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The measures taken to limit the spread of the COVID-19 virus, which at the same time severely restrict economic activity in many countries, have consequences not only on unemployment, trade, production, income and value added, but also on the environment. This analysis examines the effects on greenhouse gas emissions in Austria. For this purpose, a new, lean and very flexible model, ALICE, was developed, which quantifies the short to medium-term effects of changes in production and consumption with regard to output, value added and greenhouse gas emissions. In order to determine the consequences as precisely as possible, 74 economic activities and households are distinguished. The model results show not only the direct consequences, but also the consequences resulting from the interdependence of the economic system. The scenario presented here is based on the forecast published by WIFO in late June 2020, which forecasts a decline in gross domestic product by 7 percent in 2020. The sector-specific declines in value added and expected changes in household consumption behaviour are the input parameters for the model that calculates the associated greenhouse gas emissions. Greenhouse gas emission – as defined by the Austrian inventory – is estimated to decline by 9.9 percent. This decline is due to the change of economic activities. Factors that also affect the level of emissions, such as ambient temperatures, changes in land use and forest growth, are not considered here. Following the conventions of the greenhouse gas inventory, international aviation is not included in the calculation either. There are several uncertainties because the economy may suffer even more than expected in June 2020. The actual production of industries and the behaviour of households throughout the year, especially with regard to their travel activities, may unfold in a different manner than expected.

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Abstract

The measures taken to limit the spread of the Covid-19 virus, which at the same time severely restrict economic activity in many countries, have consequences not only on unemployment, trade, production, income and value added, but also on the environment. This analysis examines the effects on greenhouse gas (GHG) emissions in Austria. For this purpose, a new, lean and very flexible model, ALICE, was developed, which quantifies the short to medium-term effects of changes in production and consumption with regard to output, value added and GHG emissions. In order to determine the consequences as precisely as possible, 74 economic activities and households are distinguished.

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1. Introduction and problem definition[1]

In order to reduce the risk of infection of large parts of the population and its consequences, social contacts and economic activities have been massively restricted throughout Europe since March 2020. As the reduction in trade and economic relations also affected the most important trading partners with a slight time lag, there was not only a sharp drop in travel and a reduction in the volume of trade, but also a significant reduction in the level of production in many sectors.

The restrictions were implemented to attain the maximum reduction in the number of infected persons while maintaining the provision of essential basic services such as health care, food, energy, public transport, basic services and other everyday goods. In 2020, the restriction of personal mobility to the bare essentials, the de facto ban on the provision of many personal services and the restriction of cultural and sporting activities directly affected many industries that were only indirectly affected by the decline in economic activity through reduced demand in the wake of the major financial and economic crisis of 2008 and 2009.

Our economic system is still closely interwoven with the consumption of fossil materials and energy sources (Köppl et al., 2020). This is most clearly visible in the fact that a sharp decline in economic activity is regularly associated with a reduction in emissions. This was most evident in 2008 and 2009, when emissions of greenhouse gases (excluding LULUCF)[2] fell by 0.7 and 7.6 percent respectively. In the phase of the subsequent upturn, emissions increased swiftly (in 2010 by 5.6% compared to 2009). Since then there have been four years with increases and five years with decreases in greenhouse gas emissions (see Figure 1).

The subject of the analysis is to present a methodology to quantify the GHG emissions and to estimate the extent of the decline due to the current COVID-induced crisis. The change in emissions is determined according to the definitions of the greenhouse gas inventory. Emissions from international aviation, which in 2018 had a global share of approximately 2.4% or 0.92 gigatonnes (Graver et al., 2019), are not considered in our analysis.

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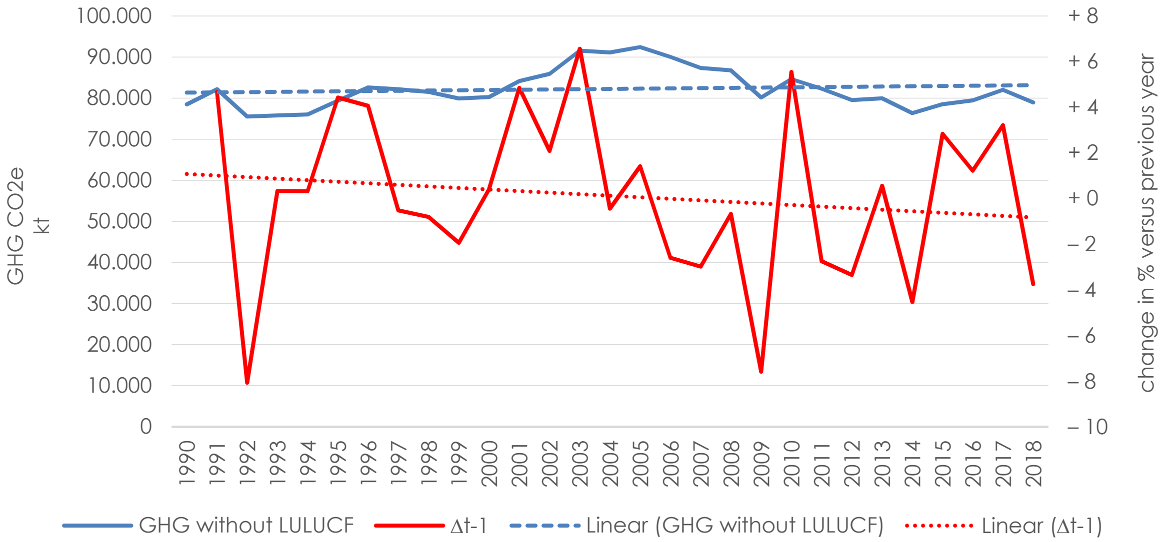
[1] The authors would like to thank Angela Köppl, Mathias Kirchner and Claudia Kettner for valuable suggestions and comments on an earlier version of the manuscript (Sommer, Sinabell and Streicher, 2020). Remaining deficiencies are the responsibility of the authors.

[2] LULUCF is the abbreviation for Land Use, Land Use Change and Forestry, i.e. the storage or release of carbon from the atmosphere in the soil and standing timber.

Figure 1: GHG emissions of Austria without LULUCF in 1,000 t according to inventory reporting (left scale) and the annual change in % (right scale) and their trends



Q: IPCC Inventory 2020, Submission 2020 v2. left scale: GHG CO2e: right scale Δt-1. The dotted lines represent the trends.

The aim is to quantify the effects associated with the decline in economic output. This is only part of the effects shown in the greenhouse gas inventory. The annual overview of the development of greenhouse gas (GHG) emissions, which is compiled by Umweltbundesamt (2020a,b) measures the actual changes, which are also influenced by other factors. These include weather conditions that induce higher or lower consumption of heating or cooling, the reaction of consumers to relative price changes compared to neighbouring countries, for example in fuel consumption, or changes in land use and forest growth.

The intention of the present study is not to determine the expected effects of these further influencing factors, but on the contrary to abstract from them and thus isolate the economic effects. The result of the present analysis is therefore not a forecast, but rather the quantification of the effects directly related to the economic crisis and the emission intensity of the sectors and activities. Umweltbundesamt is expected to present the first results of the greenhouse gas balance, which will include factors that are excluded here, in mid 2021[3].

The following section presents the data and the method of quantitative analysis of the emission effects of the economic lockdown. As these are already proven methods in many cases, such as input-output analysis, this section will be kept short. The procedure for determining GHG emissions associated with economic activities is presented in more detail. The inventory is not easy to understand, as important emission categories are not added to the total emissions. However, since their purpose is primarily to make compliance with international treaties visible,

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[3] A flash estimate of GHG emissions for 2018 was published on 31st of July 2019 (Umweltbundesamt, 2019a).

the conventions are comprehensible. For the understanding of the results presented in this analysis, these particularities are important and are therefore explained in more detail. The central item is the emission of greenhouse gases expressed in CO2e (i.e. CO_2 equivalents)[4] without LULUCF (Land Use Land Use Change and Forestry). CO_2 equivalents are a single measure of various gases covered by the Kyoto Protocol (see Table 6 in the Annex).

In the following sections, the data, the assumptions of the scenario calculation and the results are presented and discussed. Finally, a short outlook is given on necessary further steps to improve the validity of the results and to increase the usefulness of the model employed in this analysis.

2. Data and method

2.1 Core elements of the greenhouse gas inventory

In 1992 Austria joined the United Nations *Framework Convention on Climate Change* (UNFCCC), whose primary objective is to stabilise atmospheric greenhouse gas concentrations[5]. The *Framework Convention on Climate Change* covers all greenhouse gases not covered by the Montreal Protocol (ozone-depleting gases), specifically carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as hydrogenated fluorocarbons (HFCs), perfluorinated halocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

The *Kyoto Protocol*[6] was adopted in 1997. This is a protocol by which legally binding restrictions on greenhouse gas emissions were contractually agreed. Industrialised countries committed themselves to reducing greenhouse gas emissions by 5% below 1990 levels in the period 2008-2012. The European Union is also party and has agreed to a reduction target of 8% below 1990 levels over a five-year commitment period. The reduction target for Austria was minus 13% compared to 1990 (Umweltbundesamt, 2020a).

After five years of negotiations (UN Climate Change Conference in Bali 2007 to the UN Climate Change Conference in Doha 2012), the Parties agreed on a second commitment period ("Kyoto II") from 2013 to 2020, but this has not yet come into force, as by 18 February 2020 only 137 of the required 144 Parties had deposited their instruments of acceptance

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[4] The greenhouse effect of different gases is standardised on a uniform scale using CO2 equivalents. An overview is available at: https://unfccc.int/resource/docs/2011/cop17/eng/09a02.pdf (accessed April 30, 2020) Currently, the factors of the IPCC Fourth Assessment Report (4AR) are used. The factor of methane is 25, that of nitrous oxide is 298 and those of fluorine compounds range from 11 to 22,800.

[5] See Federal Law Gazette No. 414/1994: United Nations Framework Convention on Climate Change and its Annexes. Amendment by Federal Law Gazette III No. 12/1999.

[6] Kyoto Protocol to the United Nations Framework Convention on Climate Change.

(Umweltbundesamt, 2020a). The agreed reduction for the EU by 2020 is 20% compared to 1990, which is in line with the EU's 2020 climate and energy package.

The European Union implements international commitments by means of objectives and mechanisms binding on the Member States. The most important of these are *emissions trading* and regulatory requirements, known as *effort sharing*. One of the legal bases is the burden-sharing decision[7]. The reduction target of the relevant sectors for Austria for 2020 stated in Annex II of this decision is -16% compared to 2005. The other emission sources, i.e. industry and heat generation and, since 2012, domestic EU air traffic, are regulated in the EU Emission Trading System (EU ETS).[8] Its aim is to reduce emission by 21% in 2020 compared to 2005. This target is to be achieved in stages, with the third period of action extending from 2013 to 2020.

International air traffic (i.e. crossing the borders of EU member states) is *not* part of the Kyoto Protocol and is currently not subject to any restrictions within the EU either.[9] More details on climate policy regulations in the EU and on progress towards reducing emissions are provided in EEA (2019).

As a party to the United Nations Framework Convention on Climate Change (UNFCCC), Austria is obliged to draw up and regularly update its national greenhouse gas inventory (GHG inventory) (see Table 6 in the Annex). Methodology, content and format of the inventory are prescribed by the IPCC in its reporting guidelines (IPCC, 2020). For a complete submission of the inventory, a National Inventory Report and tables in the Common Reporting Format are required: the GHG inventory from a National Inventory Report (NIR) and Common Reporting Format (CRF) tables. The current report of the Umweltbundesamt with the results of the GHG inventory was published in early 2020 (Umweltbundesamt, 2020a) and covers the period 1990 to 2018. The detailed data are available on the UNFCC website.[10] The figures from the Umweltbundesamt (2020a) and IPCC differ slightly.

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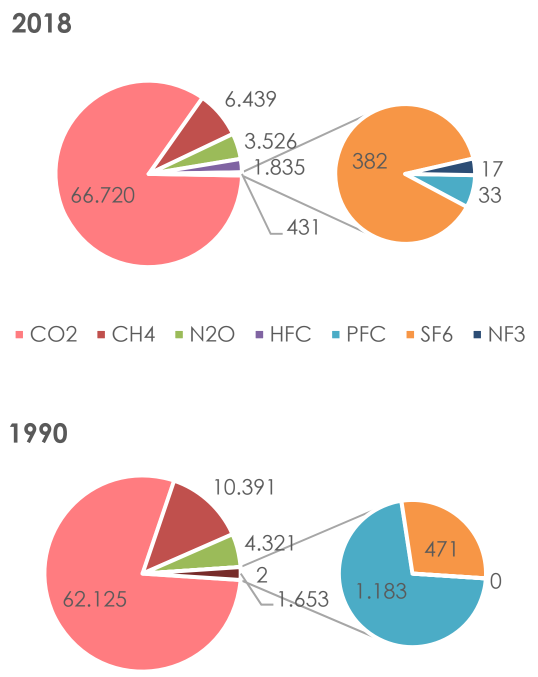
[7] Decision 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.

[8] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (Emissions Trading Directive)

[9] Regulation (EU) 2017/2392 of the European Parliament and of the Council of 13 December 2017 amending Directive 2003/87/EC maintaining the current limitation of its application to aviation activities and preparing for the implementation of a global market-based mechanism from 2021

[10] https://unfccc.int/ghg-inventories-annex-i-parties/2020 (accessed on 26 April 2020).

Figure 2: Composition of GHG emissions of Austria without LULUCF in 1,000 t according to inventory reporting (measured in CO2e) in 2018 and 1990



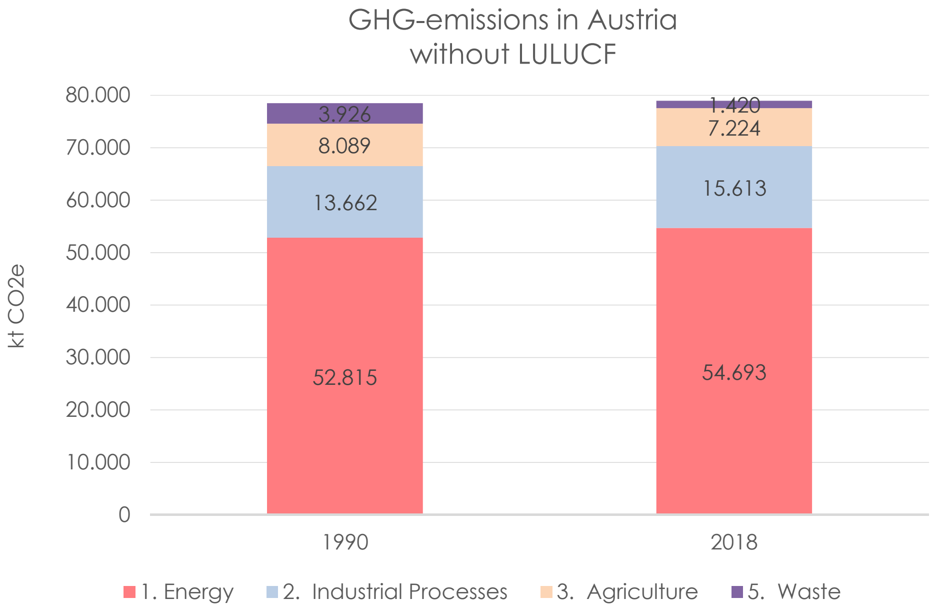
Q: IPCC Inventory 2020, Submission 2020 v2.

The most important greenhouse gas emitted in terms of quantity is carbon dioxide (CO_2). In Austria, this gas accounted for 85% of total GHG emissions (in CO_2 equivalents) in 2018. CO_2 emissions result primarily from the burning of fossil fuels and are also the result of chemical processes (e.g. cement production). Methane (CH_4) is released, among other things, in animal husbandry and waste disposal and contributed 8.2% to total national GHG emissions (in CO2 equivalents). The remaining components are nitrous oxide (N_2O), which is emitted from agricultural soils (4.5%), and emissions of fluorinated compounds (2.9%), most of which are used to replace ozone-depleting substances in refrigeration equipment and some of which escape (Umweltbundesamt, 2020a). Figure 2 (calculated in CO2e) shows which greenhouse gases have been emitted in Austria.

In 2018 Austria's greenhouse gas emissions (without LULUCF) according to the inventory regulations amounted to 79.0 million t CO_2 equivalents. Compared to the base year 1990, GHG emissions increased by 0.6%, compared to 2017 they decreased by 3.7% (Umweltbundesamt, 2020a). The most important category for GHG emissions in Austria is the sector "energy" (with the sub-categories energy production, manufacturing industry and construction, transport - see Table 6a in the Annex), i.e. energy use of fuels, which accounted for 69% of total national greenhouse gas emissions in 2018 (67% in 1990). The second most important category is

"Industrial Process and Other Product Use" (20% in 2018; the abbreviation is IPPU) and agriculture (9.2% in 2018). Figure 3 shows the distribution of greenhouse gas emissions by source in Austria in the years 1990 and 2018.

Figure 3: Sources of Austria's GHG emissions without LULUCF in 1,000 t according to inventory reporting (in CO2e) in 1990 and 2018



Q: IPCC Inventory 2020, Submission 2020 v2.

The most important sub-category of the category "energy" was transport with a 31% share of total emissions (excluding LULUCF; Table A.I-1 in Umweltbundesamt, 2020a), the share of the energy industries was 13% in 2018. The third most important source of greenhouse gas emissions in Austria is the metal industry (assigned to IPPU) with a contribution to total national emissions (without LULUCF) of 12% in 2018 (Umweltbundesamt, 2020a).

It should be noted that the allocation used here follows UNFCC (cf. tables 6a and 6b). It differs from the allocation according to the Austrian Climate Protection Act (cf. Umweltbundesamt, 2019b). The allocation of the sectors according to the Austrian Climate Protection Act is recorded in Annex 3 of Umweltbundesamt (2019b).

2.2 Core elements of the input-output analysis

Input-output (I-O) tables show in detail the interdependence of an economy in terms of production and goods. It not only shows the interactions within a country's economic activities, but also the flow of goods between the domestic economy and the rest of the world. The focus is particularly on the allocation of goods that pass through the production process. In I-O tables goods are not recorded in terms of quantities, but in terms of values. The national accounts are based on input-output analysis as their core element. A schematic representation of this calculation is shown in Figure 4.

Input is the use, expressed in monetary terms, of intermediate consumption, i.e. goods and services that are consumed, processed or transformed in the course of production (see input matrix). The production factors labour and capital (primary inputs) are also included in the calculation (matrix of primary inputs), but they are not part of intermediate consumption. Soil and other elements of living and non-living nature are not included in the input-output accounts.

Output is the value of the goods and services produced, the production value. For this purpose, the quantity of goods produced is multiplied by their price. Depending on whether market prices are used for the calculation or whether taxes and subsidies on products are also considered, output values differ. If government influence on prices is taken into account, this is called valuation at *basic prices*. The distinction to *market prices* is necessary to calculate factor compensation (see block *components of value added*) correctly. Such a correction is applied, for example, in the agriculture sector where product related support is granted.

Goods and services in each sector are not only supplied to other sectors (or to other industries), but are also further processed in the same sector, consumed by households, used as capital goods or exported (see block *final demand*). *Total use* must be equal to *total supply* in order to ensure an accounting equilibrium. Consistency ensures that the flows of goods are fully recorded and that the economic cycle is fully reflected.

The input-output tables of the Austrian national economy are published on the EUROSTAT website; Statistics Austria also offers supplementary tables that are necessary for more in-depth analyses. The procedure for compiling the input-output table with supply and use tables in conjunction with the calculation of Austrian gross domestic product in 2015 is described in detail in Statistik Austria (2020).

In the columns of the intermediate consumption matrix, each cell shows how many intermediate goods from domestic production and from imports were consumed by each production unit.

Figure 4: Schematic representation of an input-output table (goods x goods) at basic prices

		(1)	(2)							(3)=(1)+(2)
		INTERMEDIATE CONSUMPTION	**FINAL CONSUMPTION**							**TOTAL USE**
		PRODUCTION SECTORS / GOODS (ÖCPA)	FINAL CONSUMPTION EXPENDITURE			GROSS CAPITAL FORMATION			EXPORT**S**	
(1)	**GOODS** (ÖCPA)	Intermediate consumption by production sectors and goods at basic prices	**Households**	**Public**	**Private non-profit services**	**Gross fixed capital formation**	**Acquisitions of valuables**	**Changes in inventories**	**Exports, FOB**	Use of goods
(2)	**TOTAL** (1)	Intermediate consumption by production sectors	Final consumption expenditure by category							**Total use**
(3)	Taxes less Subsidies on products	**Net t**axes on products of **i**ntermediate consumption	Net taxes on final consumption							**Total net taxes on products**
(4)	**TOTAL** (2)+(3)	Intermediate consumption at purchaser prices	Final consumption expenditure at purchaser prices							**Total use at purchaser prices**
(5)	VALUE ADDED	Value added of components and sectors								
(6)	**TOTAL** (5)	Value added of production sectors								
(7)	**TOTAL** (4)+(6)	Output of production sectors								
(8)	IMPORTS	Imports of goods, CIF								
(9)	**TOTAL** (7)+(8)	Supply of goods								

Q: Statistics Austria, 2020, page 21; own translation.

One of the main advantages of using input-output analysis to evaluate the economic interactions is that it can be used to determine the effects of indirect interactions:

- the economic effects are recorded systematically and, in their entirety, and the effects on consumption are also quantified
- the method used has been established for decades and is very often applied in the analysis of economic policy measures (such studies are often called impact analyses);
- because of the wide dissemination of this access, the results can be reproduced or tested by a large number of researchers, so the analysis is not based on a black box model
- the assumptions on which the model is based are simple and transparent – one of them is on technology (linear limitational production function; this means that proportional changes are represented in each case).

The latter assumption is often cited as a disadvantage of the method, since production adjustments are in many cases more reliably represented with production functions of a different functional form. However, errors are small if the effects examined are small in relation to the total volume of goods and the structure of the economy and technology is still well represented, i.e. the table is up to date.

In an analysis of the effects of a scenario, it is assumed that the equilibrium of the economy is disturbed by the changes cited (shocks occur which affect output or demand in different ways). The effects of such a shock (e.g. higher or lower demand for a good) have several effects:

- *Direct effects* represent the "first round effect" of an exogenous shock within the sector concerned. For example, the expansion of demand for construction is directly linked to an increased number of employees in the construction industry.
- *Indirect effects*: directly affected sectors increase output and intermediate demand, thus triggering a demand chain reaction that can affect several sectors (indeed, most of the economy). This means that these sectors also change their production and in turn trigger changes in demand for other goods. This *indirect* knock-on effect decreases after each cycle until a new equilibrium is reached. In the input-output analysis, the so-called *Leontief Type I inverse is* used to calculate these effects. This matrix maps the entire demand chain reaction and allows the sum of the *indirect effects to be* calculated.
- *Induced effects*: Such effects are calculated with the help of *type II Leontief inverse*. This approach takes account of the fact that changes in production in the sectors also affect incomes. Since part of the income is used for consumption, the demand for goods thus changes, which in turn affects production and income. Here - as in the case of indirect effects - a chain reaction takes place, which is captured by the inverse.

The sum of *direct, indirect* and *induced* effects is then evaluated as the *total effect* of the exogenous shock. The effects can be standardised as "multipliers". The size of the multipliers depends on two main factors:

- The structure and type of the goods: Depending on the type of demand, either mainly tangible goods (e.g. cars by private households) or services (e.g. education by the public sector) are in demand.
- The share of imports in the quantity of goods: The more is purchased from "abroad" during the production process, the less value added remains in the region under consideration.

The effects of shocks can be related to various indicators of the economy. Effects on *value added* and *employment* are most frequently evaluated. It is also possible to determine the consequences for output (i.e. the quantity of goods and services valued in money terms) or tax revenue. For the present analysis, the impact on value added is in the foreground, since the most important indicator of the economic forecast for 2020 is gross domestic product (GDP), which is based on the total value added of all industries.

2.3 Energy balances and GHG emissions

In assessing the impact of the economic crisis on GHG emissions, the link between economic activity and energy use is important. The relevance of energy is mainly its large share (85%) of greenhouse gas emissions. CO_2 comes from the combustion of fossil fuels[11].

A key challenge is to link GHG emissions with economic data. Most relevant economic parameters are available in monetary units, but GHG emissions are measured in physical units. A second challenge is that the behaviour of households must also be considered, as household consumption is crucial for the long-term development.

Figure 5 gives an overview of the core elements of the energy balance, the fuels and energy sources. Depending on the source, conversion, technology and application, no (hydropower) to very much (lignite) greenhouse gas is released in addition to the primary purpose, useful energy or heat. Energy sources of non-fossil organic origin (e.g. firewood, fuel from biomass) also emit greenhouse gases during combustion. This is CO_2, which has previously been removed from the atmosphere by plants. A discussion on implications for the Paris agreement is provided by Norton et al. (2019).

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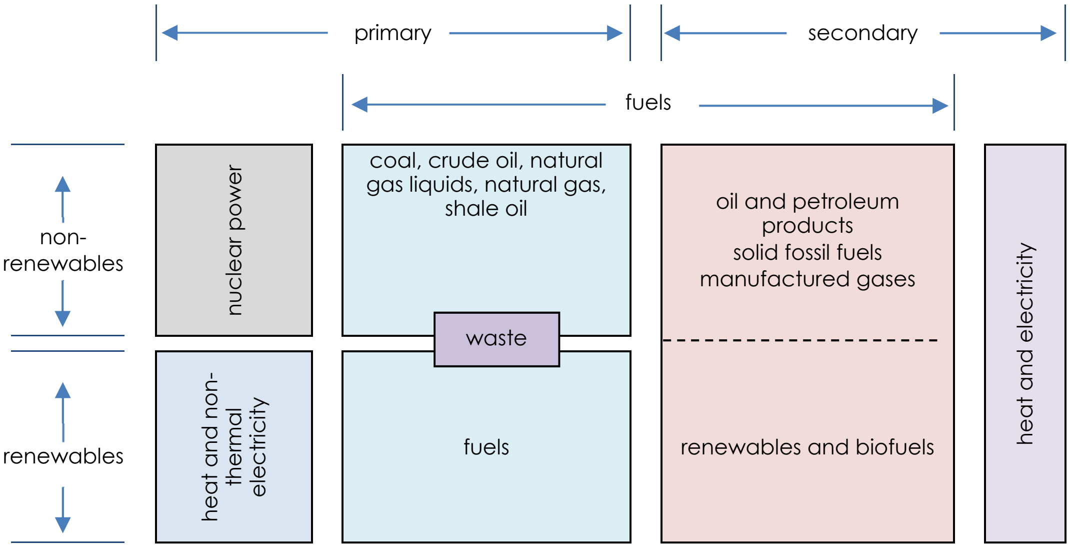
[11] CO2 is also emitted when burning biomass. In this case, however, the CO2 emitted is comensated by the carbon uptake during plant growth, making the burning of biomass largely carbon neutral

Figure 5: Overview of fuels and energy sources



Q: OECD, IEA and EUROSTAT, 2005, page 21.

Table 1 provides a highly aggregated overview of energy flows in Austria. The core elements of the energy balance presented in this table are available in a detailed breakdown for individual economic sectors, households, provinces and by energy source.

Table 1: Overview of Austria's energy balance in petajoules

	1990	2000	2005	2010	2015	2016	2017	2018
Domestic production of raw energy	341	413	413	507	512	524	529	502
Imports from abroad	776	926	1,240	1,259	1,261	1,333	1,343	1,327
Stock	-13	12	-8	36	48	17	-3	7
Exports to foreign countries	51	125	206	343	410	448	411	412
Gross inland consumption	1,052	1,225	1,438	1,458	1,411	1,426	1,457	1,423
Conversion insert	774	804	882	873	882	868	886	883
Conversion output	669	711	765	759	787	775	786	791
Consumption of the energy sector	105	106	126	126	117	105	118	102
Non-energy consumption	65	72	67	76	76	79	71	78
Final energy consumption (EE)	763	936	1,104	1,116	1,096	1,124	1,141	1,126

Q: Statistics Austria, 2020b

For the purposes of this study, a detailed breakdown of the energy balance is particularly important, the "Physical Energy Flow Accounts" (PEFA). This statistic was published by Statistik Austria for the first time in 2017 (see Table 5 in the Annex)[12]. In these statistics, the energy consumption relevant to emissions is presented and allocated to the individual sectors of the economy

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[12] see https://www.statistik.at/web_de/statistiken/energie_umwelt_innovation_mobilitaet/energie_und_umwelt/ energie/physische_energieflussrechnungen/index.html (accessed 27 April 2020)

in energy units (specifically terajoules, TJ), and broken down to energy sources. The energy consumption of households (for room heating and air conditioning, car use and other energy inputs) is available for the years 2013 to 2017 (see Table 2 in the Annex).

2.4 Core elements of the ALICE model

The model used for the analysis is kept relatively compact to ensure traceability and can be used flexibly due to the low data requirements. The name of the model is ALICE (A Laboratory to Investigate Carbon Emissions). In addition to input-output tables for Austria from the year 2016, the most important element is the physical energy flow for Austria. Both data sources were published by Statistik Austria (2020 b, c). The physical energy flow (PEFA) is also available for most EU member states. The PEFA gives values in terajoules, the input-output tables are available in monetary units, the target results are quantities of greenhouse gases in CO2e (i.e. equivalents of CO_2 scaled in terms of their effectiveness in warming the atmosphere). Coefficients are therefore required from which energy sources specified in units of energy content are converted to $CO2_{e.}$ For this purpose, the conversion factors according to Umweltbundesamt (2020) were used and adjusted to the calculation method of the Austrian energy balance (calorific value).

In a simulation run, final demand is changed in purchaser prices ***fAP*** (the price paid by the buyer of the good) of a given good. This value is converted into (1), taking into account net taxes on products ***t*** and transport and trade margins ***m***, into (2), in final demand into basic prices ***fHP*** (i.e. the amount received by the producer or importer of the goods) (3).

$$f^{AP}_{Tax} = f^{AP}\,\alpha_{Tax} \tag{1}$$

$$f^{AP}_{Span} = f^{AP}_{Tax}\,\alpha^{pos}_{Span} - \mathrm{sum}\left(f^{AP}_{Tax}\,\alpha^{pos}_{Span}\right)\,\alpha^{neg}_{Span} \tag{2}$$

$$f^{HP} = \left(f^{AP} - f^{AP}_{Tax} - f^{AP}_{Span}\right) \tag{3}$$

Only the effect on domestic value added or domestic emissions is of interest here. Therefore the tables of domestic production are used for the calculation. Thus, in (4) the direct imports, using the import propensity ***n***, are deducted since only those goods that are bought from domestic producers are relevant for domestic value added.

$$f^{HP}_{home} = f^{HP}(1 - \alpha_{Imports}) \tag{4}$$

The domestic final demand vector $\boldsymbol{f^{HP}_{home}}$ is multiplied by the input-output coefficients in (5) to calculate the production level ***q*** on the basis of the economic interdependencies of the industrial and service sectors (represented by the technology matrix ***A).*** This production is necessary to provide final demand and the respective intermediate consumption.

$$\mathbf{q} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}_{\mathbf{home}}^{\mathbf{HP}} \tag{5}$$

The result is a new production vector ***q*** of goods. Emission ***e*** and a new value added ***v*** are associated with the changed demand for goods and are calculated using the multipliers in (6) and (7).

$$\mathrm{e}^{\mathrm{sector}} = \varepsilon^{\mathrm{sector}}\,\mathrm{q} \tag{6}$$

$$\mathrm{v} = \sigma\,\mathrm{q} \tag{7}$$

The changes are derived by comparing activity levels, value added and emission before and after the shock. These results are the basis for further analysis, in which assumptions are made about household behaviour and special emission sources.

3. Assumptions for the scenarios

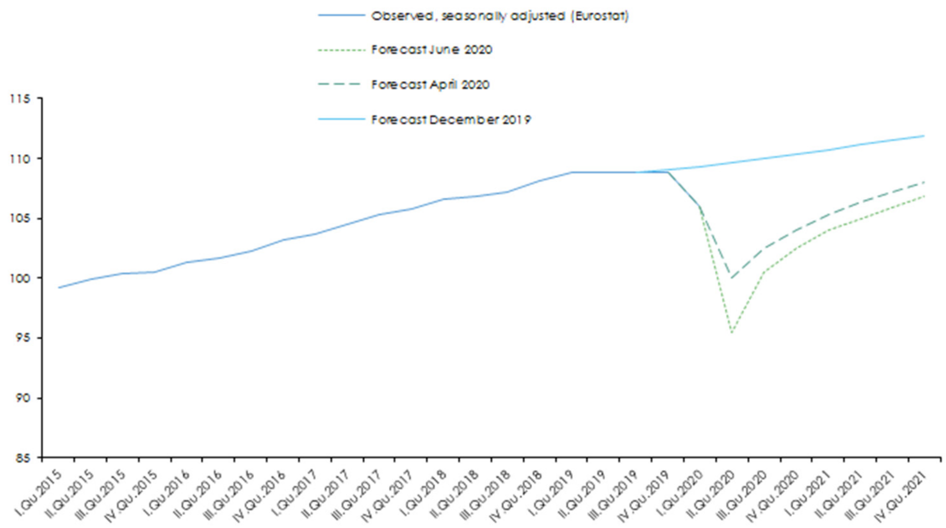
The model analysis is based on the forecast published by WIFO on June 26, 2020. The premise of this forecast is that the COVID-19 pandemic and the measures to contain it pushed the international and Austrian economy into a downturn in March 2020. A global recession of unprecedented magnitude and synchronicity was observed in the second quarter of 2020.

In line with the global economy, Austria slipped into a recession that, although essentially confined to the first half of 2020 and thus rather short, is extraordinarily severe. By now, the trough should have been passed and activity is heading up; still, the further trend is subject to high uncertainty. The main reason is the evolution of the pandemic, the required containment measures and their implicit economic repercussions.

After a fall by 7.0 percent in 2020, GDP is expected to rebound by 4.3 percent in 2021. While such a recovery would be vigorous by historical standards, economic activity by the end of the projection period would still fall short of its pre-crisis level. The manufacturing sector and market-related services (particularly transport, hotel and catering services) are shaping the profile of the slump on the supply side, exports, investment (notably in machinery and business equipment) as well as private consumption. The unemployment rate will jump from 7.4 percent in 2019 to 9.7 percent in 2020.

The core results of the forecast are shown in Figure 6. The graph on the left shows the development of Austria's real gross domestic product, distinguishing between the forecast trend for December 2019, the main variant presented in April and the forecast from June 2020. The right-hand chart shows the rates of change in real GDP per quarter compared to the same quarter of the previous year.

Figure 6: Forecast of the real gross domestic product of the Austrian economy in June 2020



Q: WIFO, 2020

The forecast for the economy as a whole is based on detailed forecasts of individual sectors (Table 2). The expected changes in real value added at basic prices compared with 2019 are used to calculate gross domestic product after extrapolating the individual sectors and adding the balance of taxes and subsidies on products (see previous section). The results of the main variant of the forecast, which takes into account Covid-19 mitigation measures and adjustments, is used for the scenario of GHG emissions (see Table 3).

Table 2: Expected change in gross value added in the economic sectors according to the WIFO forecast of June 2020

	2018	2019	2020	2021	2018	2019	2020	2021
	bn Euro (base year 2015)				Change vs previous year			
Agriculture, forestry and fisheries	4.3	4.4	4.1	4.1	4.1	0.9	-7.0	0.0
Manufacturing, including mining	67.3	67.8	59.0	63.1	5.1	0.8	-13.0	7.0
Energy and water supply, waste disposal and recycling	10.1	10.4	9.5	9.9	5.4	2.9	-9.0	4.0
Construction Industry	20.9	21.4	20.4	21.2	3.9	2.4	-4.5	3.8
Trade, maintenance/ repair Motor vehicles	38.5	38.8	35.3	38.1	1.9	0.8	-9.0	8.0
Traffic	19.2	20.0	18.0	18.9	4.5	4.2	-10.0	5.0
Accommodation and gastronomy	16.6	16.9	12.8	16.0	3.0	2.3	-24.5	25.0
Information and communication	11.9	12.2	12.2	12.5	2.7	2.6	0.0	2.0
Financial and insurance services	13.7	14.3	14.2	14.3	-0.5	4.2	-0.4	0.7
Real estate sector	30.7	31.2	30.6	30.8	0.9	1.8	-2.0	0.7
Other economic services1)	32.3	33.0	31.7	32.2	3.0	2.0	-4.0	1.7
Public administration2)	55.6	55.9	57.0	57.0	0.7	0.6	2.0	0.0
Other services3)	8.8	8.9	7.6	8.0	-0.4	0.7	-15.0	5.0
Value added by economic sectors4)	329.9	335.2	312.6	326.3	2.6	1.6	-6.7	4.4
Gross domestic product	368.9	374.8	348.7	363.9	2.4	1.6	-7.0	4.3

Source: WIFO, 2020 - 1) Professional, scientific, technical and other business activities (ÖNACE 2008, sections M to N). - 2) Including social security, defence, education, training, health and social work (ÖNACE 2008, sections O to Q). - 3) Including arts, entertainment and recreation, private households (ÖNACE 2008, sections R to U). - 4) Before deduction of subsidies on products and before allocation of taxes on products.

4. Results and discussion

The expected changes in the value added of the different sectors mentioned in the previous section were used as input for the model ALICE. Demand was shocked in a manner to reproduce the expected change in value added of the sectors listed in Table 2. The model results show not only the direct consequences of the impact of the Covid-19 induced changes on the value added and production of the individual sectors, but also the indirect and induced effects.

In order to determine the effects of the economic crisis on GHG emissions, a three-step approach is used:

1. first, the changes in CO_2 emissions (without LULUCF) are determined, which are calculated directly from the ALICE model
2. the next step is to determine the expected changes in emissions of the other gases (excluding LULUCF), and
3. finally, the GHG emissions (CO_2 + other gases) are reported as CO2e following the convention of the greenhouse gas inventory (without LULUCF).

The derivation of the results of the change in greenhouse gas emissions due to economic decline is presented step by step in the following paragraphs.

Table 3: Expected change in gross value added according to the WIFO forecast (GDP minus 5¼%) of June 2020 and effects on CO_2 emissions in percent compared to the previous year

	Benchmark	I-O Model Percent	Deviation in percentage points	Change in carbon dioxide emission
Agriculture, forestry and fisheries	-7,0	-6,9	0,1	-7,8
Manufacturing, including mining and quarrying	-13,0	-12,9	0,1	-12,9
Energy, water supply, waste disposal	-9,0	-9,3	-0,3	-11,3
Construction Industry	-4,5	-4,5	0,0	-4,5
Trade, Maintenance/ repair, Motor vehicles	-9,0	-9,0	0,0	-8,9
Traffic	-10,0	-10,0	0,0	-7,8
Accommodation and gastronomy	-24,5	-24,4	0,1	-24,4
Information and communication	0,0	-0,1	-0,1	4,8
Financial and insurance services	-0,4	-0,6	-0,2	-1,1
Real estate sector	-2,0	-2,1	-0,1	-2,1
Other economic services	-4,0	-4,3	-0,3	-4,6
Public administration	2,0	2,1	0,1	2,1
Other services	-15,0	-2,0	13,0	-4,5

Q: own calculations based on WIFO 2020

Table 3 shows the expected changes in CO_2 emissions of the sectors, which are consistent with the decline in value added in the individual sectors according to the June WIFO forecast (2020). A complete correspondence of the changes in value added in the ALICE model used with those of the WIFO forecast is not possible. One reason is that non-linear relationships were assumed in the forecast, which cannot be represented by the input-output model. There are therefore deviations whose size cannot be reduced at will.

In the results presented in Table 3, with one exception in the sector "other services", the deviation was limited to a maximum of 0.4 percentage points in order to come as close as possible to the economic forecast of the emission-intensive sectors. Deviations into the negative range are also limited, but not by a restriction, but by the simplex algorithm, which maximizes the target value, the aggregated value added of the sectors. One consequence of this is that the decline in the "other services" sector is 1.97% according to the input-output model and not 15% as forecast by WIFO (2020). These economic activities were not restricted because the associated emissions per unit of value added are comparatively low. The sector-specific change in carbon dioxide (CO_2) emissions due to the economic downturn is shown in the right-hand column of Table 3.

In addition to the sectoral view, it is important to keep an eye on the behaviour of individual companies. The company with the highest greenhouse gas emissions in Austria is Voestalpine AG. Currently, a technology is being used that makes GHG emissions associated with steel production unavoidable. In view of the given technology, there is a direct link between production and emissions. The share of iron and steel production in total emissions (excluding LULUCF) was 12% in 2018 (Umweltbundesamt, 2020a). Changes in production volume therefore have obvious consequences for total CO_2 emissions. Pig iron capacity at the Linz site was reduced by around 20% by temporarily shutting down a small blast furnace (Voestalpine, 2020). In the scenario analysis, it is assumed that operations will be resumed after a shutdown phase, resulting in the production change relevant to the sector as a whole.

The WIFO forecast does not show any results with regard to household behaviour, which is important for the assessment of greenhouse gas emissions. Important is the consumption of energy to provide room heating and cooling, the use of fuels in motor vehicle traffic and other energy use (e.g. gas for cooking). For the scenario calculation it was assumed that the other energy consumption of households will rise by 5%, since more cooking is done in the household and other energy consumption will also increase due to office activities in the household (cf. Bock-Schappelwein, 2020). The decline in motor vehicle traffic was assumed to be -15% over the year as a whole. The starting point is the observation that during the period of initial restrictions car traffic fell by 50% to 80% (Ungerböck, 2020). In the coming months, according to the assumptions made, private transport will not completely increase to the previous year's level. A big unknown is holiday traffic during the next months. If assumptions are correct, CO_2 emissions directly caused by households will decrease by almost 13.5% compared to the reference period.

Calculated across all sectors and taking into account household emissions, the expected reduction of GDP by 7% will results in a 11.0% decrease in CO_2 emissions in 2020.

Some activities of the Austrian economy that are GHG-relevant are hardly affected by the economic slump. These include the emissions associated with the management of farm manure and cattle stock and landfills. The relevant gas is methane. In the scenario analysis, it is therefore assumed that only the methane release associated with the energy demand of the economic sectors changes. Furthermore, it is assumed that emissions of the other greenhouse gases are not affected by the economic slowdown either, as explained below.

Regarding emissions from landfills, the assumption that emissions will not change is very likely to be correct. Fertiliser management is also unlikely to be directly affected by the economic crisis. Developments on the markets have an influence on the livestock population, but it is not clear whether this will affect methane emissions, and if so, in what direction. In the last decade, the cattle population has decreased by about 1% per year. Consequently, the trend would suggest a 1% reduction compared to 2019. On the other hand, since March there has been a significant reduction in slaughterings[13], so the number of animals has been increasing. A reduction is only possible if the processing capacity is available. Due to the long production cycles of one year, the cattle industry can therefore be expected to have a stable animal population in 2020, possibly even a slight increase. Given these uncertainties, it is assumed that methane emissions associated with agricultural production will not change either.

The sector-specific declines in production and changes in household consumption behaviour are the input parameters for the module of emission effects in the ALICE model. In this module, a distinction is made between emissions related to energy consumption and other emissions. Furthermore, the methods valid in the greenhouse gas inventory are used for the calculation of total GHG emission. For example, greenhouse gas emission caused by international air traffic crossing EU borders is not taken into account, and the burning of biomass is considered to be climate-neutral. Changes in land use and forestry are also not taken into account.

To assess the consequences of the decline in economic performance on emissions, it is necessary to focus on three aspects:

- All sectors that are relatively emission-intensive are affected by the economic crisis. Looking only at these sectors, one would expect greenhouse gas emissions to decrease more than 7% of the country's GDP. In fact, industry and freight transport have been hit hard and the reductions in emissions in these sectors are greater than the decrease in value added.
- However, sectors whose production hardly changes at all, at least in the short term during 2020, are also emitting GHGs, and as a consequence, emissions are expected to remain unchanged as in 2019. This applies in particular to the emission sources of methane (CH_4) and nitrous oxide (N_2O), I.e. agricultural activity. In some sectors there is an expansion of production as a result of the Covid 19 crisis (e.g. public administration services) and also in households not only reductions in emissions (fewer car journeys) can be observed, but also increases (higher energy consumption for cooking with gas) and also heating and cooling requirements will probably be higher due to quarantine.
- After taking into account the factors that increase or decrease greenhouse gas emissions and the transition of the change in greenhouse gas emissions into the calculation scheme of the greenhouse gas inventory, a decrease in greenhouse gas emissions in

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Austria of 9.9% is expected in 2020 compared to 2019 (see Table 4). This decline is due to the measures taken to prevent the spread of the virus and the resulting consequences in Austria and the other countries.

Table 4: The impact of the Covid 19 crisis on greenhouse gas emissions and their subcomponents according to the WIFO forecast of June 2020

Position of the greenhouse gas inventory	Δ in percent over the previous year
Total GHG without LULUCF measured as CO2e	-9.9
thereof energy and other sectors	-11.0
thereof agriculture	0.0
thereof solid waste	0.0

Q: Own calculations based on IPCC, 2020 and WIFO 2020 The delineation of the sectors corresponds to the greenhouse gas inventory for UNFCC (i.e. without LULUCF, without international aviation).

Table 4 shows the expected changes in GHG emissions in Austria in 2020 compared to 2019 due to the decline in GDP of 7% as forecast by WIFO in June 2020. Based on the model results and the assumptions made, the expected decrease in GHG emissions is calculated to be 9.9%.

The change in GHG emissions was calculated on the basis of changes in the value added of the sectors of the economy. Other influencing factors such as heating degree days (relevant for actual energy consumption) or forest growth (relevant for LULUCF) are excluded. Uncertainty exists at the time of analysis not only about the actual distribution of production impacts, but also about household behaviour, especially with regard to travel.

5. Outlook

In the present analysis, the example of WIFO's economic forecast for the year 2020 was used to show that the ALICE model is suitable for rapidly delivering results on environmental impacts on the basis of input data derived directly from the forecast and supplementary assumptions. Due to its model structure, ALICE is also suitable for determining the uncertainty of the results in the course of Monte Carlo analyses due to the uncertainty of the input parameters. Thus - as is usual for WIFO forecasts - the expectation range of the results can also be determined. For the present analysis this evaluation was not yet implemented.

The report shows that multi-level changes affecting several sectors and households can be analysed simultaneously. The model takes into account not only direct but also indirect and induced effects, i.e. the total impact, with interactions on other sectors and household income. It is therefore not only a tool that is suitable for making statements about the effects on greenhouse gas emissions, but can also be used to assess economic policy measures.

Already in its present form, the model ALICE is suitable for ranking measures for economic stabilization according to how well they affect the decision variables in the immediate or medium term: production, value added, CO_2 emission and greenhouse gas emissions. It should be noted, however, that the model is only an auxiliary tool that provides a quantitative basis for decisions. The model results must be supplemented with expert knowledge, since a model cannot take into account all interactions or the emergence of innovative, structure-changing technologies that are relevant to practical issues.

Model extensions are therefore necessary in order to quantify other variables relevant to economic policy. These include, above all, the effect on employment and on labour markets. A model that quantifies economic impacts and emissions at the regional level and uses the modules presented here can be a suitable starting point for this.

Another important area that is not yet implemented in the present model version concerns changes in technology and the resulting consequences for greenhouse gas emissions. With the current model version it is possible, for example, to quantify the effects directly associated with the construction of facilities for the electrification of railway lines. The long-term associated greenhouse gas savings result from changes in the technology of rail transport and its additional attractiveness for consumers. Such effects must currently be analysed with additional modules.

For more forward-looking analyses, a model type should be used that captures dynamic processes and more accurately represent household behaviour. The DYNK model provides the most important prerequisites for this and has already been applied in connection with several questions (see Sommer and Kratena, 2017; Sommer and Kratena, 2019; Kirchner et al., 2019; Sinabell and Kirchner, 2018; Sinabell et al., 2019). The ALICE model presented here fits into the structure of specialized models at WIFO, which focus on further aspects, e.g. the regional economy of Austria in the ASCANIO model (Streicher et al., 2017) or the world model ADAGIO (Kratena et al., 2017). The climate modules of these models are currently being further developed and updated.

In addition to the above-mentioned methodological improvements to the model, the updating of the databases must also be kept in mind. The delay of four years in the base table (from 2016) compared to the current period (2020) causes uncertainty, the extent of which cannot be accurately estimated. Facilitating access to timely data is therefore an essential step towards improving the informative value of the scenario calculations with the ALICE model.

As soon as the near-term forecast of Austria's emissions for 2019 is available (this will be published by the Umweltbundesamt end of July 2020), the available calculations should be updated in conjunction with the results of the September forecast by WIFO. In this way, the results of the simulation presented here can be continuously updated.

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ANNEX

Table 5: Key indicators of the physical energy flow accounts in TJ

	Primary energy sources taken from the environment1)	Domestic production of energy sources2)	Intermediate consumption of energy sources	Combustible waste, household waste, organic fraction and pellets+wood briquettes	(Gross) domestic consumption3)	Total energy input/output
NACE sectors Total	450,183	1,022,063	1,394,011	64,063	886,193	1,908,256
Agriculture, forestry and fisheries	129,963	129,747	21,833	0	22,050	151,796
Mining and quarrying	74,068	73,968	13,816	0	13,916	87,884
production of goods	49,996	484,621	888,545	36,608	490,528	975,149
Energy supply	191,388	333,727	237,154	27,431	122,246	455,973
Water supply, sewage and refuse disposal	32	0	6,686	0	6,718	6,718
Construction	4	0	19,884	24	19,912	19,912
Sale, maintenance and repair of motor vehicles	481	0	23,014	0	23,495	23,495
Transport and storage	664	0	103,702	0	104,366	104,366
Accommodation and gastronomy	314	0	12,342	0	12,656	12,656
Information and communication	126	0	3,747	0	3,873	3,873
Provision of financial and insurance services	83	0	3,849	0	3,933	3,933
Real estate and housing	20	0	5,178	0	5,198	5,198
Professional, scientific and technical activities	396	0	4,365	0	4,760	4,760
Provision of other economic services	248	0	5,601	0	5,849	5,849
Public administration, defence, social security	935	0	9,880	0	10,814	10,814
Education and teaching	871	0	9,335	0	10,206	10,206
Health and social services	28	0	16,035	0	16,063	16,063
Arts, entertainment and recreation	16	0	5,030	0	5,046	5,046
Provision of other services	548	0	4,017	0	4,565	4,565
Private households with domestic staff etc.	0	0	0	0	0	0
Extraterritorial organisations and bodies	0	0	0	0	0	0
Households Total energy use				0	395,250	395,250
Combustible waste production						64,063
Total	450,183	1,022,063	1,394,011	64,063	1,281,444	2,367,569

Q: Statistics Austria, 2020c.

Table 6a: Greenhouse gas inventory for Austria 1990 and 2018 - first part

	1990	2018	1990	2018
	CO2e in kt		CO2 in kt	
1. energy	52,815	54,693	51,176	53,482
A. Fuel combustion (sectoral approach)	52,114	54,323	51,073	53,355
1. energy industries	14,034	10,098	13,984	9,973
2. Manufacturing industries and construction	9,844	10,933	9,762	10,788
3. transport	13,976	24,426	13,777	24,142
4. other sectors	14,223	8,815	13,516	8,401
5. other	36	52	35	51
B. Fugitive emissions from fuels	702	370	102	127
1. solid fuels	333	NO,IE,NA	NO,IE,NA	NO,IE,NA
2. Oil and natural gas and other emissions from energy production	369	370	102	127
C. CO2 transport and storage	NO	NO	NO	NO
2. industrial processes	13,662	15,613	10,871	13,115
A. Mineral industry	3,092	2,908	3,092	2,908
B. Chemical industry	1,555	644	644	542
C. metal industry	8,177	9,529	6,786	9,524
D. Non-energy products from fuels and solvent use	349	142	349	142
E. Electronic industry	134	83		
F. Product uses as ODS substitutes	NO	1,830		
G. Other product manufacture and use	355	478	NO,NA	NO,NA
H. Other	NA	NA	NA	NA
3. agriculture	8,089	7,224	50	120
A. Enteric fermentation	4,821	4,118		
B. Manure management	980	986		
C. Rice cultivation	NO	NO		
D. Agricultural soils	2,237	1,999		
E. Prescribed burning of savannas	NO	NO		
F. Field burning of agricultural residues	2	1		
G. Liming	46	97	46	97
H. Urea application	4	24	4	24

Q: IPCC, 2020, Submission 2020 v2

Table 6b: Greenhouse gas inventory for Austria 1990 and 2018 - continued

	1990	2018	1990	2018
	CO_2e in kt		CO_2 in kt	
4. Land use, land-use change and forestry LULUCF	-11,988	-5,153	-12,157	-5,311
A. Forest land	-10,862	-4,280	-10,892	-4,306
B. Cropland	190	128	176	105
C. Grassland	650	314	626	291
D. Wetlands	42	66	42	66
E. Settlements	642	440	570	375
F. Other land	457	166	444	159
G. Harvested wood products	-3,122	-2,001	-3,122	-2,001
H. Other	NO	NO	NO	NO
5. Waste	3,926	1,420	28	2
A. Solid waste disposal	3,644	1,045	NO,NA	NO,NA
B. Biological treatment of solid waste	36	179		
C. Incineration and open burning of waste	28	2	28	2
D. Waste water treatment and discharge	219	194		
E. Other	NO	NO	NO	NO
Total CO_2 equivalent emissions without LULUCF = 1+2+3+5	78,493	78,950	62,125	66,720
Total CO_2 equivalent emissions with LULUCF = 1+2+3+5+4	66,504	73,798	49,968	61,408
Memo items:				
International bunkers	950	2,599	935	2,574
Aviation	896	2,551	886	2,530
Navigation	55	47	49	44
Multilateral operations	NO	NO	NO	NO
CO_2 emissions from biomass	10,403	22,656	10,403	22,656
CO_2 captured	NO	NO	NO	NO
Long-term storage of C in waste disposal sites	22,779	30,287	22,779	30,287
Indirect N2O	15	14	-	-

Q: IPCC, 2020, Submission 2020 v2