Commission modelling inventory and knowledge management system (MIDAS)

Report generation date 24/11/22

MIDAS includes the descriptions of models in use by the Commission in support to the policy cycle. MIDAS is developed and managed by the **Competence Centre on Modelling** of the European Commission.

Find out more at https://ec.europa.eu/knowledge4policy/modelling_en

Contact: EU-MIDAS@ec.europa.eu

Factsheet

SWD/2022/545

Impact Assessment accompanying the document Proposal for a Directive of the European Parliament and of the Council on ambient air quality and cleaner air for Europe (recast)

Supporting model(s)

GAINS

GEM-E3

Impact assessment
SWD/2022/545

Fact sheet on model contributions

Source: Commission modelling inventory and knowledge management system (MIDAS)

Date of Report Generation: 24/11/2022

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Contents

Overview of model contributions to the impact assessment SWD/2022/545

Title
Impact Assessment accompanying the document Proposal for a Directive of the European Parliament and of the Council on ambient air quality and cleaner air for Europe (recast)

Document ID
SWD/2022/545

Year of publication
2022

Led by
ENV

Model(s) used
GAINS
GEM-E3

Additional information
-

GAINS

Full title
Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS)-Model

Run for this impact assessment by
International Institute for Applied Systems Analysis (IIASA)

Contributed to
Baseline and assessment of policy options

Helped to assess the following impacts
Air Quality

GEM-E3

Full title
General Equilibrium Model - Economy, Energy, Environment

Run for this impact assessment by
European Commission

Contributed to
Baseline and assessment of policy options

Helped to assess the following impacts
Macroeconomic environment
Economic growth and employment

Overview of models

GAINS

Overview

Acronym GAINS
Full title Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS)-Model

Main purpose
GAINS is an analytical framework for assessing future potentials and costs for reducing air pollution impacts on human health and the environment while simultaneously mitigating climate change through reduced greenhouse gas emissions. It explores synergies and trade-offs in cost-effective emission control strategies so as to maximize benefits across multiple scales.

Summary
The **G**reenhouse gas - **A**ir pollution **In**teractions and **S**ynergies (GAINS) model (http://gains.iiasa.ac.at/) developed by the International Institute for Applied Systems Analysis (IIASA), describes the pathways of atmospheric pollution from its anthropogenic origin to the most relevant environmental impacts (Amann et al. 2011). It brings together information on future economic, energy and agricultural development, emission control potentials and costs, atmospheric dispersion and environmental sensitivities towards air pollution. The model addresses threats to human health posed by fine particulates and ground-level ozone, risk of ecosystems damage from acidification, excess nitrogen deposition (eutrophication) and exposure to elevated levels of ozone, as well as various global and regional climate metrics to calculate warming potential or temperature change. The assessed impacts are considered in a multi-pollutant context, quantifying the contributions of sulphur dioxide (SO2), nitrogen oxides (NOx), ammonia (NH3), non-methane volatile organic compounds (VOCs), primary emissions of particulate matter (PM2.5, PM10), carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), fluorinated gases (HFCs, PFCs and SF6), and black and organic carbon (BC, OC).

The GAINS model can explore cost-effective strategies to reduce emissions of air pollutants and greenhouse gases in order to meet specified environmental targets. It also assesses how specific control measures simultaneously influence different pollutants, permitting a combined analysis of air pollution and climate change mitigation strategies, which can reveal important synergies and trade-offs between these policy areas. The optimization mode of the GAINS model balances emission control measures across countries, pollutants and economic sectors such that user-defined target levels on various environmental impacts are met at least costs.

The GAINS model framework has global coverage with a geographic representation of 180 countries/regions and spanning the period 1990 to 2050 in five-year intervals with extension to 2070 for the European region. The estimation of emissions is combining activity data with emission factors describing alternative sets of pollutant reduction technologies. The emphasis lies on a rich representation of more than a thousand emission source sectors with associated alternative sets of abatement technologies. This allows for identification and quantification of emission sources, exposure levels, and mitigation potentials at a policy relevant level, e.g., by region (EU, country, sub-national, city level), by sector (industry, residential, transport, agriculture), by farm size, by urban/rural contribution. Atmospheric dispersion processes are modeled using a source-receptor methodology that linearly approximates results of full chemical transport models. Critical load information (characterizing ecosystem sensitivities) are often compiled exogenously and incorporated into the GAINS model framework.

The model can be operated in the 'scenario analysis' mode, i.e., following the pathways of the emissions from their sources to their impacts. In this case the model provides estimates of regional costs and environmental benefits of alternative emission control strategies. The Model can also operate in the 'optimization mode', which identifies cost-optimal allocations of emission reductions in order to achieve specified deposition levels, concentration targets, or GHG emissions ceilings. The current version of the model can be used for viewing activity levels and emission control strategies, as well as calculating emissions and control costs for those strategies.

GAINS is frequently used to provide model input for air pollution and climate policy formulation. For example, GAINS has been used for policy analyses by the European Commission for the EU Reference Scenario (Energy, transport and GHG emissions: trends to 2070) and for the EU Thematic Strategy on Air Pollution and the air policy review (e.g., Amann et al., 2016, 2018; EC, 2019).

Keywords
Air Pollution, climate change, emissions, air pollutant emissions

Model category (thematic)
Climate and air quality

Model home page
https://iiasa.ac.at/web/home/research/researchPrograms/air/GAINS.html

Ownership & license

Ownership
Third-party ownership (commercial companies, Member States, other organisations, …)

Ownership details
International Institute for Applied Systems Analysis (IIASA)

Licence type
Non-Free Software licence. The license has one or more of the following restrictions: it prohibits creation of derivative works; it prohibits commercial use; it obliges to share the licensed or derivative works on the same conditions.

Details

GAINS structure and approach

No information provided

Input and parametrization

GAINS uses externally produced activity scenarios for the macroeconomic, energy sector and agricultural sector developments. These are imported through links to partial equilibrium models, e.g., PRIMES for energy sector developments in Europe, CAPRI for developments in agricultural activity (livestock numbers and fertilizer use) in Europe, and the IEA-WEO and FAO for global energy and agricultural sector scenarios, respectively. In consistency with respective macroeconomic developments, GAINS generates internally projections for waste generation, relevant industry production, and consumption of F-gases. Technology-specific emission factors and cost parameters are developed internally in GAINS through information from literature and from direct dialogues and iterative consultations with stakeholders.

Main output

GAINS estimates emissions, mitigation potentials and costs for the major air pollutants (SO2, NOx, PM, NH3, VOC, BC/OC) and for the six greenhouse gases included in the Kyoto Protocol.

Outputs include emissions, impacts and costs of alternative policy configurations, prescribed or identified as cost-effective.

Spatial - temporal extent

The output has the following spatial-temporal resolution and extent:

Parameter	Description
Spatial Extent / Country Coverage	EU Member states 27; ALL countries of the WORLD GAINS has global coverage, distinguishing 180 regions including 48 European countries and 46 provinces/states in China and India.
(Spatial) resolution	Regular Grid 1km – 10km; Regular Grid 10km – 50km Depends on the indicator. Grid resolution for calculating ambient PM2.5 in Europe: 0.125^{o} (longitude) x 0.0625^{o} (latitude), approx. 7x7km. Different resolution in the global domain outside Europe.
Temporal extent	Long term (more than 15 years) 1990 to 2050 with extension to 2070 for the European region
Temporal resolution	Multiple years Five years intervals

Quality & transparency

Quality

Question	Answer	Details
Models are by definition affected by uncertainties (in input data, input parameters, scenario definitions, etc.). Have the model uncertainties been quantified? Are uncertainties accounted for in your simulations?	Yes	Uncertainty is in GAINS handled through: - The use of alternative activity data scenarios reflecting a range of macroeconomic, energy and agricultural sector developments - Extension of sector/technology model resolution to reflect policy relevant implications of e.g., scale, urban/rural differences, etc. on emission factors and costs - Consideration of a wealth of country-specific factors and circumstances in the derivation of emission factors, cost parameters, and emission control strategies.
Sensitivity analysis helps identifying the uncertain inputs mostly responsible for the uncertainty in the model responses. Has the model undergone sensitivity analysis?	Yes	Sensitivity analyses are frequently performed on GAINS model results on a case-by-case basis, e.g., by the use of alternative activity data scenarios or by using ranges for emission factors and costs in simulations.
Have model results been published in peer-reviewed articles?	Yes	GAINS model results have been presented in numerous peer-reviewed publications.
Has the model formally undergone scientific review by a panel of external experts? (Please note that this does not refer to the cases when model results were validated by stakeholders)	Yes	GAINS has been evaluated by an external expert panel on a few occasions as part of regular IIASA program reviews, see https://webarchive.iiasa.ac.at/rains/reports/gains-review.pdf.
Has model validation been done? Have model predictions been confronted with observed data (ex-post)?	Yes	Modelled ambient PM concentrations at (urban or rural) background level have been validated against observations, see Kiesewetter et al (2015a,b) and Amann, M., Kiesewetter, G., Schoepp, W., Klimont, Z., Winiwarter, W. et al., 2020. Reducing global air pollution: The scope for further policy interventions. Phil. Trns. R. Soc. A. (In press). GAINS bottom-up emission inventory for global methane emissions evaluated against top-down atmospheric measurements of CH4 concentration, see HöglundIsaksson et al. (2020); Saunois et al. (2020).

References related to external peer-review and publication in scientific journals:

- Höglund-Isaksson, L., Gómez-Sanabria, A., Klimont, Z., Rafaj, P., & Schöpp, W. (2020). Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe –results from the GAINS model. Environmental Research Communications, 2(2), 025004. doi:10.1088/2515-7620/ab7457

- Kiesewetter, G., Borken-Kleefeld, J., Schöpp, W., Heyes, C., Thunis, P., Bessagnet, B., … Amann, M. (2015). Modelling street level PM10 concentrations across Europe: source apportionment and possible futures. Atmospheric Chemistry and Physics, 15(3), 1539– 1553. doi:10.5194/acp-15-1539-2015
- Kiesewetter, G., Schoepp, W., Heyes, C., & Amann, M. (2015). Modelling PM2.5 impact indicators in Europe: Health effects and legal compliance. Environmental Modelling & Software, 74, 201–211. doi:10.1016/j.envsoft.2015.02.022
- Saunois, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B., … Patra, P. K. (2020). The Global Methane Budget 2000–2017. Earth System Science Data, 12(3), 1561–1623. doi:10.5194/essd-12-1561-2020

Transparency

Question	Answer	Details
To what extent do input data come from publicly available sources? (Note: this may include sources accessible upon subscription and/or payment)	Entirely based on publicly available sources	
Is the full model database as such available to external users? (The answer 'yes' comprises the cases when access to the database implies a specific procedure or a fee)	Yes	The GAINS database is publicly available and can be accessed through the GAINS website. The information supplied on the GAINS website or parts thereof may be freely used for non-commercial and educational purposes. Data from this site is for informational purposes only, and may only be used as input to other models with explicit permission of IIASA. Information from this site may be reproduced with proper acknowledgment to IIASA, Laxenburg, Austria. http://gains.iiasa.ac.at/models/index.html
Have model results been presented in publicly available reports?	Yes	
Have output datasets been made publicly available? (Note: this could also imply a specific procedure or a fee)	No	Simulation mode results can be produced within the public model framework. Optimization mode results have been made available through peer-reviewed publications.
Is there any user-friendly interface presenting model results – such as dashboards or interactive interfaces – that is accessible to the public?	Yes	
Is the model code open source?	No	
Can the code be accessed upon	Yes	

request?		
Has the model been documented in a publicly available dedicated report or a manual? (Note: this excludes IA reports)	Yes	Amann et al. (2011): general model approach for Europe; Höglund-Isaksson et al. (2018): documentation of methodology for non-CO2 policy scenarios for EU-28, see https://ec.europa.eu/clima/sites/clima/files/strategies/analysis/models/docs/non_co2_methodology_report_en.pdf ; Klimont et al (2017): documentation of methodology for PM emission calculation; Klimont and Winiwarter (2015): documentation of NH3 emission and cost calculation.
Is there a dedicated public website where information about the model is provided?	Yes	

References related to documentation:

- Nguyen, T. B., Wagner, F., & Schoepp, W. (2011). GAINS – An Interactive Tool for Assessing International GHG Mitigation Regimes. Information and Communication on Technology for the Fight Against Global Warming, 124–135. doi:10.1007/978-3-642-23447-7_12
- Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund-Isaksson, L., … Winiwarter, W. (2011). Cost-effective control of air quality and greenhouse gases in Europe: Modeling and policy applications. Environmental Modelling & Software, 26(12), 1489–1501. doi:10.1016/j.envsoft.2011.07.012
- Klimont, Z., Kupiainen, K., Heyes, C., Purohit, P., Cofala, J., Rafaj, P., … Schöpp, W. (2017). Global anthropogenic emissions of particulate matter including black carbon. Atmospheric Chemistry and Physics, 17(14), 8681–8723. doi:10.5194/acp-17-8681-2017
- Klimont, Z., & Winiwarter, W. (2015). Estimating Costs and Potential for Reduction of Ammonia Emissions from Agriculture in the GAINS Model. Costs of Ammonia Abatement and the Climate Co-Benefits, 233–261. doi:10.1007/978-94-017-9722-1_9

The model's policy relevance and intended role in the policy cycle

The model is designed to contribute to the following policy areas

- Climate action
- Public health

The model is designed to contribute to the following phases of the policy cycle

- Formulation

The model's potential

The model is designed to contribute to the following policy areas:

- Climate action through mitigation potentials for non-CO2 GHGs and Black Carbon
- Climate action through harnessing health co-benefits
- Public health through air pollution exposure levels
- Ecosystem protection through critical loads

GAINS is used for policy analyses under the Convention on Long-range Transboundary Air Pollution (CLRTAP), e.g., for the revision of the Gothenburg Protocol, and by the European Commission for the EU Thematic Strategy on Air Pollution and the air policy review, and it was among the models used to inform the EC proposal "A Clean Planet for All" (COM (2018) 773). GAINS is used to assess domestic mitigation potential of non-CO2 GHGs for EU climate policy analyses. Scientists and government agencies in many nations (e.g., in Europe, China, India, Vietnam) use GAINS as a tool to assess emission reduction potentials in their regions.

In "scenario analysis" mode, it follows emission pathways from sources to impacts, providing estimates of regional costs and the environmental benefits of alternative emission control strategies.

In "optimization" mode, GAINS identifies cost-optimal portfolios of emission control measures for achieving specified targets, such as absolute emission limits, or health impacts.

Previous use of the model in ex-ante impact assessments of the European Commission

Use of the model in ex-ante impact assessments since July 2017.

In the Year	GAINS contributed to the Impact assessment called	Led by	By providing input to the	The model was run by	Details of the contribution
2022	Impact Assessment accompanying the document Proposal for a Directive of the European Parliament and of the Council on ambient air quality and cleaner air for Europe (recast) SWD/2022/545	ENV	Baseline and assessment of policy options	*International Institute for Applied Systems Analysis*	The model helped to assess the following impacts: Air Quality
2021	Impact assessment accompanying the document Proposal for a regulation of the European Parliament and of the Council: amending Regulation (EU) 2018/842 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement SWD/2021/611 final	CLIMA	Baseline and assessment of policy options	*International Institute for Applied Systems Analysis*	GAINS models non-CO2 greenhouse gases for diverse sectors such as agriculture, waste, energy and industry and their associated cost for reducing emissions of non-CO2 greenhouse gases (CH4, N2O, Fgases).
2021	Impact assessment accompanying the document Proposal for a Regulation of the European Parliament and the Council: amending Regulations (EU) 2018/841 as regards the scope, simplifying the compliance rules, setting out the targets of the Member States for 2030 and committing to the collective achievement of climate neutrality by 2035 in the land use, forestry and agriculture sector, and (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review SWD/2021/609 final	CLIMA	Baseline and assessment of policy options	*International Institute for Applied Systems Analysis*	GAINS was used to assess costs and mitigation potential of nonCO2 greenhouse gases in the agriculture sector.

2021	Impact assessment accompanying the document Directive of the European Parliament and of the Council: amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757 SWD/2021/601 final	CLIMA	Baseline and assessment of policy options	*International Institute for Applied Systems Analysis*	General modelling of ETS strengthening and possible extension to buildings and transport/ all fossil fuel combustion.
2020	Impact Assessment accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Stepping up Europe's 2030 climate ambition SWD/2020/176 final	CLIMA	Baseline and assessment of policy options	*International Institute for Applied Systems Analysis*	GAINS models non-CO2 greenhouse gases for diverse sectors such as agriculture, waste, energy and industry and their associated cost for reducing emissions of non-CO2 greenhouse gases (CH4, N2O, Fgases).

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- *Höglund-Isaksson, L., Gómez-Sanabria, A., Klimont, Z., Rafaj, P., & Schöpp, W. (2020). Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe –results from the GAINS model. Environmental Research Communications, 2(2), 025004. doi:10.1088/2515-7620/ab7457*

- *Saunois, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B., … Patra, P. K. (2020). The Global Methane Budget 2000–2017. Earth System Science Data, 12(3), 1561–1623. doi:10.5194/essd-12-1561-2020*

- *Rafaj, P., Kiesewetter, G., Gül, T., Schöpp, W., Cofala, J., Klimont, Z., … Cozzi, L. (2018). Outlook for clean air in the context of sustainable development goals. Global Environmental Change, 53, 1–11. doi:10.1016/j.gloenvcha.2018.08.008*

- *Winiwarter, W., Höglund-Isaksson, L., Klimont, Z., Schöpp, W., & Amann, M. (2018). Technical opportunities to reduce global anthropogenic emissions of nitrous oxide. Environmental Research Letters, 13(1), 014011. doi:10.1088/1748-9326/aa9ec9*

- *Klimont, Z., Kupiainen, K., Heyes, C., Purohit, P., Cofala, J., Rafaj, P., … Schöpp, W. (2017). Global anthropogenic emissions of particulate matter including black carbon. Atmospheric Chemistry and Physics, 17(14), 8681–8723. doi:10.5194/acp-17-8681-2017*

- *Purohit, P., & Höglund-Isaksson, L. (2017). Global emissions of fluorinated greenhouse gases 2005–2050 with abatement potentials and costs. Atmospheric Chemistry and Physics, 17(4), 2795–2816. doi:10.5194/acp-17-2795-2017*

- *Klimont, Z., & Winiwarter, W. (2015). Estimating Costs and Potential for Reduction of Ammonia*
  Emissions from Agriculture in the GAINS Model. Costs of Ammonia Abatement and the Climate Co-Benefits, 233–261. doi:10.1007/978-94-017-9722-1_9

- *Kiesewetter, G., Borken-Kleefeld, J., Schöpp, W., Heyes, C., Thunis, P., Bessagnet, B., … Amann, M. (2015). Modelling street level PM₁₀ concentrations across Europe: source apportionment and possible futures. Atmospheric Chemistry and Physics, 15(3), 1539– 1553. doi:10.5194/acp-15-1539-2015*

- *Kiesewetter, G., Schoepp, W., Heyes, C., & Amann, M. (2015). Modelling PM2.5 impact indicators in Europe: Health effects and legal compliance. Environmental Modelling & Software, 74, 201– 211. doi:10.1016/j.envsoft.2015.02.022*

- *Schucht, S., Colette, A., Rao, S., Holland, M., Schöpp, W., Kolp, P., … Rouïl, L. (2015). Moving towards ambitious climate policies: Monetised health benefits from improved air quality could offset mitigation costs in Europe. Environmental Science & Policy, 50, 252–269.*

doi:10.1016/j.envsci.2015.03.001

- *Kiesewetter G, Borken-Kleefeld J, Schoepp W, Heyes C, Thunis P, Bessagnet B, Terrenoire E, Gzella A, Amann M. Modelling NO2 concentrations at the street level in the GAINS integrated assessment model: projections under current legislation. ATMOSPHERIC CHEMISTRY AND PHYSICS 14 (2); 2014. p. 813-829. JRC84253*

- *Reis, S., Grennfelt, P., Klimont, Z., Amann, M., ApSimon, H., Hettelingh, J.-P., … Williams, M. (2012). From Acid Rain to Climate Change. Science, 338(6111), 1153–1154. doi:10.1126/science.1226514*

- *Höglund-Isaksson, L., Winiwarter, W., Purohit, P., Rafaj, P., Schöpp, W., & Klimont, Z. (2012). EU low carbon roadmap 2050: Potentials and costs for mitigation of non-CO2 greenhouse gas emissions. Energy Strategy Reviews, 1(2), 97–108. doi:10.1016/j.esr.2012.05.004*

- *Nguyen, T. B., Wagner, F., & Schoepp, W. (2011). GAINS – An Interactive Tool for Assessing International GHG Mitigation Regimes. Information and Communication on Technology for the Fight Against Global Warming, 124–135. doi:10.1007/978-3-642-23447-7_12*

- *Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund-Isaksson, L., … Winiwarter, W. (2011). Cost-effective control of air quality and greenhouse gases in Europe: Modeling and policy applications. Environmental Modelling & Software, 26(12), 1489–1501. doi:10.1016/j.envsoft.2011.07.012*

GEM-E3

Overview

Acronym GEM-E3
Full title General Equilibrium Model - Economy, Energy, Environment

Main purpose
A macro-economic model used to assess energy, climate and air quality policies.

Summary
The GEM-E3 model is a global multi-sectoral general equilibrium model. GEM-E3 covers the interactions between the economy, the energy system and the environment. The model is used to calculate macroeconomic impacts such as GDP, welfare, consumption, trade, employment, sectoral output, and carbon price.

It covers all EU Member States and the rest of the world, which is divided into 19 major economies. Countries are linked through endogenous bilateral trade. The calibration of the model is based on the
GTAP database and uses techno-economic inputs from sectoral models such as POTEnCIA, PRIMES, POLES, GAINS, and GLOBIOM. The model simultaneously computes the equilibrium prices of goods, services, labour, capital and tradable emission rights such that all markets are in equilibrium. It integrates micro-economic behaviour into a macro-economic framework and allows assessing the medium to long-term implications of policies. The model evaluates the emissions of carbon dioxide (CO2) and other GHG (e.g. CH4). There are three mechanisms of emission reduction: (i) substitution between fuels, and between energetic and non-energetic inputs, (ii) emission reduction due to less production and consumption, and (iii) purchasing abatement equipment.

The model can be used for policy anticipation, formulation and implementation to assess macroeconomic impacts of energy, climate and air quality policies. The model has been used, among others, for the Impact Assessments of the 2030 Framework of Energy and Climate Policies, its implementation in the context of the Energy Union, the Paris Agreement, and the Clean Air Package.

Keywords
Energy , Environment , Climate , General equilibrium , Climate policy , Air Pollution

Model category (thematic)
Economy

Model home page
https://ec.europa.eu/jrc/gem-e3

Ownership & license

Ownership
Co-ownership (EU & third parties)

Ownership details
The ownership is shared with the institutions that developed the model and the JRC, European Commission: a) Institute of Communication and Computer Systems - National Technical University of Athens (ICCS/NTUA); b) CES, Centre for Economic Studies, Katholieke Universiteit Leuven c) DG JRC, European Commission (C6) which has developed various modules for GEM-E3, as well as extended and updated the supporting databases (incl. GTAP).

Licence type
Non-Free Software licence. The license has one or more of the following restrictions: it prohibits creation of derivative works; it prohibits commercial use; it obliges to share the licensed or derivative works on the same conditions.

Details

GEM-E3 structure and approach
GEM-E3 can be used for policy anticipation, formulation and implementation.

In terms of anticipation and formulation, as applied general equilibrium model covering the interactions between the Economy, the Energy system and the Environment with high level of details, the GEM-E3 Model is well suited to assess the impact of climate, energy, and transport regulations, as well as fiscal, air quality, and labour market policies. It can simulate the welfare effects of alternative regulation regimes as well as the consequences of emission targets.

The Clean Air Programme for Europe envisages a regular update of the impact assessment analysis, to track progress towards the objectives of the Directive and to serve as input into the regular Clean Air Forum. In 2018 GEM-E3 was used to update the Impact Assessment during the implementation phase. For more information see http://ec.europa.eu/environment/air/clean_air/outlook.htm. Results featured in the First Clean Air Outlook.

One of the applications of the model includes an economic and employment impact assessment of different EU decarbonisation scenarios for 2050. This is included in the in-depth analysis accompanying the European Commission's *Clean Planet for All* communication of 2018. See https://ec.europa.eu/clima/policies/strategies/2050_en#tab-0-1

See https://ec.europa.eu/jrc/en/gem-e3 for latest updates.

Input and parametrization

- Input/Output tables and SAM (GTAP, Eurostat)
- Energy balances (International Energy Agency, IEA)
- Elasticity of Substitution and Armington elasticity (economic literature)
- Costs of Abatement Technology (Research Projects)
- Emission coefficients (Research Projects)
- Techno-economic inputs from sectoral models such as POTEnCIA, PRIMES, POLES, GAINS, and GLOBIOM

Main output
GEM-E3 analyzes the economic and distributional effects of environmental and economic policies for sectors, agents and regions. The output of GEM-E3 includes projections of

- input-output tables
- employment

- trade
- capital flows
- government revenues
- household consumption
- energy use
- atmospheric emissions.

The model allows the evaluation of the welfare and distributional effects of various environmental policy scenarios, including different burden sharing scenarios, environmental instruments (i.e. taxes, pollution permits or command-and-control policy) and revenue recycling scenarios.

Spatial - temporal extent

The output has the following spatial-temporal resolution and extent:

Parameter	Description
Spatial Extent / Country Coverage	ALL countries of the WORLD Global coverage; EU 27 Member States + UK and 18 World Regions
(Spatial) resolution	World-regions (supranational); National Country level for each of the 27 EU Member States and for 8 non-EU countries; regional resolution for the rest of the world
Temporal extent	Long-term (more than 15 years) Currently, typical runs go up to 2050 (but can be extended beyond if there is a need to)
Temporal resolution	Multiple years The model is solved in 5-year steps

Quality & transparency

Quality

Question	Answer	Details
Models are by definition affected by uncertainties (in input data, input parameters, scenario definitions, etc.). Have the model uncertainties been quantified? Are uncertainties accounted for in your simulations?	Yes	Policy uncertainty is covered by running several scenarios in a what-if fashion
Sensitivity analysis helps identifying the uncertain inputs mostly responsible for the uncertainty in the model responses. Has the model undergone sensitivity analysis?	Yes	Sensitivity of output results is done on ad-hoc basis
Have model results been published in peer-reviewed articles?	Yes	The output published in academic papers and presented on academic conferences have been reviewed by peers. In addition, separate versions of the model are run independently by JRC and NTUA / E3M-Lab in Athens, enabling comparison of findings and investigation of differences.
Has the model formally undergone scientific review by a panel of external experts? (Please note that this does not refer to the cases when model results were validated by stakeholders)	No	
Has model validation been done? Have model predictions been confronted with observed data (ex-post)?	Yes	As the model does not aim to predict the future, we mainly validate the model through results with our peer group. In addition, elasticity parameters are based on historical data to validate partial model responses, such as reactions to changes in energy prices

References related to external peer-review and publication in scientific journals:

- Vandyck, T., Weitzel, M., Wojtowicz, K., Rey Los Santos, L., Maftei, A., & Riscado, S. (2021). Climate policy design, competitiveness and income distribution: A macro-micro assessment for 11 EU countries. Energy Economics, 103, 105538. https://doi.org/10.1016/j.eneco.2021.105538

- Vandyck T; Keramidas K; Saveyn B; Kitous A; Vrontisi Z. A global stocktake of the Paris pledges: Implications for energy systems and economy. GLOBAL ENVIRONMENTAL CHANGE-HUMAN AND POLICY DIMENSIONS 41; 2016. p. 46-63. JRC101134

- Vandyck, T., Keramidas, K., Kitous, A., Spadaro, J., Van Dingenen, R., Holland, M. and Saveyn, B., Air quality co-benefits for human health and agriculture counterbalance costs to meet Paris Agreement pledges, NATURE COMMUNICATIONS, ISSN 2041-1723 (online), 9, 2018, p. 4939, JRC111245

Transparency

Question	Answer	Details
To what extent do input data come from publicly available sources? (Note: this may include sources accessible upon subscription and/or payment)	Entirely based on publicly available sources	
Is the full model database as such available to external users? (The answer 'yes' comprises the cases when access to the database implies a specific procedure or a fee)	Yes	The core data, GTAP, are publicly available (if purchased) Other major inputs like IEA energy balances etc. are as well. The input-output tables for future years are published and freely available for the GECO report (from 2018 onwards).
Have model results been presented in publicly available reports?	Yes	
Have output datasets been made publicly available? (Note: this could also imply a specific procedure or a fee)	No	Output usually is published in Report and academic papers. Most of them can be downloaded from https://ec.europa.eu/jrc/en/gem-e3/publications. More detailed output can be published upon request
Is there any user-friendly interface presenting model results – such as dashboards or interactive interfaces – that is accessible to the public?	No	
Is the model code open source?	No	
Can the code be accessed upon request?	No	The GAMS model code is not published as such, but can be replicated from the published set of equations
Has the model been documented in a publicly available dedicated report or a manual? (Note: this excludes IA reports)	Yes	See model documentation. JRC C.6 published a complete manual as an open-access Technical Report in 2013 with a detailed description of the model. Documentation of the NTUA/E3M-Lab version is also available online under http://www.e3mlab.eu/e3mlab/index.php?option=com_content&view=article&id=56%3Amanual-of-gem-e3-model&catid=36%3Agem-e3&Itemid=71&lang=en
Is there a dedicated public website where information about the model	Yes	E3M-Lab The GEM-E3 Model

is provided?	EU Science Hub

References related to documentation:

- Capros P, Van Regemorter D, Paroussos L, Karkatsoulis P, Fragkiadakis C, Tsani S, Charalampidis I, Revesz T, authors Perry M, Abrell J, Ciscar Martinez J, Pycroft J, Saveyn B, editors. GEM-E3 Model Documentation. EUR 26034. Luxembourg (Luxembourg): Publications Office of the European Union; 2013. JRC83177

The model's policy relevance and intended role in the policy cycle

The model is designed to contribute to the following policy areas

- Climate action
- Taxation
- Employment and social affairs
- Energy
- Environment
- Transport

The model is designed to contribute to the following phases of the policy cycle

- Anticipation
- Formulation
- Implementation

The model's potential

GEM-E3 can be used for policy anticipation, formulation and implementation.

In terms of anticipation and formulation, as applied general equilibrium model covering the interactions between the Economy, the Energy system and the Environment with high level of details, the GEM-E3 Model is well suited to assess the impact of climate, energy, and transport regulations, as well as fiscal, air quality, and labour market policies. It can simulate the welfare effects of alternative regulation regimes as well as the consequences of emission targets.

The Clean Air Programme for Europe envisages a regular update of the impact assessment analysis, to track progress towards the objectives of the Directive and to serve as input into the regular Clean Air Forum. In 2018 GEM-E3 is used to update the Impact Assessment during the implementation phase. For more information see http://ec.europa.eu/environment/air/clean_air/outlook.htm. Results featured in the First Clean Air Outlook.

One of the applications of the model includes an economic and employment impact assessment of the European Commission's strategic long-term vision for greenhouse gas reductions, a document that sets the stage for the debate on the long-term climate policy in the EU.

Concerning contributions to Impact Assessments see www.gem-e3.net for latest updates.

Previous use of the model in ex-ante impact assessments of the European Commission

Use of the model in ex-ante impact assessments since July 2017.

In the Year	GEM-E3 contributed to the Impact assessment called	Led by	By providing input to the	The model was run by	Details of the contribution
2022	Impact Assessment accompanying the document Proposal for a Directive of the European Parliament and of the Council on ambient air quality and cleaner air for Europe (recast) SWD/2022/545	ENV	Baseline and assessment of policy options	*European Commission*	The model helped to assess the following impacts: Macroeconomic environment; Economic growth and employment The model helped to assess the following impacts: - Macroeconomic environment - Economic growth and employment
2021	Impact assessment accompanying the document Proposal for a Council Directive: restructuring the Union framework for the taxation of energy products and electricity (recast) SWD/2021/641 final	TAXUD	Baseline and assessment of policy options	*European Commission*	The model helped to assess the following impacts: - Equal treatment of products and businesses - Affects on individual Member States - EU Exports & imports - Investment flows & trade in services - Cost of doing business - Business' capacity to innovate - Market share & advantages in international context - Free movement of goods, services, capital and workers - Competition - Innovation for productivity/resource efficiency - Budgetary consequences for public authorities - Consumer's ability to benefit from the internal market or to access goods and services from outside the EU - Prices, quality, availability or choice of consumer goods and services - Significant effects on sectors - Disproportionately affected region or sector - Goods traded with developing countries - Economic growth and employment - Investments and functioning of markets - Macro-economic stabilisation - Impact on jobs

					- Impact on jobs in specific sectors, professions, regions or countries - Indirect effects on employment levels - Wages, labour costs or wage setting mechanisms - Employment, social protection and poverty impacts in nonMember States (including developing countries) - Emission of greenhouse gases
2021	Impact assessment accompanying the Proposal for a Directive of the European Parliament and the Council: amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652 SWD/2021/621 final	ENER	Baseline and assessment of policy options	*Energy - Economy - Environment Modelling Laboratory, National Technical University of Athens*	The model helped to assess the following impacts: - Significant effects on sectors - Economic growth and employment - Investments and functioning of markets - Macro-economic stabilisation - Impact on jobs - Impact on jobs in specific sectors, professions, regions or countries - Indirect effects on employment levels - Households income and at risk of poverty rates - Inequalities and the distribution of incomes and wealth - Access to and quality of social protection benefits
2021	Impact assessment accompanying the Proposal for a Directive of the European Parliament and of the Council: on energy efficiency (recast) SWD/2021/623 final	ENER	Baseline and assessment of policy options	*Energy - Economy - Environment Modelling Laboratory, National Technical University of Athens*	The model helped to assess the following impacts: - EU Exports & imports - Cost of doing business - Economic growth and employment - Impact on jobs - Impact on jobs in specific sectors, professions, regions or countries - Wages, labour costs or wage setting mechanisms
2021	Impact assessment accompanying the document Proposal for a regulation of the European Parliament and of the Council: establishing a carbon border adjustment mechanism SWD/2021/643 final	TAXUD	Baseline and assessment of policy options	*European Commission*	The model helped to assess the following impacts: - Equal treatment of products and businesses - Affects on individual Member States - EU Exports & imports - Investment flows & trade in services - Non-trade barriers - Cost of doing business - Business' capacity to innovate - Market share & advantages in international context - Free movement of goods, services,

					capital and workers - Competition - Innovation for productivity/resource efficiency - Budgetary consequences for public authorities - Consumer's ability to benefit from the internal market or to access goods and services from outside the EU - Prices, quality, availability or choice of consumer goods and services - Significant effects on sectors - Disproportionately affected region or sector - Adjustment costs in developing countries - Goods traded with developing countries - Economic growth and employment - Investments and functioning of markets - Macro-economic stabilisation - Impact on jobs - Impact on jobs in specific sectors, professions, regions or countries - Indirect effects on employment levels - Wages, labour costs or wage setting mechanisms - Employment, social protection and poverty impacts in nonMember States (including developing countries) - Emission of greenhouse gases - Economic incentives set up by market based mechanisms - Sustainable production and consumption - Relative prices of environmental friendly and unfriendly products - Polution by businesses - Environment in third countries - Energy and fuel consumption
2021	Impact assessment accompanying the document Proposal for a Regulation of the European Parliament and of the Council: amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition SWD/2021/613 final	CLIMA	Baseline and assessment of policy options	*Energy - Economy - Environment Modelling Laboratory, National Technical University of Athens*	GEM-E3 is used for macroeconomic assessment of different CO2 emission standards for vehicles levels.

2020	Impact Assessment accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Stepping up Europe's 2030 climate ambition SWD/2020/176 final	CLIMA	Baseline only	*Energy - Economy - Environment Modelling Laboratory, National Technical University of Athens*	GEM-E3 is used for sectoral economic assumptions used as inputs for the PRIMES energy system model.
2020	Impact Assessment accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Stepping up Europe's 2030 climate ambition SWD/2020/176 final	CLIMA	Baseline and assessment of policy options	*European Commission*	GEM-E3 is used for the assessment of the impacts of policy options on key economic variables, including GDP, sectoral output and aggregate and sectoral employment.
2017	Impact assessment accompanying the document Proposal for a Regulation of the European Parliament and of the Council: setting emission performance standards for new passenger cars and for new light commercial vehicles as part of the Union's integrated approach to reduce CO2 emissions from light-duty vehicles and amending Regulation (EC) No 715/2007 (recast) SWD/2017/0650 final	CLIMA	Baseline and assessment of policy options	*European Commission*	GEM-E3 was used to assess macroeconomic impacts of target setting based on GDP per capita.

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