European Commission

DG DIGIT
Unit D1

Study on informed public policy-making on base of policy modelling and simulation

Data analytics for Member States and Citizens

Date: 22/07/2020
Doc. Version: Final

THE REPORT HAS BEEN PRODUCED FOR THE EUROPEAN COMMISSION BY:

Deloitte. theLisboncouncil think tank for the 21st century

The research presented in the report has been carried out within the scope of the study Data Analytics for Member States and Citizens (Framework Contract DI/07624 - ABC IV Lot 3) commissioned by the European Commission, Directorate-General for Informatics, to Deloitte and the Lisbon Council for Economic Competitiveness and Social Renewal. The project has been carried out within the scope of the ISA² Action 2016.03 – Big Data for Public Administrations. More information is available at https://ec.europa.eu/isa2/sites/isa/files/library/documents/isa2-work-programme-2016-detailed-action-descriptions_en.pdf.

Contact information
DIGIT-DATA-SERVICES@ec.europa.eu

DISCLAIMER

The information and views set out in this publication are those of the author(s) and do not necessarily reflect the official opinion of the European Commission. The European Commission does not guarantee the accuracy of the data included in this document. Neither the European Commission nor any person acting on the European Commission's behalf may be held responsible for the use which may be made of the information contained therein.

© European Union, 2020. Reproduction is authorised provided the source is acknowledged.

TABLE OF CONTENTS

1 INTRODUCTION AND KEY FINDINGS

The data explosion is affecting all aspects of the society and the economy – and public administration is no exception. Data is a fundamental resource for carrying out all government activities, from regulation to service provision. And governments everywhere and at all levels are looking into the opportunities of data driven innovation, and in many cases experimenting with it. IDC estimates that central government is the fifth largest industry of the of the big data analytics market, covering about 7% of the expenditure, and growing fast. A recent study by Deloitte (2016) identified 103 cases of big data analytics in government. In that regard, the Communication on "Data, Information and Knowledge management" calls for a more strategic use of data, information and knowledge. In this context, a data strategy (DataStrategy@EC) and a related Action Plan have been set-up in 2018, with the objective of transforming the EC in a data-driven organisation. The eight actions of the Action Plan are centred around 5 different dimensions: data, people, technology, organisation, policy. The data strategy highlights indeed that these dimensions need to mature and evolve harmonically to deliver a real transformation on how data is used in the decision-making processes. In 2019, an operational governance framework has been set up to closely follow-up the implementation and the evolution of the Action Plan. The 2016-2020 ISA² (Interoperability solutions for public administrations, citizens and businesses) programme funded with a budget of 131 million euro, aims to support the development of digital solutions that enable public administrations, businesses and citizens in Europe to benefit from interoperable cross-border and cross-sector public services. All these initiatives foster data-centric public administration. But where do we stand? To understand that the European Commission has commissioned the study **Data Analytics for Member States and Citizens,** which provides policy Directorate Generals of the European Commission and Member States public administrations with a knowledge base and guidance on the adoption of public sector data strategies, policy modelling and simulation tools and methodologies, and data technologies fostering a data-centric public administration. Specifically, the study covers three domains in relation to data analytics in government:

1. **Data strategies, policies and governance**: initiatives in the public sector both at the strategic level, such as data strategies, data strategies, data governances and data, management plans; and at organisational level, aimed to create units or departments, and to elaborate new processes and role.
2. **Policy modelling and simulation**: initiatives to improve policy analysis through new data sources, robust and reliable models to perform "what-if" scenarios, predictive analytics and hypothesis testing, and tools allowing policy makers to carry out scenario analysis through intuitive interfaces.
3. **Data technologies**: new architectures, frameworks, tools and technologies to be used by public administrations to gather, store, manage, process, get insights and share data. This domain includes the study of how data are governed as well as data collaboratives, and in particular stresses the joint analysis of governance and technologies.

In this draft report are featured the case studies related to domain two. Specifically, the aim of the analysis is to provide the European Commission with guidance on how to increment the use of modelling and simulation for policy making, especially for what concerns technological solutions, data collection and aggregation, improvement of skills and capacity, data collection and aggregation, co-development of models, procedures and governance. Apart from the cases that were elected at the beginning of the study, the research team took the opportunity to provide a critical review of predictive models used to tackle the COVID-19 epidemics.

Specifically, the report depicts the description and cross-analysis of five simulation models:

- **NAWM II - The European Central Bank New Area-Wide Model II.** The model was first developed in 2008 at the European Central Bank. NAWM, a micro-founded open-economy model of the euro area, was designed for use in the (Broad) Macroeconomic Projection Exercises regularly undertaken by ECB/Eurosystem staff and for policy analysis. A new version of the model has been developed in 2018, called New Area-Wide Model II, in the view to incorporate a financial sector with the following objectives: (i) accounting for the role of financial frictions in the propagation of economic shocks and policies and for the presence of shocks originating in the financial sector itself, (ii) capturing the prominent role of bank lending rates and the gradual interest-rate pass-through in the transmission of monetary policy in the euro area, and (iii) providing a structural framework that can be used for assessing the macroeconomic impact of the ECB's large-scale asset purchases conducted in recent years;
- **WEM - World Energy Model.** Since 1993, the International Energy Agency (IEA) has provided medium- to long-term energy projections using the World Energy Model (WEM). The model is a large-scale simulation model designed to replicate how energy markets function and is the principal tool used to generate detailed sector-by-sector and region-by-region projections for the World Energy Outlook (WEO) scenarios. Updated every year and developed over many years, the model consists of three main modules: final energy consumption (covering residential, services, agriculture, industry, transport and non-energy use); energy transformation including power generation and heat, refinery and other transformation; and energy supply. Outputs from the model include energy flows by fuel, investment needs and costs, CO2 emissions and end-user pricing.
- **PRIMES - Price-Induced Market Equilibrium System.** The PRIMES (Price-Induced Market Equilibrium System) energy system model has been developed by the Energy-Economy Environment Modelling Laboratory at National Technical University of Athens in the context of a series of research programmes co-financed by the European Commission. The model has been designed as a modular system aiming at representing agent behaviours and their interactions in multiple markets. The model has combined microeconomic foundation with engineering representations aiming at simulating structural changes and long-term transitions. From mid-90s until today PRIMES has been continuously extended and updated. PRIMES has been widely used and established in studies of medium and long term restructuring of the EU energy system, in view of climate change, renewable energy development, energy efficiency and impact assessments of numerous Community energy and environmental policies. The PRIMES model has served to quantify energy outlook scenarios for DG TREN and DG ENER (Trends publications since 1990), impact assessment studies for DG ENV, DG TREN, DG CLIMA and DG ENER and others, including Energy Roadmap to 2050 (2011-2012) and Policies to 2030 (2013). PRIMES has been also used at national level for governments, companies and other institutions including for EURELECTRIC in the Power Choices strategic study;
- **GAINS - Greenhouse gas - Air pollution Interactions and Synergies.** GAINS was launched in 2006 as an extension to the RAINS model which is used to assess cost-effective response strategies for combating air pollution, such as fine particles and ground-level ozone. GAINS provides an authoritative framework for assessing strategies that reduce emissions of multiple air pollutants and greenhouse gases at least costs, and minimize their negative effects on human health, ecosystems and climate change. 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. Scientists in many nations use GAINS as a tool to assess emission reduction potentials in their regions. For the negotiations under the United Nations Framework Convention on Climate Change (UNFCCC), a special version of GAINS has been developed to compare greenhouse gas mitigation efforts;

- **MESSAGE - Model for Energy Supply Strategy Alternatives and their General Environmental Impact.** MESSAGE stands at the core of ENE's modelling framework. It provides a flexible framework for the comprehensive assessment of major energy challenges and has been applied extensively for the development of energy scenarios and the identification of socioeconomic and technological response strategies to these challenges. The modelling framework and the results provide core inputs for major international assessments and scenarios studies, such as the Intergovernmental Panel of Climate Change (IPCC), the World Energy Council (WEC), the German Advisory Council on Global Change (WBGU), the European Commission, and most recently the Global Energy Assessment (GEA).

Specifically, the analysis (see the annex) provides an analysis of the use and type of models, data sources, drivers and challenges, role of beneficiaries and technological providers, scalability and sustainability, outcomes and impacts, co-creation and composability, data aggregation methodology, model evaluation and validation, input from providers, success factors, bottlenecks and lessons learnt, and finally advice to prospective adopters.

Further, the report depicts the description and analysis of **27 predictive models from six countries (DE, ES, FR, IT, UK, US)** aimed to provide insights to policy makers in copying with the COVID-19 outbreak. The information provided for each model (see the Annex) include the type of model and its predictions, the extent to which the model and its results are published, the extent to which the model is explicitly used by policy makers at this moment, and finally whether the model focusses on estimating epidemic variables (e.g. number of infected individuals), estimating healthcare variables (e.g. availability of Intensive Care Units), assessing mitigation actions (e.g. school closures), or assessing epidemic spread and mobility of population. In addition, in Table 1 follows a summary description of the 27 predictive models surveyed and discussed:

Table 1 – List of models surveyed and analyzed

Model name	**Topic**
IHME	Epidemic and healthcare variables such as number of infected, deaths, hospital beds, ICU, and invasive ventilation needed
Los Alamos	Estimate at US state level the number of cases and deaths
Epirisk	EpiRisk is a computational platform designed to allow a quick estimate of the probability of exporting infected individuals from sites affected by a disease outbreak to other areas in the world through the airline transportation network and the daily commuting patterns. It also lets the user to explore the effects of potential restrictions applied to airline traffic and commuting flows.
COVID-19 Modelling	Global Epidemic and Mobility Model (GLEAM), an individual-based, stochastic, and spatial epidemic model used to analyze the spatiotemporal spread and magnitude of the COVID-19 epidemic in the continental US. The model generates an ensemble of possible epidemic projections described by the number of newly generated infections, times of disease arrival in different regions, and the number of traveling infection carriers.
Bakker et al.	Use of mobility data from January 1st 2020 to March 25th 2020 to figure out how has social distancing policy changed mobility and social behavior, how social distancing behavior differs across the physical space of New York City, and how social distancing behavior differs across demographic groups
Columbia University	Estimate of the number of hospital critical care beds, including ICU beds and other hospital beds used for critical care purposes, that could be made available by hospitals in response to patient surges. Various scenarios are considered.

Imperial College (1)	Assess the potential role of a number of public health measures – so-called non-pharmaceutical interventions aimed at reducing contact rates in the population and thereby reducing transmission of the virus
Imperial College (2)	Combine data on age-specific contact patterns and COVID-19 severity to project the health impact of the pandemic in 202 countries in the view to compare predicted mortality impacts in the absence of interventions or spontaneous social distancing with what might be achieved with policies aimed at mitigating or suppressing transmission
Imperial College (3)	Attempt to infer the impact of policy interventions across 11 European countries.
UO	Percentage of population exposed to the virus.
LSHTM	Age specific social mixing patterns by encounter context (home, work, school or other, in respective rows) and type of contact (physical only shown with dashed lines or all contacts in solid line).
RKI (1)	Estimation of the impact of mitigation measures on the reproduction number.
RKI (2)	Relative import risk at the airport, country and continental levels, as predicted by the computational model and the worldwide air transportation network.
COVID Mobility Project	General picture of mobility reduction in Germany due to Covid-19 mobility restrictions.
Hartl et al.	The impact of the German public shutdown on the spread of COVID-19.
COVID-19 working group et al.	It is provided a descriptive epidemiological summary on the first 62,843 COVID-19 cases in Italy as well as estimates of the basic and net reproductive numbers by region.
Signorelli et al.	Impact of mitigation measures.
Italian STC	Assessment of the risks of epidemic spread for COVID-19 disease associated with various scenarios for the release of the lockdown introduced on 11 March on national territory.
Grasselli et al.	Estimation of ICU capacity and admissions.
COVID-19 MMP	Investigate the number of unique contacts made by a person on a typical day, and evaluate the effect of interventions on the social mixing of our users' sample by defining a proxy of the potential encounters each user could have in one hour. In order to do that, the researchers build a proximity network among users based on the locations they visited and the hour of the day when these visits occurred.
PREDICT COVID-19	Predictive model on the development of positive and death cases due to COVID-19. The study assumes that the first 17 days of infection are those that determine the slope of the curve, the duration of the epidemic depends on when the daily peak is reached which depends in turn on the containment strategies, and the curve can be divided into two different sections, before and after daily peak.
Martinez et al.	Prediction tool that is helping Spanish emergency departments know how many patients with Covid-19 will need to be admitted in intensive care units (ICU) and prepare adequately.
Uni Cat	The model estimates the number of cases, and permits the evaluation of the quality of control measures made in each state and a short-term prediction of tendencies.
Inverence	The modelling strategy considered the number of daily ICU admissions in every region and linking it, via a transfer function, to the number of deaths, assuming that the number of ICU admissions is a good indicator of the number of infected individuals in critical

	condition. Later on, the research team has developed models for the number of infected cases, based on a dynamical transmission rate model, which allows to understand in a straightforward way the effect of public authorities' actions, which are aimed precisely at reducing this transmission rate.
University of Zaragoza	The model is used to predict the incidence of the epidemics in a spatial population through time, permitting investigation of control measures.
Massonnaud et al.	Estimation of the daily number of COVID-19 cases, hospitalizations and deaths, the needs in ICU beds per Region and the reaching date of ICU capacity limits.
EPIcx-lab of INSERM (1)	In one study they use a stochastic age-structured transmission model integrating data on age profile and social contacts in the Île-de-France region to assess the current epidemic situation, evaluate the expected impact of the lockdown implemented in France on March 17, and finally to estimate the effectiveness of exit strategies, building on hospital admission data of the region before lockdown.
EPIcx-lab of INSERM (2)	Assess the expected impact of school closure and telework to mitigate COVID-19 epidemic in France by mean of a stochastic age-structured epidemic model integrating data on age profile and social contacts of individuals.

The analysis elaborates a series of 10 policy recommendations. The first recommendation is to **use models properly**, as they are not a commodity that provide a number which the policy makers use to take decisions, but they require a full understanding of the subtleties involved, the levels of uncertainty, the risk factors. In other words, you need in-house data and model literacy embedded in the policy making process, in house. **Models need also to be tailored** to specific questions you are trying to address: specific modelling strategies (and level of complexity) should be used to address specific research questions. By the same token, it is necessary to **consider carefully the sources of uncertainty in the model**. Such uncertainty could be merely statistically related, related to parameters in the model that are difficult to estimate, concerning the data used, or of a more conceptual level (e.g. assuming a representative agent). Also openness and transparency have a core role. In that regard, modelling exercises require a **timely collection and transparency of data,** crucial to ensure that the data collected are updated and that are collected at regular and timely intervals. Further, it is important to provide specific and complete information about the methodology and procedures for the data collection, in order to inform the users of the models of the caveats and shortcomings. Similarly, **transparency and openness of assumptions and models** is required to increase trust in the results. Such trust is obviously increased if all the assumptions made by the modellers are transparent and available for the other experts to criticize and scrutiny. In fact, openness of assumptions and modelling structure improves the comparability of the analysis and projections produced by different organizations using different models. Further, policy makers should foster the **re-use of data and software modules.** Apart from transparency of data, it is also important to make databases as open as possible in order to allow other researchers to replicate the results of the analysis carried, as well as to use the data for other research purposes. By the same token, the models should be built in modules, to be made available to researchers for re-use and recombination. This allows researchers and practitioners to download, re-adapt and re-use the modules for their analysis, therefore conceiving new applications. Models should also be subject to **validation and sensitivity analysis exercises.** The results of many modeling exercises have been deeply influenced by the modeling and estimation techniques used. In this respect, a core activity ensuring the robustness of the modelling exercises performed consists in applied different modelling and estimation techniques to the same set of data, as well as by applying several validation techniques. As for co-creation, the **collaboration of several individuals in the simulation and scenario generation** allows for policies and impact thereof to be better understood by non-specialists and even by citizens, ensuring a higher acceptance and take up, and a higher adherence to the needs of policy makers and stakeholders in general. The collaboration also includes the **development of easy to use visualizations:** policy makers should be able to independently visualize results of analysis, make sense of data and interact with them. This will help policy makers and citizens to understand the impact of containment policies: interactive visualization is instrumental in making evaluation of policy impact more effective. Finally, there is the need to allow **models integration** by mean of a flexible modelling framework made up by modules that can be integrated in order to address major global challenges in a holistic way.

Section 2 of the report depicts the simulation models, focussing in particular on use and type of models, data sources, drivers and challenges, role of beneficiaries and technological providers, scalability and sustainability, outcomes and impacts. Section 3 depicts also a short analysis of the 27 surveyed predictive models aimed at informing policy making mitigating the COVID-19 outbreak.

Section 4 briefly presents a set of preliminary recommendations regarding timely collection and transparency of data, transparency and openness of assumptions and models, use and re-use of data and software modules, perform validation and sensitivity analysis exercises, generate collaborative model simulations and scenarios, develop easy to use visualizations, consider carefully the sources of uncertainty in the model, tailor the model to specific questions you are trying to address, use models properly, and models integration. Finally, section 5 presents a set of tables presenting a thorough description of the simulation and prediction models.

2 ANALYSIS OF THE SIMULATION MODELS

2.1 Rationale and Types of Models

The cases analysed regard 5 models: one focusses on monetary policy and central banking (NAWM II), two on energy (WEM and PRIMES), and two on environment (GAINS and MESSAGE). All models are developed in modules/building blocks that in principle can be re-used. In principle, all of the models can be adapted by adding new modules and therefore can be applied to new issues. The rationale of the **NAWM II** model is to provide an analysis of the impact of several non-standard measures (NSMs) that have been implemented by the European Central Bank with the objective to mitigate the impact of the financial crisis on the economy as well as to ensure the transmission of standard monetary policy. These measures have included lowering the deposit facility rate, longer-term refinancing operations and an expanded asset purchase programme targeting a variety of investment-grade private and public sector securities. In this regard, the response in the price of assets has led to the suggestion that these NSMs had the effect of boosting economic growth, however the quantitative impact on other macroeconomic variables remains uncertain. Therefore, it became necessary to analyse the quantitative effects of NSMs by developing a coherent structural macroeconomic modelling framework, going beyond the standard DSGE models which cannot be used to study the transmission channels of NSMs. As for the type of model, NAWM II is a Dynamic Stochastic General Equilibria economy-wide model. A DSGE is a particular class of econometric, quantitative models of business cycles, proposed by Kydland and Prescott (1982) and Long and Plosser (1983). DSGE models are dynamic, in the sense that they study how the economy evolves over time; stochastic, as they measure how the economy reacts to random shocks; general, as they represent the whole economy (referring to the entire economy); and subscribing to the Walrasian general equilibrium theory. The model is composed of the following building blocks: agents such as households, firms producing intermediate and final goods, the central banking system and fiscal authorities, real and nominal frictions, financial frictions, and the rest-of-the-world block. The modelled agents include the households, the firms, the central banking system and the fiscal authority.

As for **WEM**, clearly energy is a key driver of the modern global economy, therefore modelling and simulation of energy systems are crucial. The International Energy Agency (IEA) has provided medium- to long-term energy projections using the World Energy Model (WEM) since 1993. The WEM is a large-scale simulation model designed to replicate how energy markets function and is the principal tool used to generate detailed sector-by-sector and region-by-region projections for the IEA's World Energy Outlook (WEO) scenarios. The WEO is a leading source of strategic insight on the future of energy and energy-related emissions, providing detailed scenarios that map out the consequences of different energy policy and investment choices. Developed over many years and updated annually, the WEM consists of three main modules: final energy consumption (covering residential, services, agriculture, industry, transport and non-energy use); energy transformation including power generation and heat, refinery and other transformation; and energy supply. Outputs from the model include projections of energy flows by fuel, investment needs and costs, CO2 emissions and end-user pricing. The IEA's annual World Energy Outlook report relies on the WEM to develop scenarios regarding projected future energy trends. For the World Energy Outlook 2019 (WEO-2019), detailed projections for three scenarios were modelled and presented: the Stated Policies Scenario, the Current Policies Scenario and the Sustainable Development Scenario. The WEO uses a scenario-based approach to highlight the key choices, consequences and contingencies that lie ahead, and to illustrate how the course of the energy system might be affected by changing some of the key variables, chief among them the energy policies adopted by governments around the world. The WEM-based scenarios enable the IEA to evaluate the impact of specific policies and measures on energy demand, production, trade, investment needs, supply costs and emissions.

PRIMES is a large scale applied energy system model that provides detailed projections of energy demand, supply, prices and investment. It covers the entire energy system including emissions for each individual European country and for Europe-wide trade of energy commodities. Developed by the Energy-Economy-Environment Modelling Laboratory (E3M Lab) at National Technical University of Athens, starting in 1993-1994, the PRIMES model covers individual projections for the EU28 Member States, as well as other European countries. The model simulates a multi-market equilibrium solution for energy supply and demand and for ETS and other potential markets by explicitly calculating prices which balance supply and demand. PRIMES is designed to analyse complex interactions within the energy system; its modular design aims to represent agent behaviours and their interactions in multiple markets. From the mid-90s until today, PRIMES has been continuously extended and updated. PRIMES focuses on prices as a means of balancing demand and supply simultaneously in several markets for energy and emissions. The model produces projections up to 2070 in five-year intervals. The distinctive feature of PRIMES is the combination of behavioural modelling (following a micro-economic foundation) with engineering and system aspects and technology progress, covering all energy sectors and markets. The model focuses on simulation of structural changes and long-term system transitions, rather than short-term forecasting. It handles multiple policy objectives, such as GHG emissions reductions, energy efficiency and renewable energy targets; it also provides pan-European simulation of internal markets for electricity and gas. PRIMES captures technology and engineering detail together with micro and macro interactions and dynamics. Because the PRIMES model follows a structural modelling approach, it integrates technology/engineering details and constraints in economic modelling of behaviours. The modelling of decisions draws on economics, but the constraints and possibilities reflect engineering feasibility and regulation restrictions.

MESSAGE has been developed by the International Institute for Applied Systems Analysis (IIASA) in Austria since the 1980s. This model is a systems engineering optimisation model used for the planning of medium to long-term energy systems, analysing climate change policies, and developing scenarios for national or global regions. It provides a flexible framework for the comprehensive assessment of major energy challenges, it has been applied extensively for the development of energy scenarios and the identification of socioeconomic and technological response strategies to these challenges. The energy supply model MESSAGE is a dynamic linear programming (DLP) model which minimizes total discounted costs of energy supply over a given time horizon. The main subject of the model is the balancing of demand for secondary (or final) energy and supply of primary energy resources via driver technologies. The most important model constraints reflect limits on the speed of build-up of technologies, the availabilities of indigenous and imported resources, and technological relationships. A typical model application is constructed by specifying performance characteristics of a set of technologies and defining a Reference Energy System (RES) to be included in a given study/analysis that includes all the possible energy chains that the model can make use of. The model uses a 5- or 10-year time-step to simulate a maximum of 120 years. All thermal generation, renewable, storage and conversion, and transport technologies can be simulated by MESSAGE as well as carbon sequestration. The model's principal results are the estimation of global and regional, multi-sector mitigation strategies instead of climate targets. MESSAGE allows determining cost-effective portfolios of GHG emission limitation and reduction measures. It has recently been extended to cover the full suite of GHGs and other radiative substances for the development of multi-gas scenarios that aim at stabilising future CO2-equivalent concentrations. The model stands at the heart of the IIASA Integrated Assessment Framework, including soft- and hard-links to other spatial and regional modelling tools. The IIASA modelling framework represents the global economy and its main sectors (energy, agriculture, forestry) through dedicated macroeconomic equilibrium as well as system engineering modelling tools.

As for **GAINS**, the International Institute for Applied Systems Analysis (IIASA) funds several research programs. One of these is the Air Quality and Greenhouse Gases (AIR) that is focused on researching into a wide range of links between local air pollution and other policy objectives (e.g. air quality-climate interactions, mitigation options for non-CO2 greenhouse gases, the nitrogen cycle). Within this program, IIASA developed in 2006 The Greenhouse gas - Air pollution Interactions and Synergies (GAINS) model that provides an integrated assessment framework describing the pathways of atmospheric pollution from anthropogenic driving forces to relevant health and environmental impacts. It brings together information on future economic, energy and agricultural development, emission abatement potentials and costs, atmospheric dispersion and environmental sensitivities towards air pollution. The GAINS model is implemented as an interactive web-based software tool that communicates with an ORACLE database. The GAINS portal provides access to the on-line implementations of the GAINS model for various groups of countries and parts or the world. The web interface of the GAINS model can be accessed from the home page of the IIASA APD. GAINS models emission estimates using variables such as production activity, the emission factor for the fraction of the activity subject to control by technology, the application rate of technology to activity, the no control emission factor for activity and the removal efficiency of technology when applied to activity. Further, also mitigation potentials and costs are modelled, such annualised investments, fixed and variable operating costs, and how the investments and costs depend on technology, country and activity type. Mitigation costs per unit of activity are calculated in GAINS as the sum of investment costs, labour costs, fuel costs (or cost-savings), and operation and maintenance costs (or cost-savings) unrelated to labour and fuel costs. The variables used are the sum of annual operation and maintenance costs (or cost-savings) unrelated to labour or fuel costs, the fraction of annual work hours for operating technology, a country-specific wage adjustment factor for type of sector (agriculture or manufacturing industry), the additional amount of energy used or recovered when applying technology, and the fuel price in a given country.

2.2 Data Sources

Regarding **NAWM II**, the time series, apart from the extra-euro area trade variables, are extracted from the 17th update of the Area Wide Model database, which is built on publicly available data from Eurostat and/or reported in the ECB Statistical Data Warehouse (SDW) complemented by aggregating available country data. The historical data are based on the aggregation of available country information when the original AWM database was compiled. The main source for the country information is Eurostat, complemented by the OECD National Accounts, the OECD Main economic indicators, the BIS and the AMECO databases. The sources of the financial data are the Deutsche Bundesbank database, the ECB SDW, and the FRED database of the Federal Reserve Bank of St. Louis. Data are open and available for reuse, and results are shared and published on a regular basis. The data are originally provided by the National Statistical Institutes following the Statistical Data and Metadata Exchange (SDMX) standard. The data are exchanged electronically through API.

As reported by the informant, one of the primary uses of the models is in the context of the macroeconomic projection exercises of the ECB, so this means the model then covers also the main macroeconomic aggregates that play a key role in the projection exercises, which are primarily national accounts data. As reported by the informant there are internal routines available for data aggregation. More specifically, the ECB macroeconomic projections following a bottom-up approach, according to which projections are produced at country level and there are aggregated according to routines and weights (GDP weights for the most part), allowing them to aggregate the outcomes of the country projections so as to obtain aggregate numbers for the EU area, which are then used to analyze the forecasts with the EU area-wide aggregated models. For the estimation of the original version of the model, the research team has made use of time series for 18 macroeconomic variables: real GDP, private consumption, total investment, government consumption, euro area exports and imports, GDP deflator, consumption deflator, extra-euro area import deflator, total employment and nominal wages, short-term nominal interest rate, nominal effective exchange rate of the euro, foreign demand, prices, and short-term interest rate, competitors' export prices, the price of oil. For the estimation of the second version of the model six additional time series are used: 10-year government bond yields, Composite long-term lending rate, Long-term inflation expectations, Foreign 10-year government bond yield, Long-term growth expectations, and output gap. As for the **WEM,** the IEA Energy Data Centre provides the world's most authoritative and comprehensive source of global energy data. The development and running of the WEM requires access to huge quantities of historical data on economic and energy variables. Most of the data are obtained from the IEA's own databases of energy and economics statistics. A significant amount of additional data from a wide range of external sources are also used, especially OECD, IMF, and World Bank for what concerns economic growth. Specifically, the IEA collects, assesses and disseminates energy statistics on supply and demand, compiled into energy balances. In addition, the Energy Data Centre has developed a number of other key energy-related indicators, including energy prices, public RD&D and measures of energy efficiency, with other measures in development. The time series stretches back to 1971, and currently covers up to 95% of global energy supply and over 150 countries. The focus is on quality, comparability, and alignment with internationally agreed definitions and methodologies, and close collaboration with national offices responsible for energy statistics and other relevant stakeholders.[1]

Regarding **PRIMES**, Eurostat is the primary data source, and the model is calibrated to Eurostat statistics wherever possible. Eurostat data is complemented by other statistical sources as needed. EUROSTAT data include: Energy balance sheets; energy prices (complemented by other sources, such IEA); macroeconomic and sectoral activity data; population data and projections; physical activity data (complemented by other sources); CHP surveys; CO2 emission factors; and EU ETS registry for allocating emissions between ETS and non-ETS. Other data sources include technology Databases such as MURE, ICARUS, ODYSEE (demand sectors), VGB (power technology costs), TECHPOL (supply sector technologies), NEMS model database, IPPC BAT Technologies IPTS; power plant inventory ESAP SA and PLATTS; network infrastructures such as ENTSOE, ENTSOG, GIE, TEN-T (transport infrastructure), and other databases such as district heating surveys, buildings and houses statistics and surveys (various sources), IDEES, BSO, BPIE. Data are open and available for reuse, and results are shared and published on a regular basis

The **MESSAGE** demand data are exogenously given for all the energy forms defined at the secondary, final, or useful level. The demand may have seasonal variations. MESSAGE computes seasonal demand using information on "load region" (seasonal division of the year specified by the analyst), and "load data" (distribution of the demand by load region). Examples of data in input for the MESSAGE model are energy system structure, base year energy flows and prices, energy demand via link to MACRO[2], technology and resource options & their techno-economic performance profiles, and technical and policy constraints. The IIASA Energy Program (ENE) which MESSAGE is part hosts a growing number of databases for the integrated assessment modelling community, some of which are open to the wider public: IAMC 1.5°C Scenario Explorer, CD-LINKS Scenario Database, Low Energy Demand study (LED), IPCC AR5 Scenarios Database, SSP Scenario Database, LIMITS Scenario Database, and AMPERE Scenario database.

The **GAINS** database belongs to the IIASA Air Quality & Greenhouse Gases (AIR) includes data from use in electricity and district heating sector, energy use for primary fuel production, conversion of primary to secondary energy other than conversion to electricity and heat in the power and district heating plants, and for delivery of energy to final consumers, final energy use in industry, domestic sector, transport, and non-energy use of fuels. The domestic sector covers residential and commercial sector, as well as agriculture, forestry, fishing and services. GAINS energy database includes three major components of energy system: electricity and district heat generation in the power and

1 Have a look at the World Energy Model Documentation available at https://iea.blob.core.windows.net/assets/d496ff6a-d4ca-4f6a-9471-220adddf0efd/WEM_Documentation_WEO2019.pdf

2 MACRO MODEL: https://iiasa.ac.at/web/home/research/researchPrograms/RISK/MACRO1.html

district heating sector (PP); energy use for primary fuel production, conversion of primary to secondary energy other than conversion to electricity and heat in the power and district heating plants, and for delivery of energy to final consumers (CON); final energy use in: industry (IN), domestic sector (DOM), transport (TRA), and non-energy use of fuels (NONEN). The domestic sector covers residential and commercial sector, as well as agriculture, forestry, fishing and services. Historic data have been extracted from energy statistics. GAINS contains alternative pathways of energy use up to 2030 derived from national and international energy projections (e.g., scenarios developed for Europe by the PRIMES model, projections of the International Energy Agency, scenarios based on national studies). While these data are stored in the GAINS database, they are exogenous input to GAINS. Format of energy data in GAINS is convenient for calculating emissions of air pollutants and greenhouse gases. Energy tables show fuels that are actually used in combustion processes in various economic sectors. Fuel production figures, like coal mining or oil and gas extraction, are reported in process data tables only if they are relevant for emissions calculations. In addition, crude oil input to refineries and coal input to coke plants do not appear in GAINS energy tables. Instead, products (outputs) from refineries and coke plants are shown as fuel consumption in energy consuming sectors. Again, crude oil input to refineries can be found in process activity data. Total energy consumption in a given country can be derived by summing up the fuel use in the conversion sector (CON), power sector (PP) and final demand sectors (e.g., IN, DOM, TRA, and NONEN). Although this total is a sum of primary and secondary energy, it is equal to the total primary energy demand at a country level. In detail, the GAINS database includes data from the following sectors: Aggregation of energy carriers, Power plant sector (PP), Energy production and conversion/transformation sector (CON), Industry, Domestic sector, Transport and other mobile sources. The databases used for GAINS and MESSAGE are hosted by IIASA and have been developed over time in international collaboration projects.

2.3 Collaboration in Developing and Validating the Model

As for **NAWM II**, the main actors for what concern the case are obviously the European Central Bank, and in particular its Eurosystem staff. Other important stakeholders and the EURO Area Member States, and in particular their central banks, which make use of the forecasts of the model application to calibrate and refine their policy interventions, as well as other international organizations such as OECD and International Monetary Fund, which compare their forecasts to the ones of the European Central bank. As reported by the informant, the policy makers provide input and feedback continuously on the application of the model. Further, when the model was elaborated, a wide range of stakeholders from the central banks, academia and institution was engaged in discussions. Clearly there is a regular feedback and validation from the staff within the Euro system given that the model is used to prepare input into the policy process by conducting scenarios, risk analysis, by assessing the impact of policy measures. In fact, the main objective is of course to serve the needs of the policy makers, by using these models to help them to pursue their tasks of conducting policies for the EU area. Further, the development of the model gained from discussion and input from a wide range of stakeholders. In fact, as reported by the informant, the ECB had initially support by external consultants which were mostly colleagues from other central banks from EU Member States, as well as from the New York Fed and the Sveriges Riksbank, which at the time were quite advanced in developing this type of DSGE models. After having acquired all this expertise, the ECB started to provide advice to other modeling teams that were also trying to build up their own capacities. In fact, the ECB has been quite active in supporting other institutions, other central banks, primarily in building up their modelling capacities, by directly advising on certain modelling projects, but also within the EU system of central banks which includes not only the ECB but also the national central banks. There are modelling working groups which meet several times a year, where the ECB makes available its experience and part of the applications with its models as a mean of transferring knowledge and expertise working with the respective communities. Of course there has also been a lot og exchange with the European Commission, in terms of joint projects and papers. Therefore, the model has been co-created in collaboration with all the central banking community. Further, when building the model, the ECB reached out regularly to academia by producing also academically oriented papers with the model, which have been published in several journals. This was also the chance to receive feedback and to get peer reviews of the ECB modeling work, also in light to establish a reputation of the modeling function at ECB more generally within the academic community.

Further, the informant reports that the ECB has put a lot of emphasis on model evaluation, as reflected in the working papers which document the NAWM vintages. Specifically, the ECB elaborated based on the literature a number of criteria against which to assess the performance of the model. Moreover, as the models are estimated using Bayesian techniques, there are various statistics and criteria that allow the authors to judge how good the model fits the data. Further, there are a lot of economic checks by looking at transmission mechanisms on the basis of impulse response functions as well as forecast evaluations to judge how good the model performs in terms of forecasting macro aggregates. All these checks are documented in the papers presenting the model, but also in some additional academic papers, as a good practice to establish the credibility of the model and by assuring that it performs reasonably well compared to some standard benchmarks that are used in the literature.

Concerning **WEM**, the annual WEO report based on the model is used by all OECD member nations as well as many non-member countries and other entities to inform their energy and climate policies. Specifically, the WEO report relies on the WEM to develop scenarios regarding projected future energy trends. For the World Energy Outlook 2019 (WEO-2019), detailed projections for three scenarios were modelled and presented: the Stated Policies Scenario, the Sustainable Development Scenario and the Current Policies Scenario. The scenarios differ with respect to what is assumed about future government policies related to the energy sector. The WEO uses a scenario-based approach to highlight the key choices, consequences and contingencies that lie ahead, and to illustrate how the course of the energy system might be affected by changing some of the key variables, chief among them the energy policies adopted by governments around the world. The WEM scenarios enable the IEA to evaluate the impact of specific policies and measures on energy demand, production, trade, investment needs, supply costs and emissions. Therefore, the users and stakeholders provide input to the model in terms of feedback regarding results and modelling assumptions/techniques, and policy input regarding the elaboration of new scenarios. In this respect, incorporating feedback from stakeholders in the process is deemed to be essential to success.

MESSAGE gains from input and collaboration from a wide range of stakeholders. In the structure and design process of the regional model, ministries and government officials can be involved. For instance, recently a MESSAGE model was built in collaboration with the Indian government, specifically for the Indian South Continent, working with Indian ministries, environment local authorities and energy administrations. In general, collaboration depends on which model, or which version or instance of the model, is requested, and the local authorities of the requester. Furthermore, since the model developers interact with the scientists and local decision-makers (users), they collected feedback on the best graphic interface to apply to different types of users. Indeed, previously they had less knowledge about details and mechanic indications of the model. Local experts help them to improve the system representation or face issues, which they would not consider from their global perspective.

Finally, being used in the Energy Roadmap to 2050, PRIMES has supported analysis for major energy policy and market issues, including electricity market, gas supply, renewable energy development, energy efficiency in demand sectors and numerous technology specific analysis. The model also has quantified energy outlook scenarios and has been used in impact-assessment studies by the EU. PRIMES also has supported national projections for governments, companies and other institutions, including for EURELECTRIC and EUROGAS. The model includes all European Union member states individually and also has provided detailed outlooks for Switzerland, Norway, Turkey, Albania, Bosnia, Montenegro, Serbia, FYROM and Kosovo. Numerous third-party studies have used projections produced using PRIMES; the majority of these studies focused on medium- and long-term restructuring of the EU energy system, aiming at reducing carbon emissions. On co-creation, the informant at E3-Modelling in Athens says that although the PRIMES model is proprietary there has been input from the European Commission from the beginning and it continues to this day. "Some people at the European Commission, they were quite insightful," the informant said. "They really helped, not by writing code, for example, but by providing the specifications of what they need exactly. The model has been developed according to the needs to the European Commission," he said. The informant points to the inclusion of climate-neutral scenarios in the model for the "Clean Planet for All" communication. "It was the first time we were asked to model climate-neutrality scenarios," he said. "So because of this need, we added several technologies, regarding sectorial integration or negative-emissions technologies that we didn't have in the past," he said. The European Commission undertook a project in 2018 to ensure robustness and representativeness of the technology assumptions in the PRIMES model by reaching out to relevant experts, industry representatives and stakeholders, who are in possession of the most recent data in the different sectors. The informant said the consultation work on technology assumptions "was quite positively received by the stakeholders and the Commission itself" and likely will become more routine. "I think it's going to become a thing and we will do it quite often from now on," he said. "It's going to be expanded maybe in the future to other domains" and to other assumptions. The informant said efforts are being made to address other issues as well. "An effort is being made, which started with this consultation on technology costs, to open up parts of the model that we can open, unlike other parts like the proprietary databases," he said. "This is a part of the effort to be more transparent and alleviate such concerns by some stakeholders." "Another effort is the fact that we now prepare some tools, like the compact version of PRIMES, that we deliver these versions to clients," the informant said. "We develop these tools and they reflect the PRIMES way of thinking and the PRIMES methodology, and we deliver it to clients."

As for **GAINS**, the main actor is the International Institute for Applied Systems Analysis (IIASA). GAINS is used for policy analyses by United Nations Economic Commission for Europe (UNECE) under the Convention on Long-range Transboundary Air Pollution (CLRTAP), for instance, it has been used for the revision of the Gothenburg Protocol. GAINS has also been used by the European Union for the EU Thematic Strategy on Air Pollution and the air policy review. Further, scientists in many nations use GAINS as a tool to assess emission reduction potentials in their regions. For the negotiations under the United Nations Framework Convention on Climate Change (UNFCCC), a special version of GAINS has been developed to compare greenhouse gas mitigation efforts among the involved countries. Therefore there is a continuous exchange of feedback and input among policy makers and researchers on the model application.

2.4 Success Factors and Challenges

Concerning **NAWM II**, as reported by Dou et al. (2017) there are several drivers and success factors for the adoption of DSGE models. First, DSGE models are less subject to the Lucas critique due to their explicit account for the role of expectations and their identification of deep structural parameters, making them more suitable for policy analysis and counterfactual experiments. Further, DSGE models are able to identify and decompose economic and policy structural shocks on the quantitative level by the mean of an impulse-response analysis. In this regard, the identification of structural shocks greatly improves the reliability of policy analysis and counterfactual experiments, and mitigates the Sims critique. And finally, DSGE models are able to discover deep structural parameters thanks to their capability to link model implications to time-series and cross-sectional data. On the other hand, the financial crisis of 2007-2009 has given new urgency in extending the power and reach of DSGE models. In the same way as the Great Depression inspired

Tinbergen and Klein, and the recession and stagnation of the 1970s inspired Lucas, Kydland, and Prescott, the current macroeconomic situation has prepared the way for a major shift in macroeconomic modelling for policy. Specifically, DSGE models need to take to take risk into account by incorporating individual, institutional, and regulatory responses to changing risks. Further, DSGE models need to incorporate the financial sector and its intricacies. Finally, DSGE models should departure from the assumption of optimizing agents following rational expectations, and allow for certain predictable irrationalities in their behaviour. These agents would still adapt to the economic circumstance, therefore rejecting the Lucas critique, but not in an instantaneous and fully optimal way. In summary, NAWM II represents an improvement and an advancement with respect to former modelling techniques, but in order to improve its reach and power some extensions are due.

As for **WEM**, it is a common argument (inter al. Mohn 2017) against the methodology and models of the WEM is that the flexibility of economic behaviour is effectively contained, and that the relations of the modelling system are not sufficiently responsive to shifts and shocks in technology, preferences, policies and prices. Critics also argue that the IEA's World Energy Outlook, which uses the WEM, is largely a product of historical trends and developments, which lead to a status quo bias in favour of fossil fuels. Mohn also says that "any sort of feedback effects from energy policies, technological change and energy back on economic activity (growth) is neglected in the main scenarios. This is clearly a shortcoming of the modelling approach," he says. There is also an underestimation of the power of new technologies. Hoekstra et al. (2017) argue that the WEM and other models "underestimate the potential of technologies that diverge from the status quo." The paper focuses on WEM's photovoltaic predictions in the World Energy Outlook, saying "stagnation of the solar industry is predicted over and over again." "This disconnection from reality could be due to, for example, sponsor requirements or mental biases like confirmation bias, status quo bias, or system justification bias, but the way the model works could also be a factor," the authors conclude. They argue that "most of the energy transition management model requirements that we deduce from the literature are implemented partially or not at all. The result is a model that is unable to envision and leverage the exponential developments in solar energy"'. By the same token, Mohn sees `general suspicion that IEA's methodology and modelling strategy puts too little emphasis on the flexibility in economic behaviour.' Finally, some researchers argue for a lack of transparency. Richard G. Newell, Stuart Iler and Daniel Raimi also urge greater transparency, but with a broader argument – to improve the comparability of the projections produced by different organizations. "Outlooks vary in a number of important methodological aspects, and comparing between outlooks is not straightforward," they say in a 2018 paper. "Without a way to clearly compare one outlook to the next, decision-makers may not understand the range of possibilities envisioned by different short-, medium- and long-term projections, or the assumptions that underpin those projections." On the other hand, the IEA defends itself with the argument that the WEO does not make forecasts, but provides policy-dependent projections. As declared by the IEA Executive Director Birol "Some colleagues and friends in the renewables industry have at times criticised the projections of future renewables energy supply in our main scenario as too conservative. But they rest squarely on the foundation of officially declared policy intentions.' Further, the WEO in 2017 introduced the Sustainable Development Scenario, which is focused on climate issues. In this regard, consultancy Menlo Energy Economics praised the 2018 edition of the WEO for expanding the focus beyond oil and other fossil fuels, and including the growing role of electricity as the fuel of choice among end-users. Finally, there has also been an improvement in terms of transparency. In fact, in the latest edition of the WEO, the IEA says: `We have made all the key policy assumptions available for all scenarios, along with all the underlying assumptions on population, economic growth and energy resources (which are held constant across the scenarios) and information on prices and technology costs (which vary by scenario depending on the market and policy context).'

The main driver for the use of the **PRIMES** model is the need for medium- and long-term energy system projections, in both demand and supply sides, in particular projecting prices influencing the evolution of energy supply and demand, as well as technological progress, that cover the entire energy system including emissions. Duwe and Vallejo (2018) argue that "The PRIMES model currently used by the Commission is frequently criticized for its lack of transparency on modelling inputs and assumptions, which reduces confidence in its results." But they went on to say that: "This criticism is potentially an expression of a larger concern over the lack of transparency in decision-making on long-term policy. A shared disaggregated structure describing the key indicators of the transition and an engagement process spanning more than a few months are needed to elaborate meaningful dialogue and narratives. This need to also include additional dimensions (e.g. social and cultural) that are of key interest for stakeholders but often go beyond the capacities of 6 modelling tools," according to the paper. The European Federation for Transport and Environment, in an August 2018 report, included a lack of transparency among "technical limitations" of the PRIMES model in the transport sector.[3] Among other things, the environmental campaign group urged the European Commission to improve the transparency of the process and include more active stakeholder involvement, give a stronger focus on the potential of zero-emissions technologies to achieve full decarbonization in the transport sector, include all transport emissions, particularly in the aviation and maritime sectors, better account for the societal cost of greenhouse gas emissions, including an analysis of the impact of non-action. Finally, Eurelectric said in a 2012 report on the Energy Roadmap 2050 that stakeholders needed better access to elements of PRIMES:[4] "Stakeholders are not able to access the country-specific output from the PRIMES model used to develop the different scenarios. Without this national breakdown of information (to allow comparison, for example, with national studies on 2050 pathways) it is difficult to provide detailed comments on the validity of the assumptions and output from the PRIMES 2050 pathway analysis. This national breakdown should be made available to all stakeholders," Eurelectric said. On infrastructure, Eurelectric said "further clarity would be needed to understand how cross-country transmission capacities, as well as national distribution capacities, are considered in the PRIMES approach," according to the paper.

For what concerns **GAINS**, we rest on the fact that in the atmosphere, many air pollutants contribute to climate warming or cooling. As these substances are generally shorter-lived in the atmosphere than greenhouse gases, reducing air pollution will yield climate change benefits much earlier than greenhouse gas reductions alone. Current and future economic growth will cause serious air quality problems, negatively impacting human health and crop production, unless further air pollution control policies are implemented. Increased economic activity will also lead to more greenhouse gas emissions and subsequent climate change. Yet, air pollutants and greenhouse gases can be reduced simultaneously at far lower costs because they often originate from the same sources. GAINS provides an authoritative framework for assessing strategies that reduce emissions of multiple air pollutants and greenhouse gases at least costs, and minimize their negative effects on human health, ecosystems and climate change. Specifically, GAINS provides an efficient framework for assessing strategies, which reduce emissions of multiple air pollutants and greenhouse gases at the minimum cost, and, as much as possible, their negative effects on human health, ecosystems and climate change. Further, GAINS helps identify measures to mitigate local air pollution and thus global climate change. Finally, GAINS provides a framework to cover all sectors, and can be used in conjunction with the energy model MESSAGE, the land-use model GLOBIOM, the air pollution and GHG model GAINS, the aggregated macro-economic model MACRO and the simple climate model MAGICC, creating a framework that covers all major sectors, including agriculture, forestry, energy, and industrial sources, permitting a concurrent assessment of how to address major

3 T&E source: https://www.transportenvironment.org/sites/te/files/2018_07_2050_model_paper_final.pdf
4 https://www.eurelectric.org/media/1698/roadmap_2050_response_paper_final-2012-100-0003-01-e.pdf

sustainability challenges. As in the case of MESSAGE below, transparency and interaction with stakeholders remains a challenge.

MESSAGE was developed for the application to geographical regions the size of continents. It may also be applied to smaller regions or countries, provided that some care is taken in supplying the input data and in interpreting the model results. A particular problem that may arise comes from the continuity of the model variables that, for small countries, may very likely result in sizes of energy conversion facilities that are unrealistically small. In addition, in some regions or countries the energy system may have some peculiarities, which have not been considered in the general model formulation. Another important application of MESSAGE besides its usage within the global model was the one for the Commission of the European Communities (CEC). The CEC application emphasized the disaggregation of global results. This was achieved by splitting IIASA's Region 111 into "Europe of the Nine" and "Rest of the Region" using a modified model loop. The results of the IIASA models were then compared with "bottom-up" model runs performed by the CEC. Other applications underway (such as for Brazil, Bulgaria, the FRG, and Hungary) seem to prove that the definition of MESSAGE is general enough to serve as a basis for a great variety of applications. Further, MESSAGE can be used in conjunction with other models. For instance, "MESSAGE-Access" describes a residential energy and technology choice model, which interacts with the global energy system model MESSAGE. MESSAGE-MACRO results from the linking of a detailed energy supply model (MESSAGE) with a macroeconomic model (MACRO). MESSAGE-MAGIC results from the linking of the energy model MESSAGE with the climate model MAGICC allows the integrated analysis of (probabilistic) climate. MESSAGE-GLOBIOM results from the linking of the energy model MESSAGE and the IIASA's Global Biosphere Management Model (GLOBIOM)[5]. Further, the model is used by different countries to build or design their energy strategies at the national level. The modelling results provides the quantitative bases for different ministries to define and discuss the national targets. Scenarios provided by the model are useful to initiate policy dialogues and make informed choices, based on scientific insights, and show to the decision-makers the possibilities between these different choices. It is considered an important lesson learnt because it allows for understanding the power of the model. About challenges, working with some specific government, it is not always easy to have direct communication and interaction. Indeed, with some countries, using the MESSAGE model involves larger and indirect effects.

2.5 Scalability and Sustainability

Concerning **NAWM II**, in principle the model can be scaled, as it deals with the estimates of the policy impact in the EURO Area. Therefore, the model can be adapted with including a bigger number of countries by re-estimating the parameters for calibration. The model can in principle also be transferable to another monetary area, again by re-estimating the parameters for calibration, and can be downsized to a smaller level, for instance at regional level (see the derived model EAGLE[6]). However, this is a typical macro-economic model, and therefore the transferability to other domains (e.g. energy) and/or the application to other policy questions is somehow limited, and in any case the adaptation of the model to a multi-country setting, or to other jurisdictions in general would be demanding a quite huge amount of effort.

WEM is used both at global and at national/regional level. The current version of WEM covers energy developments up to 2040 (2050 for the Sustainable Development Scenario) in 25 regions. Depending on the specific module of the WEM, individual countries are also modelled: 12 in demand; 101 in oil and gas supply; and 19 in coal supply. Demand modules can be isolated and simulations run separately. The **PRIMES** model has served to quantify energy outlook scenarios for DG TREN and DG ENER, impact assessment

[5] GLOBIOM MODEL; https://www.globiom.org/
[6] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1786417

studies for DG ENV, DG MOVE, DG CLIMA and DG ENER and others, including Energy Roadmap to 2050 and Policies to 2030 on climate. The PRIMES model covers individual projections for the EU28 Member States, and all European countries. Specifically, the model goes up to 2070 in five-year intervals and includes all EU member states individually, and has also provided detailed outlooks for Switzerland, Norway, Turkey, Albania, Bosnia, Montenegro, Serbia, FYROM and Kosovo. PRIMES also has been used at national level for governments, companies and other institutions. The PRIMES sub-models (modules) can be used in a stand-alone fashion or can be coupled with the rest of the PRIMES energy systems model. In the latter case, the integration with the PRIMES model enhances the dynamic character of the model, since the interaction of the different energy sectors is taken into account in an iterative way. PRIMES can be used in linked fashion with GEM-E3 and IIASA's GAINS to perform energy-economy-environment policy analysis in a closed loop. The PRIMES model is mostly used at maximum level. PRIMES is designed to represent agent behaviours and their interactions in multiple markets. The model has combined microeconomic foundation with engineering representations aiming at simulating structural changes and long-term transitions. Theoretically, the supply module could be run separately from the demand module, the informant said. But "because the strong point of PRIMES is the fact that it models the equilibrium of markets," it is more productive to run them together. "It balances the supply and demand of energy through prices," he said. E3-Modelling has developed a simplified version of PRIMES that does not contain the full set of equations of the full PRIMES. The simplified, or compact, version of PRIMES was developed to be used on a country-by-country basis. When running the model for a stand-alone country, it doesn't have to model the whole network of Europe in order to model only one country. "So the stand-alone model of Turkey excludes the network equations that have to balance the whole network across Europe," the informant said.

MESSAGE model is used mainly at the global level. MESSAGE was developed to be used for geographical regions with the size of continents. It may also be applied to smaller regions or countries, provided that some care is taken in supplying the input data and in interpreting the model results. A particular problem that may arise comes from the continuity of the model variables that, for small countries, may very likely result in sizes of energy conversion facilities that are unrealistically small. In addition, in some regions or countries, the energy system may have some peculiarities, which have not been considered in the general model formulation.

Currently, the **GAINS** model is implemented at a global level, in 165 regions, including 48 European countries and 46 provinces/states in China and India. The model can be adapted to a bigger number of countries. In particular, the GAINS model will be probably used soon in South Africa, to face the big challenge of premature deaths due to air pollution.

2.6 Use in Policy Making

All the models studied have extensive use in policy making. As for **NAWM II**, it is regularly used for policy making by the European Central Bank, and its results are adopted by members of the Euro Area as well as from Member States. Further, there a series of key benefits of global macroeconomic models for forecasting and what-if exercises such as the NAWM II. First, they provide a framework for understanding how economies work and interact. Secondly, they are a tool for thinking about possible identifiable risks, policy responses and wider consequences. Moreover, multiple applications are allowed, so there is no need to reinvent the wheel each time. Further, they incorporate key magnitudes and impose consistency, and finally they improve over time in reaction to new ideas and events. Specifically, the NAWM II model allows to carry out economic projections contributing to the elaboration of the projection baseline for the largest euro area countries and to forecasting with judgment and model-based projection narratives. Further, the model allows for risk analysis and policy analysis, the latter related to the impact study of monetary policy options as well of strategic issues related to Monetary-fiscal-financial policy mix in the euro area. More practically, in the last decade the ECB's standard monetary policy operations have been complemented by several non-standard measures (NSMs) which have responded to the challenges posed by the different phases of the financial crisis that had begun in 2007. These measures have included lowering the deposit facility rate, longer-term refinancing operations and an expanded asset purchase programme targeting a variety of investment-grade private and public sector securities. Asset price reactions suggest that these NSMs had expansionary effects but the quantitative impact on other macroeconomic variables remains uncertain. The only way to assess the quantitative effects of NSMs was to develop a coherent structural macroeconomic modelling framework, going beyond the standard DSGE models which cannot be used to study the transmission channels of NSMs. Therefore, the creation of NAWM II has improved the comprehension of the effects of the monetary policies and operations carried out by the ECB.

Concerning **WEM**, The IEA's WEM-based WEO is a leading source of strategic insight on the future of energy and energy-related emissions, providing detailed scenarios that map out the consequences of different energy policy and investment choices. The IEA has become one of the most important inputs into government decision-making about energy, and its annual WEO report has a significant effect on the political and economic decisions of administrations and stakeholders regarding both conventional and renewable energy. Specifically, the WEM is used by all OECD member nations as well as many non-member countries to inform energy and climate policies, and it has a broad role in promoting alternate energy sources, including renewable energy, rational energy policies, and multinational cooperation in energy technology. In fact, WEM helps policy-makers in assess the cost of each policy option related to energy, both in terms of necessary capital investments and the impact on economic growth, as well as of the overall environmental impact and climate-change adaptation costs. A core application of the WEM is also on the Paris Climate Agreement, as well as to the Sustainable Development Goals. Other policy areas where it has been used include implement energy strategies for sustainable development, including diversified energy sources using cleaner technologies, increasing the share of renewable sources to meet climate objectives, diversifying energy supplies, strengthening the EU Emissions Trading Scheme, reducing energy consumption through improved energy efficiency, promoting carbon capture and storage, and improving integration of energy efficiency and environment into energy policies.

The **MESSAGE** model was developed to conducts policy-oriented research into problems of a global nature. The model is part of the Energy Program that IIASA has created to improve the understanding of the key characteristics and determinants of energy system changes. In addition, the modeling framework provides core inputs for major international assessments and scenarios studies (among others the Intergovernmental Panel of Climate Change (IPCC), the World Energy Council (WEC), the German Advisory Council on Global Change (WBGU), the Global Energy Assessment (GEA), the European Commission). Scenarios developed with MESSAGE have been used in, for example, the assessments and special reports of the IPCC and the GEA, MESSAGE was also used to generate one of the four Representative Concentration Pathways (RCPs) currently being used to estimate future climate change in the context of the IPCC 5th Assessment Report[7], and a special agreement between IIASA and the International Atomic Energy Agency (IAEA)[8] allows MESSAGE to be used for country studies within the IAEA and its Member States. Moreover, MESSAGE is a system engineering optimization model used for the planning medium to long-term energy systems, analysing climate change policies, and developing scenario, for national or global regions. Its use of in policy modelling allows several benefits, as its developed scenarios minimise the total systems costs under the constraints imposed on the energy system, the model configures the evolution of the energy system from the base year to the end of the time horizon (medium/long term system), and finally the

[7] IPCC 5th ASSESSMENT REPORT; https://www.ipcc.ch/report/ar5/syr/
[8] THE INTERNATIONAL ATOMIC ENERGY AGENCY; https://www.iaea.org/

model provides the installed capacities of technologies, energy outputs and inputs, energy requirements at various stages of the energy system, costs, and emissions.

The **GAINS** model is used successfully as a policy support tool in Europe and Asia, and aims to support informed decision making that maximizes synergy between different measures. Then the implementation of the GAINS model would assist South Africa in the development of GHG and air quality polices and would be in line with the overall national development goals. GAINS is used for policy analyses under the Convention on Long-range Transboundary Air Pollution (CLRTAP). For instance, it has been used 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. Scientists in many nations use GAINS as a tool to assess emission reduction potentials in their regions. There are a series of key benefits related to the Gains model. In particular, the model can explore cost-effective strategies to reduce emissions of air pollutants 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. GAINS helps identify measures to mitigate local air pollution and thus global climate change. For instance, world-wide implementation of 17 emission reduction measures targeting black carbon and ozone precursors could reduce future global warming by 0.5°C and could avoid the loss of 1–4% of the global production of maize, rice, soybean and wheat each year. According to estimations made in the course of the GAINS-Asia assessment, application of advanced emission control technologies could reduce health impacts in China by 43% in 2030. GAINS in optimization mode was also able to identify the most cost-effective portfolio of measures to achieve these health improvements, but at 20% of the costs. In addition, GAINS has assisted South Africa, that reports approximately 20,000 premature deaths due to air pollution annually, in the development of GHG and air quality polices.

PRIMES includes a rich representation of policy instruments and measures. Based on long experience with using PRIMES in major policy-analysis and impact-assessment studies of the European Commission, national governments and industrial institutions, detailed mechanisms have been built in the model to represent a large variety of policy measures and regulations. Scenario construction assumptions about the inclusion of policies can be made in close collaboration with the authority getting the modelling service because the modelling detail is high allowing for mirroring policies close to reality. The model can support policy analysis in the fields: such as security of supply, environmental issues, pricing policy and taxation, energy efficiency, alternative fuels, conversion to decentralisation and electricity-market liberalization, as well as policy issues regarding electricity generation, gas distribution, and new energy forms. ETS market simulation is explicit in PRIMES. However, the projections based on PRIMES are compatible with the five-year time resolution of the model and the model algorithm only approximates the arbitration of allowances holders over time. Nonetheless, PRIMES can handle multi-target analysis, for example, simultaneously for ETS, non-ETS, RES and energy efficiency, where the aim is to determine optimal distribution of achievements (targets) by sector and by country. PRIMES has successfully provided results for that purpose in the preparation of the 2020 Energy and Climate Policy Package (2007-2008) and recently for the 2030 Policy Analysis (2013). Further, to support impact assessment studies PRIMES provides detailed reports of scenario projections. The reports calculate cost indicators (with various levels of detail distinguishing between cost components and sectors), as well as for numerous other policy-relevant indicators. Topics covered include environment, security of supply and externalities (e.g. noise and accidents in transport). Thus, the model provides elements and projections to support cost-benefit analysis studies, which are the essential components of impact assessments. When PRIMES links with the macroeconomic model GEM-E3, the coverage of projection data for the purposes of cost-benefit evaluations is completer and more comprehensive. Similarly, linkages with GAINS (from IIASA) provide wider coverage of cost-benefit projections regarding atmospheric pollution, health effects, etc.

3 COVID-19 Predictive Models

3.1 Overview of the models and main predictions

Out of the 27 models studied, six were developed in USA, six in Italy, five in UK, four in Germany, and three in France. All the models have their results published, and the vast majority have also their modelling features published (24/27), and the majority (19/27) are used to inform the policy making activity of their respective governments. Further, 16/27 estimate epidemic variables, such as the number of infected and deceased individuals; 13/27 estimate healthcare variables, such as the number of ICU available; 16/27 estimate the impact of mitigation actions, such as limitations to movement and circulation; and 9/27 estimate the spread of epidemic across countries and regions, as well as the extent of population mobility in the given country. The main predictions of the models are presented in the table below.

Model name	**Predictions**
IHME	US: bed excess demand of 64,175 and 17,380 of ICU beds at the peak of COVID-19. Further, the peak ventilator use is predicted to be 19,481 in the second week of April, while the total estimated deaths were 81,114 over the next 4 months. Then, the estimates were amended downwards by predicting the death of 60.400 individuals by August, with a peak on the 12th of April. As for the UK, the model predicted 66,314 fatalities, more than Italy (a total of 23,000) and Spain (19,209)
Los Alamos	For the state of New York the daily death where expected to peak at 3215 on the 19th of April
Epirisk	Predictions related to exported cases (probability of exporting a given number of cases) and relative importation risk (probability that a single infected individual is traveling from the index areas to that specific destination).
COVID-19 Modelling	The model points to the days around April 8, 2020 as the peak time for deaths in the US. Based on the last projections, a total of 89795 COVID-19 deaths (range of 63719 to 127002) are currently projected through May 18, 2020.
Bakker et al.	The researchers find that the instance travelled everyday dropped by 70 percent, the number of social contacts in places decreased by 93%, and that the number of people staying home the whole day has increased from 20% to 60%. Very interestingly, they found that the relative differences between different demographic groups for what concerns mobility and social contacts have been dramatically reduced. Finally, they found that supermarkets and grocery stores came to be the most common locations where social contact takes place.
Columbia University	As many as 104,120 deaths could be averted through an aggressive critical care surge response, including roughly 55% through high clearance and preparation of ICU and non-ICU critical care beds and roughly 45% through extraordinary measures like using a single ventilator for multiple patients.
Imperial College (1)	In March 2016 update the model by the Imperial College reported up to 500K deaths in the UK and up to 2.2 million deaths in the US in case of no action by the government nor population. Further, the estimated figure that 15% of hospital cases would need to be treated in an ICU was then updated to 30%, arguing that the British ICU capacity (4K beds) would be overwhelmed.
Imperial College (2)	Impact of an unmitigated scenario in the UK and the USA up to 490,000 deaths and 2,180,000 deaths respectively, and up to 7.0 billion infections and 40 million deaths globally this year
Imperial College (3)	They estimate that the intervention has averted 59,000 deaths up to 31 March across all 11 countries, that between 7 and 43 million individuals have been infected, and that the proportion of the population infected to date is the highest in Spain followed by Italy and lowest in Germany and Norway, reflecting the relative stages of the epidemics. Specifically, they estimated that in Italy and Spain, respectively 38,000 and 16,000 deaths have been avoided.

UO	In summary, the model suggests that the new coronavirus may already have infected far more people in the UK than scientists had previously estimated (maybe half of the population), and that thereby the mortality rate from the virus is much lower than what is generally thought to be, as the vast majority of infected individuals develop mild symptoms or not at all. The model suggests that the infection has reached the UK by December or January, and that therefore people started to be infected in huge numbers before the first official case was reported.
LSHTM	Estimation of high resolution age-specific social mixing matrices based on data from over 40,000 participants, stratified by key characteristics such as contact type and setting. The matrices generated are highly relevant for informing prevention and control of new outbreaks, and evaluating strategies that reduce the amount of mixing in the population (such as school closures, social distancing, or working from home). In addition, they finally provide the possibility to use multiple sources of social mixing data to evaluate the uncertainty that stems from social mixing when designing public health interventions.
RKI (1)	The policies carried out by the Federal Government, i.e. the cancellation of major events in different federal states (with more than 1,000 participants) on March 9 2020, the Federal-State Agreement on guidelines against the spread of the coronavirus on March 16 2020, and the nationwide extensive ban on contacts on March 23 2020, have had a great impact on the reproduction number.
RKI (2)	The implementation of mitigation measures altered the infection pattern and spread of the disease and helped to keep it under control.
COVID Mobility Project	Initial drop in mobility: mobility fell to -39% below normal in mid-March 2020, after the majority of restrictions in Germany took effect. Slow recovery of mobility: in late March mobility slowly increased and finally plateaued at -27% in the second week of April. As restriction policies hardly changed during this time, this increase might be attributed mostly to a relaxing of self-imposed, individual mobility restrictions, paired with increased mobility due to warmer weather. Beginnings of an opening: starting April 20th, some mobility restriction policies have been lifted. We observe an immediate increase in mobility to -21% in the week starting April 20th.
Hartl et al.	Their finding is that confirmed Covid-19 cases in Germany grew at a daily rate of 26.7% until 19 March. From March 20 onwards, the growth rate drops by half to 13.8%, which is in line with the lagged impact of the policies implemented by the German administration on 13 March and implies a doubling of confirmed cases every 5.35 days. Before 20 March, cases doubled every 2.93 days. In their update of the model they test the impact of the 22 March policies. From 30 March on, the estimated average growth rate is 5.8%, so that the cases double every 12.20 days, therefore the containment policies are being effective.
Italian[9] STC	Restarting all the sectors without teleworking and with schools open, the country would need 151 thousand intensive care units already in June and a number of hospitalizations, by the end of the year, equal to 430,866
COVID-19 working group et al.	The COVID-19 infection in Italy emerged with a clustering onset similar to the one described in Wuhan, China and likewise showed worse outcomes in older males with comorbidities. Initial R0 at 2·96 in Lombardia, explains the high case-load and rapid geographical spread observed. Overall Rt in Italian regions is currently decreasing albeit with large diversities across the country, supporting the importance of combined non-pharmacological control measures.
Signorelli et al.	The team concludes that suspending flights from China and airports' checkpoints with thermos-scan did not have a significant effect in containing the epidemic, and that the implementation of a "red zone" in Lombardy effectively contained the spread of the infection within that area, even though it did not have the same effect in the neighboring provinces (Bergamo, Brescia, and Piacenza); the failure to establish a second "red zone" near Bergamo in the Municipalities of Alzano and Nembro despite the proposal of local

[9] There is no specific and explicit information regarding which models are used by the Italian authorities to take their decisions. According to confidential sources, the Italian National Institute of Health and the Italian Scientific and Technical Committee, in agreement with the Italian Ministry of Health and Italian Civil Protection, are collaborating with Bruno Kessler Foundation in developing the models used by the Italian authorities in taking their policy decisions. The model will be available only when published.

	authorities (on March 3rd), led to a dramatic out-break with about 10,000 cases in Bergamo with over 1,000 death toll and similar figures in the neighbouring areas (Brescia and Piacenza); and finally that general mitigation measures seem to be effective to flatten the epidemic curve of new notified infections
Grasselli et al.	The article shows that despite prompt response of the local and regional ICU network, health authorities, and the government to try to contain the initial cluster, the surge in patients requiring ICU admission has been overwhelming. Therefore, other health care systems should prepare for a massive increase in ICU demand during an uncontained outbreak of COVID-19. This experience would suggest that only an ICU network can provide the initial immediate surge response to allow every patient in need to be cared for.
COVID-19 MMP	The results of the exercise show that on April 12, Easter Day, the average degree of all users was 86% lower than the pre-outbreak averages in the North, 83% in the Center and 82% in the South and the Islands. In conclusion, in the past 4 weeks, the adherence to the mobility restrictions imposed since March 12 has remained high and constant all over the country.
PREDICT COVID-19	The model shows that although the peak is close, in some regions the positive cases are underestimated, and also that containment strategies are working.
Martinez et al.	The total number of patients admitted too Spanish ICU oscillates between 90,000 and 160,000.
Uni Cat	The model predicted 203795 cases for Spain on April 19 2020.
Inverence	The number of deaths per million people shows the pandemic's different spreading velocities in different countries. Spain appears as the country with the largest epidemic spreading velocity among the set of countries considered.
University of Zaragoza	We have applied the results to the validation and projection of the propagation of COVID–19 in Spain. Our results reveal that, at the current stage of the epidemics, the application of stricter containment measures of social distance are urgent to avoid the collapse of the health system. Moreover, we are close to a scenario in which the complete lockdown appears as the only possible measure to avoid the former situation. Other scenarios can be prescribed and analyzed after lockdown, as for example pulsating open-closing strategies or targeted herd immunity.
Massonnaud et al.	At the national level, the total number of infected cases was expected to range from 22,872 in the best case (R0 = 1.5) to 161,832 in the worst considered case (R0 = 3). Regarding the total number of deaths, it was expected to vary from 1,021 to 11,032, respectively. Clearly the real data regarding mortality rate are higher. What is interesting, it is also that they estimated the timing according to which the capacity limit of French ICU would be overrun.
EPIcx-lab of INSERM (1)	They estimated that the average number of contacts is predicted to be reduced by 80% during lockdown, leading to the reduction of the reproductive number to 0.68. They show that the epidemic curve reaches ICU system capacity and slowly decreases during lockdown, and that lifting the lockdown with no exit strategy would cause a second wave. They also show that testing and social distancing strategies that gradually relax current constraints while keeping schools closed and seniors isolated will avoid a second wave and healthcare demand exceeding capacity.
EPIcx-lab of INSERM (2)	According to the model, mere school closure would have limited effects (i.e. <10% reduction with 8-week school closure for regions in the early phase of the epidemic), while coupled with teleworking for 25% adults there would be a delay of the peak by almost 2 months with an approximately 40% reduction of the case incidence at the peak. Therefore, explicit guidance on telework and interventions to facilitate its application to all professional categories who can adopt it should be urgently provided.

3.2 Caveats and Lessons Learnt in the Use of Prediction Models

There are several caveats to be taken into account when stemming from data and modelling assumption, particularly when the phenomena studied are still ongoing.[10] Considering the simplest SIR model, in principle the number of deaths from an infectious disease is given by the susceptible population times the infection rate times the fatality rate. Starting from the fatality rate, it is difficult to have an average single dimension as it depends on the age of individuals and the presence of comorbidities, and therefore it changes from cohort to cohort and from country to country. Furthermore, even in the same subset of individuals, there are many uncertainties. In fact, the fatality rate is the ratio of the number of people who have died from the disease and the number of people infected with the disease. Now, it is first of all difficult to state how many people died from COVID-19, in particular in the presence of comorbidities. There are in fact differences in how countries record Covid-19 deaths.[11] Secondly, it is extremely impractical to determine the number of people that are infected at any given moment. This suggests that there are a lot of people walking around with COVID-19 who do not know it, and therefore the fatality rates are lower than what is currently argued in many countries. On the other hand, there are also several studies that suggest a higher mortality of the COVID-19 outbreak by looking at "excess mortality", i.e. the gap between the total number of people who died from any cause, and the historical average for the same place and time of year, as well as that many individuals were killed by conditions that might normally have been treated, had hospitals not been overwhelmed by a surge of patients needing intensive care.[12][13][14] Further, it is not easy to estimate to what extent fatality rate is influence by the hospital capacity, e.g. access to the best care (ICU). It is also difficult to have a precise estimation of the symptomaticity ratio, which calculates how many people are symptomatic versus asymptomatic. In fact, it is clear that in case the healthcare capacity of a country (or a region) is overwhelmed, the fatality rate goes up. The infection rate depends on the basic reproduction number (R0), which is the average number of new infections traced back to each infected person in a population where everyone is susceptible to the disease. This is influenced by the rate of contact, which is given by how many people an infected person interacts with in a given period of time and that depends on the circumstances, and by the rate of transmission per contact, which is basically how many of the people an infected person meets will become infected themselves. In turns, there are other variables that influence the infection rate: how long the virus can survive on a given surface, how far it can be flung through the air, the duration of infectiousness, and the extent to which asymptomatic individuals are infectious in comparison with symptomatic ones. And finally, all these dimensions are influenced by interventions such as social distancing and school closing, as well as of the modelling technique and the stage of the epidemics. Taking into account more concrete cases, different assumptions and modelling approaches can lead to different results and policy recommendations. In that regard, an interesting comparison[15] can be done between top down and bottom up approaches.

The top down approach consists in fitting a curve to the data set and then to extrapolate the future data points. A bottom up approach consists in modelling a series of components mimicking the progress of the epidemics such as social distancing, allowing to separate the different mechanisms of the transmission process. The models by the Imperial College is based on the bottom up approach. In fact, they model the ways in which the virus can be transmitted, and then assess how social distance and transportation influence the

10 https://fivethirtyeight.com/features/why-its-so-freaking-hard-to-make-a-good-covid-19-model/
11 https://www.bbc.com/news/52311014
12 https://www.economist.com/graphic-detail/2020/04/16/tracking-covid-19-excess-deaths-across-countries?fsrc=scn/fb/te/bl/ed/covid19datatrackingcovid19excessdeathsacrosscountriesgraphicdetail&fbclid=IwAR2AqP18VghCYmX5PKH8ns0a-2yPXhzzNId01Ge7PWxg5HLjhaeD0yOPDng
13 https://www.ispionline.it/it/pubblicazione/fase-2-morti-sommerse-eccesso-di-zelo-25878
14 https://www.medrxiv.org/content/10.1101/2020.04.15.20067074v2
15 https://nucleardiner.wordpress.com/2020/04/07/the-ihme-epidemiological-model/amp/?__twitter_impression=true

process. On the other hand, the model by IHME fits curves representing deaths in various locations with a series of parameters, and then extrapolates the numbers of deaths and the need for hospitalization and equipment. This leads to uncertainty at the beginning of the outbreak in which less location-specific data is available. Another important issue is that the IHME model assumes that the US has had a lockdown as strict as Wuhan, but this seems not to be the case. Further, only one location Wuhan has had a generalized epidemics, and therefore modelling the US fitting curve on such location is difficult, especially because the timing and extent of social distancing is difficult to mimic. When more US data will be available, the more will become more precise. Further, even though the model takes into account age structure, some other factors are not modelled, such as the prevalence of multi and co-morbidities, chronic lung disease, use of public transport, pollution and population density. On the top of that, the reduction in healthcare quality due to overload is not explicitly taken into account.

Another interesting comparison lies in recommendations stemming from the models. For instance, the first version (16 March) of the Imperial College model has grim predictions for what concerns the death toll in US and UK (respectively up to 500K and 2.2 million deaths) and the strain on ICU capacity, prompting the government to put in place mitigation measures. On the other hand, the Oxford model suggests that the new coronavirus may already have infected far more people in the UK than scientists had previously estimated (maybe half of the population), and that thereby the mortality rate from the virus is much lower than what is generally thought to be, as the vast majority of infected individuals develop mild symptoms or not at all.

However, both models are built on a series of extreme assumptions: for the Imperial College model the value of R0, the rate of death, the length of incubation, and the period in which infected and asymptomatics can be infectious. For the Oxford model the suggestion that the infection has reached the UK by December or January, and the figure that only one in 1,000 infections will need hospitalization is removed from reality. Clearly the two models provide different recommendations: the Oxford model recommends to put more effort in trying to achieve herd immunity, and concludes that the country had already acquired substantial herd immunity through the unrecognised spread of Covid-19 over more than two months, while the model by the Imperial College recommends to put more effort on containment measures. However, both models agree with the measures of social distancing put into place by the UK government, and the only point of argument concerns the timing of removing such restrictions. In that regard, the crucial info hidden from the modellers regards the number of people that have been infected without showing symptoms, and for which a reliable test would be a game changer for modellers as it might significantly alter the predicted path of the pandemics. A final consideration is linked to the availability of data and the data collection activity. In this regard, there is a huge difference across the countries. Very interestingly, the German central register for ICU beds is based on voluntary contributions from all hospitals seems to be a unique platform and maybe something to replicate in other countries[16].

16 https://www.intensivregister.de/#/intensivregister

4 POLICY TAKE-OUTS

The following are policy take outs extracted by the cross-analysis of simulation models and of the COVID-19 predictive models:

1. **Timely collection and transparency of data.** It is crucial to ensure that the data collected are updated and that are collected at regular and timely intervals. In fact, in order to ensure the relevance of the policies, they should build on timely analysis and results. Further, it is important to provide specific and complete information about the methodology and procedures for the data collection, in order to inform the users of the models of the caveats and shortcomings. Also, it is important to provide stakeholders with access to results and outputs used to develop the different scenarios, in order to ensure comparability.
2. **Transparency and openness of assumptions and models.** Trust in the results stemming from the model are increased if all the assumptions made by the modellers are transparent and available for the other experts to criticize and scrutiny. In fact, openness of assumptions and modelling structure improves the comparability of the analysis and projections produced by different organizations using different models. There are cases in which results of the analysis vary in a number of important methodological aspects, and without a way to clearly compare one analysis and set of results to one another, decision-makers may not understand the range of possibilities envisioned by different short-, medium- and long-term projections, or the assumptions that underpin those projections. In that regard, transparency in the modelling methodology helps in ensuring transparency and trust in the resulting policy making process.
3. **Use and re-use of data and software modules.** Apart from transparency of data, it is also important to make databases as open as possible in order to allow other researchers to replicate the results of the analysis carried, as well as to use the data for other research purposes. In fact, such modelling endeavours produce a wealth of data that should not be wasted. This is also clearly linked to the issue of transparency, as the availability of metadata helps the researchers in understanding the weaknesses of the data produced and therefore the suitable methodologies of analysis. By the same token, the models should be built in modules, to be made available to researchers for re-use and recombination (see point 4). This allows researchers and practitioners to download, re-adapt and re-use the modules for their analysis, therefore conceiving new applications.
4. **Perform validation and sensitivity analysis exercises.** As we have seen, the results of many modeling exercises have been deeply influenced by the modeling and estimation techniques used. In this respect, a core activity ensuring the robustness of the modelling exercises performed consists in applied different modelling and estimation techniques to the same set of data, as well as changing the values of the input and internal parameters of a model to determine the effect upon the model output. Related to this issue is the necessity to validate the models by employing them on comparable but different data sources to see how the model results change, and to keep them open in order to scrutiny and criticisms by other researchers. Last but not least, also keeping data open allows to carry out different modelling and estimation techniques by different researchers.
5. **Generate collaborative model simulations and scenarios.** Clearly the collaboration of several individuals in the simulation and scenario generation allows for policies and impact thereof to be better understood by non-specialists and even by citizens, ensuring a higher acceptance and take up. On the other hand, modelling co-creation has also other advantages: no person typically understands all requirements and understanding tends to be distributed across a number of individuals; a group is better capable of pointing out shortcomings than an individual; individuals who participate during analysis and design are more likely to cooperate during implementation. In the case at hand, the joint elaboration of

simulations and scenarios by policy makers and scientists helps in producing models that are refined to tackle the containment policies adopted.

6. **Develop easy to use visualizations.** There are several data aggregators that visualize the data coming from the field every day and that improve the situational awareness of the policy makers. Further, an interesting feature of many models that have been developed and used by policy makers to tackle the COVID-19 pandemic is the use of visualization tools depicted the results of the underlying simulation models. In this regard, policy makers should be able to independently visualize results of analysis, make sense of data and interact with them. This will help policy makers and citizens to understand the impact of containment policies: interactive visualization is instrumental in making evaluation of policy impact more effective.
7. **Consider carefully the sources of uncertainty in the model.** As the other simulation models, also the ones used to tackle the COVID-19 pandemics suffer from several sources of uncertainty. Such uncertainty could be merely statistically related (e.g. confidence intervals), related to parameters in the model that are difficult to estimate (e.g. the rate of transmission), concerning the data used (e.g. data on fatality rate might be not precisely measured), or of a more conceptual level (e.g. assuming a representative agent).
8. **Tailor the model to specific questions you are trying to address.** Specific modelling strategies (and level of complexity) should be used to address specific research questions. For instance, the simplest structure of predictive simulation is given by the aforementioned SIR models, which use few data inputs and can be useful to assess the epidemic outbreak in the short term. Such models cannot be used to depict uncertainty, complexity and behavioural change. Another class of models is given by forecasting models, which use existing data to project conclusions over the medium term. Finally, strategic models that encompass multiple scenarios assessing the impact of different interventions are able to capture some uncertainty underlying the epidemic outbreak and the behaviour of the population and are the foundation for policy making activity.
9. **Use models properly**. Models are not a commodity that provide a number which the policy makers use to take decisions. There needs to be a full understanding of the subtleties involved, the levels of uncertainty, the risk factors. In other words, you need in-house data and model literacy embedded in the policy making process, in house. You can't outsource that. Indeed, a recent report for the US highlighted the limitations of a process that involved experts on an ad hoc, on demand basis, leaving much arbitrariness to the process: "Expert surge capacity exists in academia but leveraging those resources during times of crisis relies primarily on personal relationships rather than a formal mechanism." On a similar token, in the UK, a recent article pointed out that experts involved in the SAGE were too "narrowly drawn as scientists from a few institutions". By the same token, there was insufficient in house capacity to manage this input: In the US, "there is currently limited formal capacity within the federal government", while in the UK, "the criticism levelled at the prime minister may be that, rather than ignoring the advice of his scientific advisers, he failed to question their assumptions".
10. **Models integration.** Finally, there is the need for a flexible modelling framework for the comprehensive assessment of major challenges in the analysed domain and to be used in conjunction with other models in order to address major global challenges in a holistic way. In this respect, integration of sectoral models is a key issue to assess important interrelations and feedbacks. More generally, models should be developed in modules and in a flexible way in order to allow integration with other models.

5 Annex – Description of the models analysed

Table 2 – Synthesis of Results for the Simulation Models

	NAWM II	WEM	PRIMES	MESSAGE	GAINS
Rationale	Financial model aimed to provide an analysis of the impact of several non-standard measures (NSMs) that have been implemented by the European Central Bank with the objective to mitigate the impact of the financial crisis on the economy as well as to ensure the transmission of standard monetary policy.	Large-scale simulation model designed to replicate how energy markets function and is the principal tool used to generate detailed sector-by-sector and region-by-region projections for the IEA's World Energy Outlook (WEO) scenarios.	Large scale applied energy system model that provides detailed projections of energy demand, supply, prices and investment. It covers the entire energy system including emissions for each individual European country and for Europe-wide trade of energy commodities.	Systems engineering optimisation model used for the planning of medium to long-term energy systems, analysing climate change policies, applied for the development of energy scenarios and the identification of socioeconomic and technological response strategies to these challenges.	Provides an integrated assessment framework describing the pathways of atmospheric pollution from anthropogenic driving forces to relevant health and environmental impacts. It brings together information on future economic, energy and agricultural development, emission abatement potentials and costs, atmospheric dispersion and environmental sensitivities towards air pollution.
Data sources	The main source for the country information is Eurostat, complemented by the OECD National Accounts, the OECD Main economic indicators, the BIS and the AMECO databases. The sources of the financial data are the Deutsche Bundesbank database, the ECB SDW, and the FRED database of the Federal Reserve Bank of St. Louis.	The development and running of the WEM requires access to huge quantities of historical data on economic and energy variables. Most of the data are obtained from the International Energy Agency's own databases. A significant amount of additional data from a wide range of external sources also is used. The IEA Energy Data Centre provides the world's most authoritative and comprehensive source of global energy data. The IEA collects, assesses and disseminates energy statistics on supply and demand, compiled into energy balances. The time series stretches back to 1971, and currently covers up to 95% of global energy supply and over 150 countries.	Eurostat is the primary data source. The PRIMES model is calibrated to Eurostat statistics wherever possible. Eurostat data is complemented by other statistical sources as needed. Eurostat-sourced data include: energy balance sheets; energy prices; macroeconomic and sectoral activity data; population data and projections; physical activity data; CHP surveys; CO2 emission factors; and EU ETS registry for allocating emissions between ETS and non-ETS. Other data sources include: MURE, ICARUS, ODYSEE, NEMS model database, IPPC BAT Technologies IPTS, district heating surveys, buildings and houses statistics and surveys.	Demand data are exogenously given for all the energy forms defined at the secondary, final, or useful level. In general, MESSAGE model was developed over the last four decades, and it is difficult to identify what kind of data is collected and from which data sources. Data collected by MESSAGE concerns emissions, technology for various energy sectors, costs, water and transport demands. There are almost 20-30 different sectors, and for each, there is specific literature of data sources. Not all the data updates of these sectors are regular, depending on the characteristics of the model.	Historical data have been extracted from energy statistics. GAINS contains alternative pathways of energy use up to 2050 derived from national and international energy projections (e.g., scenarios developed for Europe by the PRIMES model, projections of the International Energy Agency, scenarios based on national studies). While these data are stored in the GAINS database, they are exogenous input to GAINS.

Collaboration	When the model was elaborated, a wide range of stakeholders from the central banks, academia and institution was engaged in discussions. Clearly there is a regular feedback and validation from the staff within the Euro system given that the model is used to prepare input into the policy process by conducting scenarios, risk analysis, by assessing the impact of policy measures. Further, policy makers provide input and feedback continuously on the application of the model.	The WEM is continually reviewed and updated to ensure its completeness and relevancy. The development of the WEM benefits from expert review within the IEA and beyond and the IEA works closely with colleagues in the modelling community, for example, by participating in the annual International Energy Workshop. The annual WEM-based WEO report is used by all OECD members as well as many non-member countries and other entities to inform their energy and climate policies. The IEA's mandate has been broadened to focus on three areas of energy policy: energy security, economic development, and environmental protection, in particular mitigating climate change.	There has been input from the European Commission from the very beginning of the PRIMES model and it continues to this day. The model has been developed according to the needs to the Commission and has served various DGs over the years, including being used in the Energy Roadmap to 2050. PRIMES has supported analysis for major energy policy and market issues, including electricity market, gas supply, renewable energy development, energy efficiency in demand sectors and numerous technology specific analysis. The model includes all EU member states individually and also has provided detailed outlooks for Switzerland, Norway, Turkey, Albania, Bosnia, Montenegro, Serbia, FYROM and Kosovo. Numerous third-party studies have used projections produced using PRIMES.	For the process of data aggregation, there are not outside service providers involved. Instead, in the structure and design process of the model, ministries and government officials can be involved. For instance, recently a MESSAGE model was built in collaboration with the Indian government, specifically for the Indian South Continent, working with Indian ministries, environment local authorities and energy administrations. In general, collaboration depends on which model, or which version or instance of the model, is requested, and the local authorities of the requester.	The GAINS model can be used in conjunction with the energy model MESSAGE, the land-use model GLOBIOM, the air pollution and GHG model GAINS, the aggregated macro-economic model MACRO and the simple climate model MAGICC, creating a framework that covers all major sectors, including agriculture, forestry, energy, and industrial sources, permitting a concurrent assessment of how to address major sustainability challenges
Success factors	DSGE models are less subject to the Lucas critique due to their explicit account for the role of expectations and their identification of deep structural parameters, making them more suitable for policy analysis and counterfactual experiments. Further, DSGE models are able to identify and decompose economic and policy structural shocks on the quantitative level by the mean of an impulse-response analysis. And finally, DSGE models are able to discover deep structural parameters thanks to their capability to link model implications to time-series and cross-sectional data.	The type and extent of energy-related pressures on the environment depend both on the sources of energy (and how they are used) and on the total amount of energy consumed. The IEA's WEO report, based on WEM projections, presents plausible scenarios of energy developments. It helps to assess achievability of policy targets related to energy consumption and energy efficiency. It can also be used to identify appropriate policy response options for making the energy sector	PRIMES captures technology and engineering detail together with micro and macro interactions and dynamics. Because the PRIMES model follows a structural modelling approach, it integrates technology/engineering details and constraints in economic modelling of behaviours. The modelling of decisions draws on economics, but the constraints and possibilities reflect engineering feasibility and restrictions. Designed to analyse complex interactions within the energy system in a framework of multiple agents and multiple markets, PRIMES is sufficiently detailed to represent concrete	The MESSAGE model's developed scenarios minimise the total systems costs under the constraints imposed on the energy system. It configures the evolution of the energy system from the base year to the end of the time horizon (medium/long term system). It also provides the installed capacities of technologies, energy outputs and inputs, energy requirements at various stages of the energy system, costs, emissions, etc. And in addition, it is used in applied projects and scientific studies around the world;	There are a series of key benefits related to the GAINS model. In particular, the model can explore cost-effective strategies to reduce emissions of air pollutants 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 GAINS methodology identifies cost-effective portfolios of specific measures that improve local air quality and, at the same time, reduce global climate change. This focus on actions that yield co-benefits at different spatial and

		more sustainable, combat climate change and reduce water and air pollution. Energy expansion projects are multibillion-dollar propositions and should be backed up with robust modeling projections to ensure that investment risks are reduced.	policy measures in various sectors, including market-design options for the EU internal electricity and gas markets. The model is well placed to simulate long-term transformations in markets.		temporal scales, provides a fresh perspective to clean air and climate policy development in many countries and world regions.
Challenges	DSGE models need to take to take risk into account by incorporating individual, institutional, and regulatory responses to changing risks. Further, DSGE models need to incorporate the financial sector and its intricacies. Finally, DSGE models should departure from the assumption of optimizing agents following rational expectations, and allow for certain predictable irrationalities in their behaviour. These agents would still adapt to the economic circumstance, therefore rejecting the Lucas critique, but not in an instantaneous and fully optimal way.	A criticism of the methodology and models of the WEM is that the flexibility of economic behaviour is effectively contained, and that the relations of the modelling system are not sufficiently responsive to shifts and shocks in technology, preferences, policies and prices. Critics also argue that the IEA's World Energy Outlook, which uses the WEM, is largely a product of historical trends and developments, combined with exogenous assumptions that lead to a bias in favour of fossil fuels.	The PRIMES model has been criticized for a lack of transparency on modelling inputs and assumptions. There also have been calls for the inclusion of additional dimensions, such as social and cultural factors, including the societal cost of greenhouse-gas emissions. The European Commission has undertaken an effort to ensure robustness and representativeness of assumptions in the model by reaching out to relevant experts, industry representatives and stakeholders.	- A complete reimplementation of the software framework that powers the MESSAGE model was needed, trying to follow the best practices of collaborative scientific programming and open source. - Local experts helped IT developers to improve the system representation, which they would not consider from their global perspective. Scenarios provided by the model are useful to initiate policy dialogues and make informed choices, based on scientific insights, and show to the decision-makers the possibilities between these different choices.	- Assessing how specific control measures simultaneously influence different pollutants permits a combined analysis of air pollution and climate change mitigation strategies, which can reveal important synergies and trade-offs between these strategies.
Degree of scalability	In principle the model can be applied to a different dimension of analysis and can be scaled. However, this is a typical macro-economic model, and therefore the transferability to other domains (e.g. energy) and/or the application to other policy questions is somehow limited, and in any case the adaptation of the model to a multi-country setting, or to other jurisdictions in general would be demanding a quite huge amount of effort.	The WEM is used both at global and at national/regional level. The current version of WEM covers energy developments up to 2040 (2050 for the Sustainable Development Scenario) in 25 regions. Depending on the specific module of the WEM, individual countries are also modelled: 12 in demand; 101 in oil and gas supply; and 19 in coal supply. Demand modules	The PRIMES sub-models/modules can be used in a stand-alone fashion or can be coupled with the rest of the energy systems model. In the latter case, the integration with the PRIMES model enhances the dynamic character of the model. PRIMES also can be used in linked fashion with GEM-E3 and IIASA's GAINS to perform energy-economy-environment policy analysis in a closed loop. E3-Modelling has developed a simplified, or compact, version	MESSAGE model is used mainly at the global level. MESSAGE was developed to be used for geographical regions with the size of continents. It may also be applied to smaller regions or countries, provided that some care is taken in supplying the input data and in interpreting the model results. A particular problem that may arise comes from the continuity of the model variables that, for small countries, may very likely result in sizes of energy conversion facilities that are unrealistically	Actually, the GAINS model is implemented at a global level, in 165 regions, including 48 European countries and 46 provinces/states in China and India. The model can be adapted to a bigger number of countries. In particular, the GAINS model would be probably used soon in South Africa, to face the big challenge of premature deaths due to air pollution.

		can be isolated and simulations run separately.	of PRIMES for use on a country-by-country basis.	small. In addition, in some regions or countries, the energy system may have some peculiarities, which have not been considered in the general model formulation.	
Openness of data	Some data are open and available, but not the final database used for running all models, which is confidential to the extent of the partial use of projection data.	There is a huge amount of data and publications available, and an entire website dedicated to the model. The IEA generates monthly statistics with timely and consistent oil, oil price, natural gas and electricity data for all OECD member countries back to 2000.	Data are open and available for reuse, and results are shared and published on a regular basis. But E3-Modelling's full database is not accessible because it includes proprietary data.	The Energy Program (ENE) hosts a growing number of databases for the integrated assessment modelling community, some of which are open to the wider public such as - IAMC 1.5°C Scenario Explorer - CD-LINKS Scenario Database - Low Energy Demand study (LED)	The GAINS model holds relevant data for European and no European countries, employing international energy and agricultural statistics and appropriate emission factors. These data are stored in the GAINS database and some of them are open and available to public.
Openness of model	Code from the previous vintage of the EU area-wide models was made available on request as well as within modelling groups, for instance belonging to the European system of central banks and important policy institutions.	WEM is a proprietary model and has been criticized for a lack of transparency. In the latest WEM-based World Energy Outlook, the IEA said it had made all the key policy assumptions available for all scenarios, along with all the underlying assumptions on population, economic growth and energy resources, and information on prices and technology costs.	The PRIMES model is proprietary, but E3M has started regular consultations with stakeholders on various issues, including a `validation workshop' in 2018 on technology costs. The plan is to have consultations and workshops regularly.	The model can be reused and combined with other models. Actually the model is used in conjunction with other models such as MESSAGE access, MESSAGE MACRO and MESSAGE-MAGIC.	The GAINS model can be used in conjunction with the energy model MESSAGE, the land-use model GLOBIOM, the air pollution and GHG model GAINS, the aggregated macro-economic model MACRO and the simple climate model MAGICC, creating a framework that covers all major sectors
Use in policy making	The model is regularly used for policy making by the European Central Bank, and its results are adopted by members of the Euro Area as well as from Member States. The model allows to carry out economic projections contributing to the elaboration of the projection baseline for the largest euro area countries and to forecasting with judgment and model-based projection narratives. Further, the model allows for risk analysis and policy analysis, the latter related to the impact study of	The International Energy Agency has a significant impact on both political and economic decisions of governments and stakeholders regarding energy. The annual WEM-based WEO report is used by all OECD member nations as well as many non-member countries and other entities to inform their energy and climate	The PRIMES model has served various European Commission DGs over the years, including being used in the Energy Roadmap to 2050 and Policies to 2030 on climate. PRIMES also has been used at national level for governments, companies and other institutions. PRIMES has supported analysis for major energy policy and market issues, including electricity	The MESSAGE model's results provide core inputs for major international assessments and scenarios studies. In particular, it is used for policy making by: • the Intergovernmental Panel of Climate Change (IPCC) , the leading international body for the assessment of climate change;	GAINS is used for policy analysis by United Nations Economic Commission for Europe (UNECE) under the Convention on Long-range Transboundary Air Pollution (CLRTAP). For instance, it has been used for the revision of the Gothenburg Protocol . GAINS has also been used by the European Union for the EU Thematic Strategy on Air Pollution and the air policy review.

	monetary policy options as well of strategic issues related to Monetary-fiscal-financial policy mix in the euro area.	policies. The IEA's mandate has been broadened to focus on three areas of energy policy: energy security, economic development, and environmental protection, in particular mitigating climate change. The IEA has a broad role in promoting alternate energy sources, including renewable energy; rational energy policies; and multinational cooperation in energy technology.	market, gas supply, renewable energy development, energy efficiency in demand sectors and numerous technology specific analysis. The model also has quantified energy outlook scenarios and has been used in impact-assessment studies by the EU. The model offers the possibility of handling market distortions, barriers to rational decisions, behaviours and market-coordination issues, as well as infrastructure investment. PRIMES includes all EU nations individually, and has also provided detailed outlooks for Switzerland, Norway, Turkey, Albania, Bosnia, Montenegro, Serbia, FYROM and Kosovo.	• the World Energy Council (WEC) , a global and inclusive forum for thought-leadership and tangible engagement; • the German Advisory Council on Global Change (WBGU) an independent, scientific advisory body; the European Commission; the Global Energy Assessment (GEA) , the first global and interdisciplinary assessment of energy challenges and solutions.	Scientists in many nations use GAINS as a tool to assess emission reduction potentials in their regions. For the negotiations under the United Nations Framework Convention on Climate Change (UNFCCC), a special version of GAINS has been developed to compare greenhouse gas mitigation efforts among the involved countries.

Table 3 – Model Description: Country, Usage and Publication, Estimates and Assessments of the Model

Model	Country	Is it published?	Are the results published?	Usage	Estimating epidemic variables[17]	Estimating healthcare variables[18]	Assessing mitigation actions[19]	Assessing Epidemic spread/mobility of population[20]
IHME	US	Yes	Yes	Used in Policy Making	**X**	**X**		
Los Alamos	US	Yes	Yes	Used in Policy Making	**X**			
COVID-19 Modelling	US	Yes	Yes	Used in Policy Making				**X**
Epirisk	US	Yes	Yes	Used in Policy Making				**X**
Bakker et al.	US	Yes	Yes	Not clear			**X**	**X**
Columbia University	US	Yes	Yes	Used in Policy Making		**X**		**X**
Imperial College (1)	UK	Yes	Yes	Used in Policy Making	**X**	**X**	**X**	
Imperial College (2)	UK	Yes	Yes	Used in Policy Making	**X**	**X**	**X**	
Imperial College (3)	UK	Yes	Yes	Used in Policy Making	**X**		**X**	
UO	UK	Yes	Yes	Used in Policy Making		**X**		
LSHTM	UK	Yes	Yes	Used in Policy Making			**X**	**X**
RKI (1)	DE	Yes	Yes	Used in Policy Making	**X**		**X**	
RKI (2)	DE	Yes	Yes	Used in Policy Making			**X**	**X**
COVID Mobility Project	DE	Yes	Yes	Used in Policy Making			**X**	**X**
Hartl et al.	DE	Yes	Yes	Not clear	**X**		**X**	
Italian STC	IT	No	Yes	Used in Policy Making	**X**	**X**	**X**	
COVID-19 working group et al.	IT	Yes	Yes	Used in Policy Making	**X**			
Signorelli et al.	IT	Yes	Yes	Not clear	**X**		**X**	
Grasselli et al.	IT	Yes	Yes	Not clear		**X**		
COVID-19 MMP	IT	Yes	Yes	Not clear			**X**	**X**

17 E.g.: number of infected and deceased individuals
18 E.g.: number of ICU available
19 E.g.: limits to circulation
20 E.g.: spread of epidemic across countries and regions, extent of population mobility in the country

PREDICT COVID-19	IT	No	Yes	Not clear	**X**			
Martinez et al.	ES	No	Yes	Used in Policy Making		**X**		
Uni Cat	ES	Yes	Yes	Used in Policy Making	**X**		**X**	
Inverence	ES	No	Yes	Not clear	**X**	**X**	**X**	
University of Zaragoza	ES	Yes	Yes	Not clear	**X**	**X**		**X**
Massonnaud et al.	FR	Yes	Yes	Used in Policy Making	**X**	**X**		
EPIcx-lab of INSERM (1)	FR	Yes	Yes	Used in Policy Making	**X**	**X**	**X**	
EPIcx-lab of INSERM (2)	FR	Yes	Yes	Used in Policy Making		**X**	**X**	

Table 4 - Model Description: Typology, Topic, Predictions and Data

Model name	**Type of model**	**Topic**	**Predictions**	**Data**
IHME	Statistical model for the cumulative death rate developing a curve-fitting tool to fit a nonlinear mixed effects model to the available administrative cumulative death data. From the projected death rates, it is estimated the hospital service utilization using an individual-level microsimulation model. Deaths by age are simulate using the average age pattern from Italy, China, South Korea, and the US.	Epidemic and healthcare variables such as number of infected, deaths, hospital beds, ICU, and invasive ventilation needed	US: bed excess demand of 64,175 and 17,380 of ICU beds at the peak of COVID-19. Further, the peak ventilator use is predicted to be 19,481 in the second week of April, while the total estimated deaths were 81,114 over the next 4 months. Then, the estimates were amended downwards by predicting the death of 60.400 individuals by August, with a peak on the 12th of April. As for the UK, the model predicted 66,314 fatalities, more than Italy (a total of 23,000) and Spain (19,209)	Data Repository by Johns Hopkins CSSE
Los Alamos	The model consists of two processes. The first process is a statistical model of how the number of COVID-19 infections changes over time. The second process maps the number of infections to the reported data. It is a forecast model and does not produce projections, meaning it does not explicitly model the effects of interventions or other "what-if" scenarios.	Estimate at US state level the number of cases and deaths	For instance, for the state of New York the daily death where expected to peak at 3215 on the 19th of April	Data from the John Hopkins dashboard and the IHME website
Epirisk	Global Epidemic and Mobility Model (GLEAM), an individual-based, stochastic, and spatial epidemic model used to analyze the spatiotemporal spread and magnitude of the COVID-19 epidemic in the continental US.	EpiRisk is a computational platform designed to allow a quick estimate of the probability of exporting infected individuals from sites affected by a disease outbreak to other areas in the world through the airline transportation network and the daily commuting patterns. It also lets the user to explore	There are many predictions related to exported cases (probability of exporting a given number of cases) and relative importation risk (probability that a single infected individual is traveling from the index areas to that specific destination).	The airline transportation data used in the platform are based on origin-destination traffic flows from the OAG database that are aggregated at specific time and spatial. Commuting flows are derived by the analysis and modeling of data for more than

		the effects of potential restrictions applied to airline traffic and commuting flows.		5,000,000 commuting patterns among 78,000 administrative regions in five continents.
COVID-19 Modelling	Based on the GLEAM model.	Global Epidemic and Mobility Model (GLEAM), an individual-based, stochastic, and spatial epidemic model used to analyze the spatiotemporal spread and magnitude of the COVID-19 epidemic in the continental US. The model generates an ensemble of possible epidemic projections described by the number of newly generated infections, times of disease arrival in different regions, and the number of traveling infection carriers.	The model points to the days around April 8, 2020 as the peak time for deaths in the US. Based on the last projections, a total of 89795 COVID-19 deaths (range of 63719 to 127002) are currently projected through May 18, 2020.	Real-world data where the world is divided into subpopulations centered around major transportation hubs (usually airports). The airline transportation data encompass daily origin-destination traffic flows from the Official Aviation Guide (OAG) and International Air Transport Association (IATA) databases, whereas ground mobility flows are derived from the analysis and modeling of data collected from the statistics offices of 30 countries on five continents.
Bakker et al.	Network analysis by mean of metrics such as mobility, which refers to how people move around a city (distance traveled, radius of gyration, number of people staying home, number of stays in public places, which we call visits); and contacts, which refers to how many people each person comes into contact with.	Use of mobility data from January 1st 2020 to March 25th 2020 to figure out how has social distancing policy changed mobility and social behavior, how social distancing behavior differs across the physical space of New York City, and how social distancing behavior differs across demographic groups	The researchers find that the instance travelled everyday dropped by 70 percent, the number of social contacts in places decreased by 93%, and that the number of people staying home the whole day has increased from 20% to 60%. Very interestingly, they found that the relative differences between different demographic groups for what concerns mobility and social contacts have been dramatically reduced. Finally, they found that supermarkets and grocery stores came to be the most common locations where social contact takes place.	Mobility data is provided by Cuebiq, a location intelligence and measurement company, and they consist in supplied anonymized records of GPS locations from users who opted-in to share their data anonymously across the U.S.
Columbia University	Metapopulation SEIR model1 to simulate the transmission of COVID-19 among 3,108 US counties. Two types of movement: daily work commuting and random movement. Information on county-to-county work commuting is publicly available from the US Census Bureau. Number of random visitors between two counties is assumed to be proportional to the average number of commuters between them. As population present in each county is different during daytime and nighttime, the transmission dynamics of COVID-19 is modelled separately for these two time periods as a discrete Markov process during both day and night times.	Estimate of the number of hospital critical care beds, including ICU beds and other hospital beds used for critical care purposes, that could be made available by hospitals in response to patient surges. Various scenarios are considered.	As many as 104,120 deaths could be averted through an aggressive critical care surge response, including roughly 55% through high clearance and preparation of ICU and non-ICU critical care beds and roughly 45% through extraordinary measures like using a single ventilator for multiple patients.	2020 Centers for Medicare & Medicaid Services (CMS), Health Care Information System (HCRIS) Data File, Sub-System Hospital Cost Report (CMS-2552-96 and CMS-2552-10), Section S-3, Part 1, Column 2; the 2018 American Hospital Association (AHA) Annual Survey; the 2020 US DHHS Health Resources and Services Administration, Area Health Resources Files (AHRF); and the 2017-2019 CMS Medicare Provider of Services file, Medicare Cost Report, Hospital Compare Files.
Imperial College (1)	Individual-based simulation model developed to support pandemic influenza planning to explore scenarios for COVID-19 in GB. The	Assess the potential role of a number of public health measures – so-called non-pharmaceutical interventions aimed at	In March 2016 update the model by the Imperial College reported up to 500K deaths in the UK and up to 2.2 million deaths in the	Data on distribution size of households and age are taken from the census, while a synthetic

	basic structure of the model remains as previously published. In brief, individuals reside in areas defined by high-resolution population density data. Contacts with other individuals in the population are made within the household, at school, in the workplace and in the wider community. Transmission events occur through contacts made between susceptible and infectious individuals in either the household, workplace, school or randomly in the community, with the latter depending on spatial distance between contacts.	reducing contact rates in the population and thereby reducing transmission of the virus	US in case of no action by the government nor population. Further, the estimated figure that 15% of hospital cases would need to be treated in an ICU was then updated to 30%, arguing that the British ICU capacity (4K beds) would be overwhelmed.	population of schools distributed proportional to local population density is derived from data on average class sizes and staff-student ratios.
Imperial College (2)	Estimation of the final epidemic size from an age-structured Susceptible-Infected Recovered model incorporating both the demographic structure of the population and the rates of contact between different individuals across different age groups. The impact of the different scenarios on the dynamics of likely healthcare demand over time was assessed by using an age-structured stochastic Susceptible-Exposed-Infected-Recovered (SEIR) model parameterised to match best estimates of key parameters determining the dynamics of spread of COVID-19.	Combine data on age-specific contact patterns and COVID-19 severity to project the health impact of the pandemic in 202 countries in the view to compare predicted mortality impacts in the absence of interventions or spontaneous social distancing with what might be achieved with policies aimed at mitigating or suppressing transmission	Impact of an unmitigated scenario in the UK and the USA up to 490,000 deaths and 2,180,000 deaths respectively, and up to 7.0 billion infections and 40 million deaths globally this year	Population sizes and age distributions by country were taken from the 2020 World Population Prospects. Estimates of household size and the age of members of each household were extracted from The Demographic and Health Surveys (DHS) Program using the rDHS package. Patterns of contact across different populations and countries were drawn from several sources, including previously published estimates of mixing from a number of HICs and a recent systematic review of social contact surveys including MICs and LMICs.
Imperial College (3)	Use of a semi-mechanistic Bayesian hierarchical model to attempt to infer the impact of mitigation interventions across 11 European countries. The methods assume that changes in the reproductive number are an immediate response to these interventions being implemented rather than broader gradual changes in behaviour. The model estimates these changes by calculating backwards from the deaths observed over time to estimate transmission that occurred several weeks prior, allowing for the time lag between infection and death.	Attempt to infer the impact of policy interventions across 11 European countries.	They estimate that the intervention has averted 59,000 deaths up to 31 March across all 11 countries, that between 7 and 43 million individuals have been infected, and that the proportion of the population infected to date is the highest in Spain followed by Italy and lowest in Germany and Norway, reflecting the relative stages of the epidemics. Specifically, they estimated that in Italy and Spain, respectively 38,000 and 16,000 deaths have been avoided.	Real-time death data from the ECDC, as well as data on the nature and type of major non-pharmaceutical interventions, excerpted from the government webpages from each country as well as their official public health division/information webpages.
UO	The researchers calibrated a susceptible-infected-recovered (SIR) model to data on cumulative deaths from the UK and Italy, building on the assumption that such deaths are well reported events that occur only in a vulnerable fraction of the population. The authors also assume estimates of critical epidemiological parameters such as the basic	Percentage of population exposed to the virus.	In summary, the model suggests that the new coronavirus may already have infected far more people in the UK than scientists had previously estimated (maybe half of the population), and that thereby the mortality rate from the virus is much lower than what is generally thought to be, as the vast majority of infected individuals develop mild	For Italy, a time series was obtained from the Italian Department of Civil Protection GitHub repository. For UK, a time series was obtained from the John Hopkins University Centre for Systems Science and Engineering COVID-19 GitHub repository.

	reproduction number (R0), infectious period and time from infection to death, probability of death in the vulnerable fraction of the population. This with the aim to assess the sensitivity of the system to the actual fraction of the population vulnerable to severe disease and death.		symptoms or not at all. The model suggests that the infection has reached the UK by December or January, and that therefore people started to be infected in huge numbers before the first official case was reported.	
LSHTM	Generation of fine-scale age-specific population contact matrices by context (home, work, school, other) and type (conversational or physical) of contact that took place.	Age specific social mixing patterns by encounter context (home, work, school or other, in respective rows) and type of contact (physical only shown with dashed lines or all contacts in solid line).	Estimation of high resolution age-specific social mixing matrices based on data from over 40,000 participants, stratified by key characteristics such as contact type and setting. The matrices generated are highly relevant for informing prevention and control of new outbreaks, and evaluating strategies that reduce the amount of mixing in the population (such as school closures, social distancing, or working from home). In addition, they finally provide the possibility to use multiple sources of social mixing data to evaluate the uncertainty that stems from social mixing when designing public health interventions.	Population contact patterns for United Kingdom based self-reported contact data from over 36,000 volunteers that participated in the massive citizen science project BBC Pandemic.
RKI (1)	The number of incident cases is estimated using the nowcasting approach and is presented as a moving 4-day average to compensate for random effects of individual days. With this approach, the point estimate of R for a given day is estimated as the quotient of the number of incident cases on this day divided by the number of incident cases four days earlier.	Estimation of the impact of mitigation measures on the reproduction number.	The policies carried out by the Federal Government, i.e. the cancellation of major events in different federal states (with more than 1,000 participants) on March 9 2020, the Federal-State Agreement on guidelines against the spread of the coronavirus on March 16 2020, and the nationwide extensive ban on contacts on March 23 2020, have had a great impact on the reproduction number.	Ministry of Health and data from the Intensive Care Register produced by the German Interdisciplinary Association for Intensive and Emergency Medicine (DIVI), the RKI and the German Hospital Federation (DKG)
RKI (2)	Stochastic network dynamic modelling of an import risk model and relative import risk analysis.	Relative import risk at the airport, country and continental levels, as predicted by the computational model and the worldwide air transportation network.	The implementation of mitigation measures altered the infection pattern and spread of the disease and helped to keep it under control.	The core of the data used come from the worldwide air transportation network (WAN). This network has 3893 nodes (airports) that are connected by 51476 directed links (flight routes). Each link is weighted by the traffic flux between nodes, i.e. the average number of passengers that travel each route per day.
COVID Mobility Project	Analysis of the deviation in mobility from a “normal” baseline by counting all movements and compare them to the number to bee expect in a usual, comparable timeframe.	General picture of mobility reduction in Germany due to Covid-19 mobility restrictions.	Initial drop in mobility: mobility fell to -39% below normal in mid-March 2020, after the majority of restrictions in Germany took effect. Slow recovery of mobility: in late March mobility slowly increased and finally plateaued at -27% in the second week of April. As restriction policies hardly changed	Mobility flows of this kind are collected by many mobile phone providers. The team uses data from the German Telekom, which is distributed by the company Motionlogic, as well as data from Telefónica, which is analyzed and

			during this time, this increase might be attributed mostly to a relaxing of self-imposed, individual mobility restrictions, paired with increased mobility due to warmer weather. Beginnings of an opening: starting April 20th, some mobility restriction policies have been lifted. We observe an immediate increase in mobility to -21% in the week starting April 20th.	aggregated by the company Teralytics. This kind of data is commercially available and is used, for example, by public transportation companies, for predicting traffic or to improve road infrastructure.
Hartl et al.	Search for a trend break in cumulated confirmed Covid-19 cases as reported by the Johns Hopkins University (2020). The trend break has been estimated though maximum likelihood methods.	The impact of the German public shutdown on the spread of COVID-19.	Their finding is that confirmed Covid-19 cases in Germany grew at a daily rate of 26.7% until 19 March. From March 20 onwards, the growth rate drops by half to 13.8%, which is in line with the lagged impact of the policies implemented by the German administration on 13 March and implies a doubling of confirmed cases every 5.35 days. Before 20 March, cases doubled every 2.93 days. In their update of the model they test the impact of the 22 March policies. From 30 March on, the estimated average growth rate is 5.8%, so that the cases double every 12.20 days, therefore the containment policies are being effective.	Data from Johns Hopkins University (2020), which links data from the Robert Koch Institute, the World Health Organization, and the European Centre for Disease Prevention and Control.
Italian[21] STC	?	Assessment of the risks of epidemic spread for COVID-19 disease associated with various scenarios for the release of the lockdown introduced on 11 March on national territory.	Restarting all the sectors without teleworking and with schools open, the country would need 151 thousand intensive care units already in June and a number of hospitalizations, by the end of the year, equal to 430,866	?
COVID-19 working group et al.	In depth review of the first month of the Italian outbreak through descriptive and analytic epidemiology and an estimation of the R0 and Rt taking into account the diversity of transmission across the country.	It is provided a descriptive epidemiological summary on the first 62,843 COVID-19 cases in Italy as well as estimates of the basic and net reproductive numbers by region.	The COVID-19 infection in Italy emerged with a clustering onset similar to the one described in Wuhan, China and likewise showed worse outcomes in older males with comorbidities. Initial R0 at 2·96 in Lombardia, explains the high case-load and rapid geographical spread observed. Overall Rt in Italian regions is currently decreasing albeit with large diversities across the country, supporting the importance of combined non-pharmacological control measures.	The team analysed data from the national case-based integrated surveillance system of all RT-PCR confirmed COVID-19 infections as of March 24th 2020, collected from all Italian regions and autonomous provinces.
Signorelli	Statistical estimate of period-prevalence of the	Impact of mitigation measures.	The team concludes that suspending flights from China and airports' checkpoints with	Data from Italian Civil Protection

21 There is no specific and explicit information regarding which models are used by the Italian authorities to take their decisions. According to confidential sources, the Italian National Institute of Health and the Italian Scientific and Technical Committee, in agreement with the Italian Ministry of Health and Italian Civil Protection, are collaborating with Bruno Kessler Foundation in developing the models used by the Italian authorities in taking their policy decisions. The model will be available only when published.

et al.	disease.		thermos-scan did not have a significant effect in containing the epidemic, the implementation of a “red zone” in Lombardy effectively contained the spread of the infection within that area, even though it did not have the same effect in the neighboring provinces (Bergamo, Brescia, and Piacenza); the failure to establish a second “red zone” near Bergamo in the Municipalities of Alzano and Nembro despite the proposal of local authorities (on March 3rd), led to a dramatic out-break with about 10,000 cases in Bergamo with over 1,000 death toll and similar figures in the neighbouring areas (Brescia and Piacenza); and finally that General mitigation measures seem to be effective to flatten the epidemic curve of new notified infections	and from Local Authorities
Grasselli et al.	Based on data to March 7, when 556 COVID-19–positive ICU patients had been admitted to hospitals over the previous 15 days, linear and exponential models were created to estimate further ICU demand.	Estimation of ICU capacity and admissions.	The article shows that despite prompt response of the local and regional ICU network, health authorities, and the government to try to contain the initial cluster, the surge in patients requiring ICU admission has been overwhelming. Therefore, other health care systems should prepare for a massive increase in ICU demand during an uncontained outbreak of COVID-19. This experience would suggest that only an ICU network can provide the initial immediate surge response to allow every patient in need to be cared for.	Patients in 15 first-responder hub hospitals, chosen because they either had expertise in infectious disease or were part of the Venous-Venous ECMO Respiratory Failure Network (RESPIRA).
COVID-19 MMP	The researchers built a proximity network among users based on the locations they visited and the hour of the day when these visits occurred. In this way, they assess the effect of intervention on the average contact rate, or the number of unique contacts made by a person on a typical day.	Investigate the number of unique contacts made by a person on a typical day, and evaluate the effect of interventions on the social mixing of our users' sample by defining a proxy of the potential encounters each user could have in one hour. In order to do that, the researchers build a proximity network among users based on the locations they visited and the hour of the day when these visits occurred.	The results of the exercise show that on April 12, Easter Day, the average degree of all users was 86% lower than the pre-outbreak averages in the North, 83% in the Center and 82% in the South and the Islands. In conclusion, in the past 4 weeks, the adherence to the mobility restrictions imposed since March 12 has remained high and constant all over the country.	Mobility data is provided by Cuebiq, a location intelligence, and measurement platform.
PREDICT COVID-19	?	Predictive model on the development of positive and death cases due to COVID-19. The study assumes that the first 17 days of infection are those that determine the slope of the curve, the duration of the epidemic depends on when the daily peak is reached which depends in turn on the containment	The model shows that although the peak is close, in some regions the positive cases are underestimated, and also that containment strategies are working.	Data from Italian Civil Protection and from Local Authorities

		strategies, and the curve can be divided into two different sections, before and after daily peak.		
Martinez et al.	Verhulst model, a population growth scale that looks at the initial population to identify velocity and propagation constant. This approach enables to calculate the level of uncertainty in the short run, by adjusting epidemics history and identifying parameters.	Prediction tool that is helping Spanish emergency departments know how many patients with Covid-19 will need to be admitted in intensive care units (ICU) and prepare adequately.	The total number of patients admitted too Spanish ICU oscillates between 90,000 and 160,000.	Data at regional level from Asturias, Cantabria and Castile Leon, together with data from the Spanish ministry of health since March 18th, and the estimations issued by Johns Hopkins University.
Uni Cat	Empirical model, verified with the evolution of the number of confirmed cases in previous countries where the epidemic is close to conclude, including all provinces of China. The model and predictions are based on two parameters that are daily fitted to available data: the velocity at which spreading specific rate slows down; the higher the value, the better the control; the final number of expected cumulated cases, which cannot be evaluated at the initial stages because growth is still exponential.	The model estimates the number of cases, and permits the evaluation of the quality of control measures made in each state and a short-term prediction of tendencies.	The model predicted 203795 cases for Spain on April 19 2020.	The data sources of the model are World Health Organization (WHO) surveillance reports the European Centre for Disease Prevention and Control (ECDC) and the Spanish Ministry of Health.
Inverence	Based on data released by Spain's Ministry of Health (Ministerio de Sanidad), predictive models have been developed based on Bayesian time series analysis.	The modelling strategy considered the number of daily ICU admissions in every region and linking it, via a transfer function, to the number of deaths, assuming that the number of ICU admissions is a good indicator of the number of infected individuals in critical condition. Later on, the research team has developed models for the number of infected cases, based on a dynamical transmission rate model, which allows to understand in a straightforward way the effect of public authorities' actions, which are aimed precisely at reducing this transmission rate.	The number of deaths per million people shows the pandemic's different spreading velocities in different countries. Spain appears as the country with the largest epidemic spreading velocity among the set of countries considered.	Data released by Spain's Ministry of Health.
University of Zaragoza	The research team adapted a Microscopic Markov Chain Approach (MMCA) metapopulation mobility model to capture the spread of COVID-19 that stratifies the population by ages, and accounts for the different incidences of the disease at each stratum.	The model is used to predict the incidence of the epidemics in a spatial population through time, permitting investigation of control measures.	We have applied the results to the validation and projection of the propagation of COVID–19 in Spain. Our results reveal that, at the current stage of the epidemics, the application of stricter containment measures of social distance are urgent to avoid the collapse of the health system. Moreover, we are close to a scenario in which the complete lockdown appears as the only possible measure to avoid the former situation. Other scenarios can be prescribed and analyzed after lockdown, as for example pulsating	Estimates of the epidemiological parameters and the mobility and demographic census data of the national institute of statistics (INE).

			open-closing strategies or targeted herd immunity.	
Massonnaud et al.	Deterministic SEIR model for hospital areas with predictions at one month and 17 five-year age groups (last 80 and over) to estimate the ICU resource deficit. Specifically, the model is based on country-specific contact matrices (social interactions) between age groups.	Estimation of the daily number of COVID-19 cases, hospitalizations and deaths, the needs in ICU beds per Region and the reaching date of ICU capacity limits.	At the national level, the total number of infected cases was expected to range from 22,872 in the best case (R0 = 1.5) to 161,832 in the worst considered case (R0 = 3). Regarding the total number of deaths, it was expected to vary from 1,021 to 11,032, respectively. Clearly the real data regarding mortality rate are higher. What is interesting, it is also that they estimated the timing according to which the capacity limit of French ICU would be overrun.	Population structure was inferred for each catchment area from 2016 and 2017 census data provided by the French National Institute of Statistics and Economic Studies (Insee). Catchment areas were then aggregated by metropolitan Regions [13 French administrative areas with an averaged population of 4.75 millions ranging from 300,000 (Corse) to 12.55 millions (Ile-de-France)]. Data on ICU beds capacity per French Region were retrieved from the "Statistique Annuelle des Etablissements de Santé" (SAE)
EPIcx-lab of INSERM (1)	Stochastic age-structured transmission model integrating data on age profile and social contacts in the Île-de-France region to assess the current epidemic situation, and estimate the effectiveness of possible exit strategies. The model is calibrated on hospital admission data of the region before lockdown and validated on syndromic and virological surveillance data.	In one study they use a stochastic age-structured transmission model integrating data on age profile and social contacts in the Île-de-France region to assess the current epidemic situation, evaluate the expected impact of the lockdown implemented in France on March 17, and finally to estimate the effectiveness of exit strategies, building on hospital admission data of the region before lockdown.	They estimated that the average number of contacts is predicted to be reduced by 80% during lockdown, leading to the reduction of the reproductive number to 0.68. They show that the epidemic curve reaches ICU system capacity and slowly decreases during lockdown, and that lifting the lockdown with no exit strategy would cause a second wave. They also show that testing and social distancing strategies that gradually relax current constraints while keeping schools closed and seniors isolated will avoid a second wave and healthcare demand exceeding capacity.	The model is calibrated on hospital data specifying the number of COVID-19 positive hospital admissions in Île-de-France prior to lockdown. Data for that period was consolidated up to April 3, to account for delays in reporting. The simulated incidence of clinical cases (mild and severe symptoms) is compared to the regional incidence of COVID-19 cases estimated by the syndromic and virological surveillance system for the weeks 12 (March 16 to 22, 2020) and 13 (March 23 to 29).
EPIcx-lab of INSERM (2)	Stochastic age-structured data-driven epidemic model based on demographic and social contact data between children and adults for each region, and is parameterized to COVID-19 epidemic, accounting for current uncertainties in the relative susceptibility and transmissibility of children.	Assess the expected impact of school closure and telework to mitigate COVID-19 epidemic in France by mean of a stochastic age-structured epidemic model integrating data on age profile and social contacts of individuals.	Mere school closures have limited effects (i.e. <10% reduction with 8-week school closure for regions in the early phase of the epidemic), while coupled with teleworking for 25% adults there would be a delay of the peak by almost 2 months with an approximately 40% reduction of the case incidence at the peak. Therefore, explicit guidance on telework and interventions to facilitate its application to all professional categories should be urgently provided.	Demographic and age profiles of the regions of Île-de-France, Hauts-de-France, Grand Est