV_NEW_B	New stove - biomass
STV_NEW_C	New stove - coal
STVNT	Stripping and vent gas treatment
STVNTOPT	STVNT plus optimization of emission treatment
SUB_V	Use of 30% solvent based additives and 70% low solvent additives (100% vulcanized rubber produced)
SUB1_VT	Use of 30% solvent based additives and 70% low solvent additives (90% vulcanized rubber and 10% thermoplastic rubber produced)
TIWEUI	Rail & inl. waterways, off-road -1998, as EUROI for HDV
TIWEUII	Rail & inl. waterways, off-road -2000/02, as EUROII for HDV
TIWEUIII	Rail & inl. waterways, off-road; as EUROIII for HDV
TIWEUIV	Rail & inl. waterways, off-road; as EUROIV for HDV
TIWEUV	Rail and Inland Waterways Off-road; as EUROV for HDV
TIWEUVI	Rail and Inland Waterways Off-road; as EUROVI for HDV
TSBP_IA	Use of traditional solvent based paints but improved application efficiency up to 65%
VHSS	Very high solids systems (5% solvent content), application process with an efficiency of 35%
VHSS+PRM	Very high solids systems (5% solvent content), application process with an efficiency of 75%
VIS	Improved application technique (vacuum impregnation system)
WBD	Water based cleaning process
WBI+INC	Water based inks and biofiltration (large inst.)
WBP	Use of water based paints (5%): application efficiency as above
WCLEAN	Water cleaning
WPR	Use of water based preservatives (conventional application methods)
WPR+VIS	Combination of the above options

Annex 4: Sum-up of the main abatement measures

	Main Sources	Abatement Measures
NOx	Transport	European emission standards.
NH_3	Agriculture	Feeding and housing techniques and banish of the opening burning.
PM2.5	Industry	Replacement of cyclones by high efficient dedusters
SO_2	Industry	Application of a furnace sorbent injection; Increase in the use of low sulphur fuel oil; Increase in the consumption of biomass fuel.
NMVOC	Industry	Efficient leak detention and consequent modification or replacement of leaking equipment
	Solvents and Products use	Schumacher-type Desolventizer/Toaster/Dryer/Cooler Powder coating system High solids paints and water based paints