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Online at www.gcci.earth/global/gem

GEM-GLO Content and References

GEM-GHG Emissions Monitoring – Domain Gobal

Version GCCIv1.1 Information Sheet on the GEM-GLO Variables
Tabular List of Variables & SubVariables together with explanations and data source references

How-to-Read Template: **Format and content of the information per Variable in the Table below**

<table>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="10">VN.
Variable N
Name
[Unit]</td><td colspan="2">Explanation: brief explanation of what Variable N expresses and optionally (e.g., in case of an index variable in units [%]) how it is computed</td></tr>
<tr><td colspan="2"><DataSourceShortCite V<i>N</i> string> (as cited within the chart at the GCCI data portal)</td></tr>
<tr><td rowspan="2">SV<i>N</i>.1
SubVariable <i>N</i>.1
Name</td><td><DateSources SV<i>N</i>.1 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.1, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
<tr><td rowspan="2">SV<i>N</i>.2
SubVariable <i>N</i>.2
Name</td><td><DateSources SV<i>N</i>.2 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.2, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
<tr><td rowspan="2">SV<i>N</i>.3
SubVariable <i>N</i>.3
Name</td><td><DateSources SV<i>N</i>.3 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.3, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
<tr><td rowspan="2">SV<i>N</i>.4
SubVariable <i>N</i>.4
Name</td><td><DateSources SV<i>N</i>.4 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.4, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
</table>

GEM-GLO Information Sheet Table: GEM-GHG Emissions Monitoring – Domain Global

Variable (V) Name	SubVariable (SV) Name	Variable Explanation and Data Source References
V1. CO2-based climate change (CC) mitigation index [%]	***Explanation:*** This is one of the two primary index variables of GEM-GLO, the one based on annual CO_2 emissions of countries, relevant country groups, and globally since 1990. It indicates the success of emission reductions in any given year as a percentage against the annual-average 1990-1994 CO_2 emissions ("Em(Year *i*)" vs "AvgEm(1990-1994)"). The SubVariables include the main GCCI climate change mitigation index (SVs 1.1&1.2) as well as the production-based (SVs 1.3&1.5) and consumption-based (SVs 1.4&1.6) emission reduction indices, respectively, either up to the latest year with data (first SVs) or also including a reduction scenario to 2050 compliant with the Paris climate goals ("incl path2Paris" SVs). The scenarios are modeled for GCCIv1 according to a simple "linear reduction & residual floor emission path model" of Kirchengast (2021) following Williges et al. (2021) (except for SVs 1.2&1.5 for Austria as explained in GEM-AT). This model provides 2017-2050 paths consistent with the CO_2 budget allocated to a country or country group on an equal-per-person basis from a remaining 2017-2050 global CO_2 budget of 700 $GtCO_2$ with a residual-floor annual global emission of 3.5 $GtCO_2$/yr. ***Formula for the GCCI climate change mitigation index gauging emission reductions:*** *(based on the production-based emission data)* **Index(Year *i*) [%] = 100 x [Em(Year *i*) / AvgEm(1990-1994) – 1]** *Formula for the production- and consumption-based emission reduction indices:* Index(Year *i*) [%] = 100 x [Em(Year *i*) / AvgEm(1990-1994)] The main GCCI index hence expresses the level of reductions against 0 % near 1990. It indicates success for achieving percentage values below 0 % towards –100 % (climate neutrality) while it indicates failure by values that stick above 0 % or even increase. The complementary two indices rather gauge the changes against 100 % near 1990.	
	WEGC-GCCI 2021 & EEA-Eurst-GCP-EmDBs 2020	
	SV1.1 GCCI CC mitigation index|CO2 emission reduction (goal -100% vs 1990-94=0%)	WEGC-GCCI/Kirc-etal 2021 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see under "Explanation" above on the index computation)
	SV1.2 GCCI CC mitigation index|CO2 emission reduction incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO. DocID GCCIv1.1-GLO-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
	SV1.3 Production-based CO2 emission reduction index	WEGC-GCCI/Kirc-etal 2021 & GCP-GloCarbProj 2020 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see under "Explanation" above on the index computation)

<table>
<tr><td></td><td></td><td>– Friedlingstein et al. (2020). Global Carbon Budget 2020. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020</td></tr>
<tr><td></td><td>SV1.4
Consumption-based CO2 emission reduction index</td><td>WEGC-GCCI/Kirc-etal 2021 & GCP-GloCarbProj 2020
– Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO. DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see under "Explanation" above on the index computation)
– Friedlingstein et al. (2020). Global Carbon Budget 2020. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020</td></tr>
<tr><td></td><td>SV1.5
Production-based CO2 emission reduction index incl path2Paris</td><td>WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen)
– Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO. DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem
– Kirchengast (2021). Simple budget-based linear&floor emission reduction path modeling following Williges et al. (2021) Fairness critically conditions the carbon budget allocation across countries. Global Environ. Change in rev. (until online, available on request)</td></tr>
<tr><td></td><td>SV1.6
Consumption-based CO2 emission reduction index incl path2Paris</td><td>WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen)
– Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO. DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem
– Kirchengast (2021). Simple budget-based linear&floor emission reduction path modeling following Williges et al. (2021) Fairness critically conditions the carbon budget allocation across countries. Global Environ. Change in rev. (until online, available on request)</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">V2.
GHG-based climate change (CC) mitigation index
[%]</td><td colspan="2">Explanation: See the explanation at the beginning of the Variable V1 block above—the SubVariables of this Variable V2 are constructed in exactly the same way but based on the annual greenhouse gas (GHG) emissions of countries, relevant country groups, and globally since 1990 rather than on CO_2 emissions only.
The GHG emissions include all climate-relevant GHGs according to international accounting principles (also CH_4, N_2O, etc.) and are measured in Million tons of CO_2 equivalent [$MtCO_2eq$] (see under Variable V4 below). The scenarios to 2050 are in this case based on a remaining 2017-2050 global GHG budget of 1000 $GtCO_2eq$ with a residual-floor annual global emission of 5 $GtCO_2eq$/yr.</td></tr>
<tr><td colspan="2">WEGC-GCCI 2021 & UN&GCP EmDBs 2020</td></tr>
<tr><td>SV2.1
GCCI CC mitigation index|GHG emission reduction</td><td>WEGC-GCCI/Kirc-etal 2021
– Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO. DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see under "Explanation" above on the index computation)</td></tr>
</table>

	(goal -100% vs 1990-94=0%)	
	SV2.2 GCCI CC mitigation index|GHG emission reduction incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
	SV2.3 Production-based GHG emission reduction index	WEGC-GCCI/Kirc-etal 2021 & UN-EmissionsDB 2020 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see under "Explanation" above on the index computation) – United Nations Framework Convention on Climate Change (UNFCCC) (2020). *Greenhouse Gas Inventory Data*. Online at https://di.unfccc.int/time_series
	SV2.4 Consumption-based GHG emission reduction index	WEGC-GCCI/Kirc-etal 2021 & UN&GCP EmissionsDBs 2020 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see under "Explanation" above on the index computation) – United Nations Framework Convention on Climate Change (UNFCCC) (2020). *Greenhouse Gas Inventory Data*. Online at https://di.unfccc.int/time_series – Friedlingstein et al. (2020). Global Carbon Budget 2020. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020
	SV2.5 Production-based GHG emissions incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
	SV2.6 Consumption-based GHG emissions incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem

		– Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
V3. CO2 annual emissions [$MtCO_2$]	***Explanation:*** This is one of the two primary amount-of-emissions variables of GEM-GLO, the one based on annual CO_2 emissions of countries, relevant country groups, and globally since 1990 (except production-based CO_2 emissions being available from 1960). The SubVariables include production-based (SVs 3.1&3.3) and consumption-based (SVs 3.2&3.4) annual emissions measured in Million tons of CO_2 [$MtCO_2$], either up to the latest year with data (first SVs) or also including a reduction scenario to 2050 compliant with the Paris climate goals ("incl path2Paris" SVs). The scenarios are modeled for GCCIv1 according to a simple "linear reduction & residual floor emission path model" of Kirchengast (2021) following Williges et al. (2021) (except for SV3.3 for Austria as explained in GEM-AT). This model provides 2017-2050 paths consistent with the CO_2 budget allocated to a country or country group on an equal-per-person basis from a remaining 2017-2050 global CO_2 budget of 700 $GtCO_2$ with a residual-floor annual global emission of 3.5 $GtCO_2$/yr.	
	GCP-Global Carbon Project 2020 & WEGC 2021	
	SV3.1 Production-based CO2 emissions	GCP-Global Carbon Project 2020 / WEGCupd 2021 – Friedlingstein et al. (2020). *Global Carbon Budget 2020*. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020
	SV3.2 Consumption-based CO2 emissions	GCP-Global Carbon Project 2020 / WEGCupd 2021 – Friedlingstein et al. (2020). *Global Carbon Budget 2020*. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020
	SV3.3 Production-based CO2 emissions incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see also the reference under SubVariable SV3.1 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
	SV3.4 Consumption-based CO2 emissions incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see also the reference under SubVariable SV3.2 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)

<table>
<tr><td rowspan="7">V4.
GHG annual emissions [$MtCO_2eq$]</td><td colspan="2">Explanation: See the explanation at the beginning of the Variable V3 block above—the SubVariables of this Variable V4 are constructed in exactly the same way but based on the annual greenhouse gas (GHG) emissions of countries, relevant country groups, and globally since 1990 rather than on CO_2 emissions only. The GHG emissions include all climate-relevant GHGs according to international accounting principles (also CH_4, N_2O, etc.) and are measured in Million tons of CO_2 equivalent [$MtCO_2eq$]. The scenarios to 2050 are in this case based on a remaining 2017-2050 global GHG budget of 1000 $GtCO_2eq$ with a residual-floor annual global emission of 5 $GtCO_2eq$/yr.
Compared to Variable V3, one additional amount-of-emissions SubVariable is available here for GHGs for most countries: the production-based GHG emissions including from land use change, which means to also count in the annual net emissions from Land Use, Land Use Change, and Forestry (LULUCF). These are sometimes negative in case the LULUCF sector acts as net sink (SV4.2 emissions are then lower than those of SV4.1).</td></tr>
<tr><td colspan="2">UNFCCC & GCP EmissionsDBs & WEGC 2021</td></tr>
<tr><td>SV4.1
Production-based GHG emissions</td><td>UNFCCC EmissionsDB 2020 / WEGCupd 2021
– United Nations Framework Convention on Climate Change (UNFCCC) (2020). Greenhouse Gas Inventory Data. Online at https://di.unfccc.int/time_series</td></tr>
<tr><td>SV4.2
Production-based GHG emissions incl from Land use change</td><td>UNFCCC EmissionsDB 2020 / WEGCupd 2021
– United Nations Framework Convention on Climate Change (UNFCCC) (2020). Greenhouse Gas Inventory Data. Online at https://di.unfccc.int/time_series</td></tr>
<tr><td>SV4.3
Consumption-based GHG emissions</td><td>UNFCCC & GCP EmissionDBs 2020 / WEGCupd 2021
– United Nations Framework Convention on Climate Change (UNFCCC) (2020). Greenhouse Gas Inventory Data. Online at https://di.unfccc.int/time_series
– Friedlingstein et al. (2020). Global Carbon Budget 2020. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020</td></tr>
<tr><td>SV4.4
Production-based GHG emissions incl path2Paris</td><td>WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen)
– Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO. DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see also the reference under SubVariable SV4.1 above)
– Kirchengast (2021). Simple budget-based linear&floor emission reduction path modeling following Williges et al. (2021) Fairness critically conditions the carbon budget allocation across countries. Global Environ. Change in rev. (until online, available on request)</td></tr>
<tr><td>SV4.5
Consumption-based GHG emissions incl path2Paris</td><td>WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen)
– Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO. DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see also the references under SubVariable SV4.3 above)</td></tr>
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		– Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
V5. CO2 annual emissions per person [tCO_2/Person]	***Explanation:*** This is one of the two primary amount-of-emissions-per-person variables of GEM-GLO, the one based on annual CO_2 emissions of countries, relevant country groups, and globally since 1990 (except production-based CO_2 emissions per person available from 1960). The per-person data of this variable are derived from dividing the amount-of-emissions data of Variable V3 by the respective population size data (Variable V7 below). The SubVariables include production-based (SVs 5.1&5.3) and consumption-based (SVs 5.2&5.4) annual emissions per person measured in tons of CO_2 per person [tCO_2/Person], either up to the latest year with data (first SVs) or also including a reduction scenario to 2050 compliant with the Paris climate goals ("incl path2Paris" SVs). The relevant amount-of-emission scenarios are modeled for GCCIv1 according to a simple "linear reduction & residual floor emission path model" of Kirchengast (2021) following Williges et al. (2021) (except for SV5.3 for Austria as explained in GEM-AT). This model provides 2017-2050 paths consistent with the CO_2 budget allocated to a country or country group on an equal-per-person basis from a remaining 2017-2050 global CO_2 budget of 700 $GtCO_2$ with a residual-floor annual global emission of 3.5 $GtCO_2$/yr (i.e., same data as for Variable V3, just divided by the respective scenario-based population size data of Variable V7).	
	GCP-EmissionDB & UN-PopDB 2020 & WEGC 2021	
	SV5.1 Production-based CO2 emissions per Person	GCP-EmDB & UN-PopDB 2020 / WEGCupd 2021
		– Friedlingstein et al. (2020). *Global Carbon Budget 2020.* Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020 – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV5.2 Consumption-based CO2 emissions per Person	GCP-EmDB & UN-PopDB 2020 / WEGCupd 2021
		– Friedlingstein et al. (2020). *Global Carbon Budget 2020.* Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020 – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV5.3 Production-based CO2 emissions per Person incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen)
		Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see also the references under SubVariable SV5.1 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)

	SV5.4 Consumption-based CO2 emissions per Person incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see also the references under SubVariable SV5.2 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
V6. GHG annual emissions per person [tCO_2eq/Person]	***Explanation:*** See the explanation at the beginning of the Variable V5 block above—the SubVariables of this Variable V5 are constructed in exactly the same way but based on the annual greenhouse gas (GHG) emissions of countries, relevant country groups, and globally since 1990 rather than on CO_2 emissions only. The GHG emissions include all climate-relevant GHGs according to international accounting principles (also CH_4, N_2O, etc.) and are, on a per-person basis, measured in tons of CO_2 equivalent per person [tCO_2eq/Person]. The scenarios to 2050 are in this case based on a remaining 2017-2050 global GHG budget of 1000 $GtCO_2eq$ with a residual-floor annual global emission of 5 $GtCO_2eq$/yr. Compared to Variable V5, one additional amount-of-emissions-per-person SubVariable is available here for GHGs for most countries: the production-based GHG emissions per person including from land use change, which means to also count in the annual net emissions from Land Use, Land Use Change, and Forestry (LULUCF). These are negative in case the LULUCF sector acts as net sink (in which case the SV6.2 emissions are then lower than those of SV6.1).	
	UNFCCC&GCP-EmDBs & UN-PopDB 2020 & WEGC 2021	
	SV6.1 Production-based GHG emissions per Person	UNFCCC-EmDB & UN-PopDB 2020 / WEGCupd 2021 – United Nations Framework Convention on Climate Change (UNFCCC) (2020). *Greenhouse Gas Inventory Data*. Online at https://di.unfccc.int/time_series – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV6.2 Production-based GHG emissions per Person incl from Land use change	UNFCCC-EmDB & UN-PopDB 2020 / WEGCupd 2021 – United Nations Framework Convention on Climate Change (UNFCCC) (2020). *Greenhouse Gas Inventory Data*. Online at https://di.unfccc.int/time_series – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV6.3 Consumption-based GHG emissions per Person	UNFCCC&GCP-EmDBs & UN-PopDB 2020 / WEGCupd 2021 – United Nations Framework Convention on Climate Change (UNFCCC) (2020). *Greenhouse Gas Inventory Data*. Online at https://di.unfccc.int/time_series – Friedlingstein et al. (2020). *Global Carbon Budget 2020*. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020

		– United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV6.4 Production-based GHG emissions per Person incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see also the references under SubVariable SV6.1 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
	SV6.5 Consumption-based GHG emissions per Person incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-GLO.* DocID GCCIv1.1-GEM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/gem (see also the references under SubVariable SV6.3 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
V7. GHG annual concentrations [ppm]	***Explanation*:** This variable provides annual global greenhouse gas (GHG) concentrations in the atmosphere since 1960 in two forms: 1. CO_2-equivalent concentration (SV7.1), which is the concentration that CO_2 would have in the air if the total radiative forcing of all GHGs (incl. also CH_4, N_2O, etc.) would come from CO_2 only, and 2. the concentration of just CO_2, which is the main GHG that has contributed about 80 % of the radiative forcing increase since 1990 that drives global warming (see under CWM-GLO for a range of global warming-related variables, including radiative forcing). The units of parts per million [ppm], used for expressing concentrations of trace gases such as CO_2 in the air, denote the number of molecules of a trace gas per million of total air molecules. In Earth's atmosphere about 99 % of this total are made up by molecular nitrogen (N_2) and oxygen (O_2), termed the main constituents of the air.	
	NOAA 2020 & Meinetal 2017 & Etmietal 2016 & WEGC 2021	
	SV7.1 CO2-equivalent concentration (all GHGs)	NOAA 2020 & Meinsh-etal 2017 & Etmin-etal 2016 / WEGCupd 2021 – Meinshausen et al. (2017). *Historical greenhouse gas concentrations for climate modelling (CMIP6).* Geosci. Model Dev., 10, 2057-2116. Online at https://doi.org/10.5194/gmd-10-2057-2017 – Butler and Montzka-NOAA (2020). *The NOAA Annual Greenhouse Gas Index (AGGI)*. Online at https://gml.noaa.gov/aggi/aggi.html – Etminan et al. (2016). *Radiative forcing of carbon dioxide, methane, and nitrous oxide: A significant revision of the methane radiative forcing*. Geophys. Res. Lett., 43, 12,614–12,623. Online at https://doi.org/10.1002/2016GL071930
		NOAA 2020 & Meinsh-etal 2017 / WEGCupd 2021

	SV7.2 CO2 concentration (no other GHGs)	– Meinshausen et al. (2017). *Historical greenhouse gas concentrations for climate modelling (CMIP6).* Geosci. Model Dev., 10, 2057-2116. Online at https://doi.org/10.5194/gmd-10-2057-2017 – Butler and Montzka-NOAA (2020). *The NOAA Annual Greenhouse Gas Index (AGGI)*. Online at https://gml.noaa.gov/aggi/aggi.html
V8. Population size [No. of Persons]	***Explanation:*** This auxiliary variable of GEM-GLO provides the population size of countries, relevant country groups, and globally since 1960. It expresses on an annual basis the number of residents, counted as [No. of Persons], who live in countries, relevant country groups, and globally. While the annual population sizes up to the latest year with data (SV7.1) are based on population census data collected by the UN, the scenario data to 2050 (SV7.2) are drawn from the UN population dynamics database, using the "medium estimate" scenario. In this scenario the global population rises from about 7.7 to 9.7 billion over 2019 to 2050 while, for example, the European one slightly decreases from about 615 to 590 million residents.	
	UN PopulationDB 2020 & WEGCupd 2021	
	SV8.1 Past-to-present population size	UN PopDB 2020 / WEGCupd 2021 – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV8.2 Scenario-based population size	UN PopDB 2020 / WEGCupd 2021 – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/

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Online at www.gcci.earth/europe/gem

GEM-EUR Content and References

GEM-GHG Emissions Monitoring – Domain Europe

Version GCCIv1.1 Information Sheet on the GEM-EUR Variables
Tabular List of Variables & SubVariables together with explanations and data source references

How-to-Read Template: **Format and content of the information per Variable in the Table below**

<table>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="10">VN.
Variable N
Name
[Unit]</td><td colspan="2">Explanation: brief explanation of what Variable N expresses and optionally (e.g., in case of an index variable in units [%]) how it is computed</td></tr>
<tr><td colspan="2"><DataSourceShortCite V<i>N</i> string> (as cited within the chart at the GCCI data portal)</td></tr>
<tr><td rowspan="2">SV<i>N</i>.1
SubVariable <i>N</i>.1
Name</td><td><DateSources SV<i>N</i>.1 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.1, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
<tr><td rowspan="2">SV<i>N</i>.2
SubVariable <i>N</i>.2
Name</td><td><DateSources SV<i>N</i>.2 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.2, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
<tr><td rowspan="2">SV<i>N</i>.3
SubVariable <i>N</i>.3
Name</td><td><DateSources SV<i>N</i>.3 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.3, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
<tr><td rowspan="2">SV<i>N</i>.4
SubVariable <i>N</i>.4
Name</td><td><DateSources SV<i>N</i>.4 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.4, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
</table>

GEM-EUR Information Sheet Table: GEM-GHG Emissions Monitoring – Domain Europe

Variable (V) Name	SubVariable (SV) Name	Variable Explanation and Data Source References
V1. CO2-based climate change (CC) mitigation index [%]	***Explanation:*** This is one of the two primary index variables of GEM-EUR, the one based on annual CO_2 emissions of Europe, its countries, and the EU since 1990. It indicates the success of emission reductions in any given year as a percentage against the annual-average 1990-1994 CO_2 emissions ("Em(Year *i*)" vs "AvgEm(1990-1994)"). The SubVariables include the main GCCI climate change mitigation index (SVs 1.1&1.2) as well as the production-based (SVs 1.3&1.5) and consumption-based (SVs 1.4&1.6) emission reduction indices, respectively, either up to the latest year with data (first SVs) or also including a reduction scenario to 2050 compliant with the Paris climate goals ("incl path2Paris" SVs). The scenarios are modeled for GCCIv1 according to a simple "linear reduction & residual floor emission path model" of Kirchengast (2021) following Williges et al. (2021) (except for SVs 1.2&1.5 for Austria as explained in GEM-AT). This model provides 2017-2050 paths consistent with the CO_2 budget allocated to a country (or country group) on an equal-per-person basis from a remaining 2017-2050 global CO_2 budget of 700 $GtCO_2$ with a residual-floor annual global emission of 3.5 $GtCO_2$/yr. ***Formula for the GCCI climate change mitigation index gauging emission reductions:*** *(based on the production-based emission data)* **Index(Year *i*) [%] = 100 x [Em(Year *i*) / AvgEm(1990-1994) – 1]** *Formula for the production- and consumption-based emission reduction indices:* Index(Year *i*) [%] = 100 x [Em(Year *i*) / AvgEm(1990-1994)] The main GCCI index hence expresses the level of reductions against 0 % near 1990. It indicates success for achieving percentage values below 0 % towards –100 % (climate neutrality) while it indicates failure by values that stick above 0 % or even increase. The complementary two indices rather gauge the changes against 100 % near 1990.	
	WEGC-GCCI 2021 & EEA-Eurst-GCP-EmDBs 2020	
	SV1.1 GCCI CC mitigation index|CO2 emission reduction (goal -100% vs 1990-94=0%)	WEGC-GCCI/Kirc-etal 2021 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see under "Explanation" above on the index computation)
	SV1.2 GCCI CC mitigation index|CO2 emission reduction incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR. DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
	SV1.3 Production-based CO2 emission reduction index	WEGC-GCCI/Kirc-etal 2021 & GCP-GloCarbProj 2020 (also EEA-Eurst) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see under "Explanation" above on the index computation)

		– Friedlingstein et al. (2020). Global Carbon Budget 2020. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020
	SV1.4 Consumption-based CO2 emission reduction index	WEGC-GCCI/Kirc-etal 2021 & GCP-GloCarbProj 2020 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see under "Explanation" above on the index computation) – Friedlingstein et al. (2020). Global Carbon Budget 2020. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020
	SV1.5 Production-based CO2 emission reduction index incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
	SV1.6 Consumption-based CO2 emission reduction index incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
V2. GHG-based climate change (CC) mitigation index [%]	***Explanation:*** See the explanation at the beginning of the Variable V1 block above—the SubVariables of this Variable V2 are constructed in exactly the same way but based on the annual greenhouse gas (GHG) emissions of Europe, its countries, and the EU since 1990 rather than on CO_2 emissions only. The GHG emissions include all climate-relevant GHGs according to international accounting principles (also CH_4, N_2O, etc.) and are measured in Million tons of CO_2 equivalent [$MtCO_2eq$] (see under Variable V4 below). The scenarios to 2050 are in this case based on a remaining 2017-2050 global GHG budget of 1000 $GtCO_2eq$ with a residual-floor annual global emission of 5 $GtCO_2eq/yr$.	
	WEGC-GCCI 2021 & EEA-Eurost-GCP EmDBs 2020	
	SV2.1 GCCI CC mitigation index|GHG emission reduction	WEGC-GCCI/Kirc-etal 2021 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see under "Explanation" above on the index computation)

	(goal -100% vs 1990-94=0%)	
	SV2.2 GCCI CC mitigation index|GHG emission reduction incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
	SV2.3 Production-based GHG emission reduction index	WEGC-GCCI/Kirc-etal 2021 & EEA-Eurostat EmissionsDB 2020 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see under “Explanation” above on the index computation) – European Environment Agency (EEA) (2020). *Greenhouse gas emissions by source sector*. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en
	SV2.4 Consumption-based GHG emission reduction index	WEGC-GCCI/Kirc-etal 2021 & EEA-Eurostat & GCP EmDB 2020 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see under “Explanation” above on the index computation) – European Environment Agency (EEA) (2020). *Greenhouse gas emissions by source sector*. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en – Friedlingstein et al. (2020). Global Carbon Budget 2020. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020
	SV2.5 Production-based GHG emissions incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
		WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen)

	SV2.6 Consumption-based GHG emissions incl path2Paris	– Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
V3. CO2 annual emissions [$MtCO_2$]	***Explanation:*** This is one of the two primary amount-of-emissions variables of GEM-EUR, the one based on annual CO_2 emissions of Europe, its countries, and the EU since 1990 (except production-based CO_2 emissions being available from 1960). The SubVariables include production-based (SVs 3.1&3.3) and consumption-based (SVs 3.2&3.4) annual emissions measured in Million tons of CO_2 [$MtCO_2$], either up to the latest year with data (first SVs) or also including a reduction scenario to 2050 compliant with the Paris climate goals ("incl path2Paris" SVs). The scenarios are modeled for GCCIv1 according to a simple "linear reduction & residual floor emission path model" of Kirchengast (2021) following Williges et al. (2021) (except for SV3.3 for Austria as explained in GEM-AT). This model provides 2017-2050 paths consistent with the CO_2 budget allocated to a country (or country group) on an equal-per-person basis from a remaining 2017-2050 global CO_2 budget of 700 $GtCO_2$ with a residual-floor annual global emission of 3.5 $GtCO_2$/yr.	
	GCP-GlobCarbProj & WEGC Kircetal 2021	
	SV3.1 Production-based CO2 emissions	GCP-Global Carbon Project 2020 / WEGCupd 2021 – Friedlingstein et al. (2020). *Global Carbon Budget 2020.* Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020
	SV3.2 Consumption-based CO2 emissions	GCP-Global Carbon Project 2020 / WEGCupd 2021 – Friedlingstein et al. (2020). *Global Carbon Budget 2020.* Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020
	SV3.3 Production-based CO2 emissions incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see also the reference under SubVariable SV3.1 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
	SV3.4 Consumption-based CO2 emissions incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see also the reference under SubVariable SV3.2 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness*

		critically conditions the carbon budget allocation across countries. Global Environ. Change in rev. (until online, available on request)
V4. GHG annual emissions [$MtCO_2eq$]	**_Explanation:_** See the explanation at the beginning of the Variable V3 block above—the SubVariables of this Variable V4 are constructed in exactly the same way but based on the annual greenhouse gas (GHG) emissions of Europe, its countries, and the EU since 1990 rather than on CO_2 emissions only. The GHG emissions include all climate-relevant GHGs according to international accounting principles (also CH_4, N_2O, etc.) and are measured in Million tons of CO_2 equivalent [$MtCO_2eq$]. The scenarios to 2050 are in this case based on a remaining 2017-2050 global GHG budget of 1000 $GtCO_2eq$ with a residual-floor annual global emission of 5 $GtCO_2eq$/yr. Compared to Variable V3, one additional amount-of-emissions SubVariable is available here for GHGs for most countries: the production-based GHG emissions including from land use change, which means to also count in the annual net emissions from Land Use, Land Use Change, and Forestry (LULUCF). These are sometimes negative in case the LULUCF sector acts as net sink (SV4.2 emissions are then lower than those of SV4.1).	
	EEA-Eurostat-GCP EmDBs & WEGC Kircetal 2021	
	SV4.1 Production-based GHG emissions	EEA-Eurostat EmissionsDB 2020 / WEGCupd 2021 – European Environment Agency (EEA) (2020). *Greenhouse gas emissions by source sector*. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en
	SV4.2 Production-based GHG emissions incl from Land use change	EEA-Eurostat EmissionsDB 2020 / WEGCupd 2021 – European Environment Agency (EEA) (2020). *Greenhouse gas emissions by source sector*. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en
	SV4.3 Consumption-based GHG emissions	EEA-Eurostat & GCP EmissionDBs 2020 / WEGCupd 2021 – European Environment Agency (EEA) (2020). *Greenhouse gas emissions by source sector*. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en – Friedlingstein et al. (2020). *Global Carbon Budget 2020*. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020
	SV4.4 Production-based GHG emissions incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see also the reference under SubVariable SV4.1 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)

<table>
<tr><td></td><td>SV4.5
Consumption-based GHG emissions incl path2Paris</td><td>WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen)

– Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR. DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see also the references under SubVariable SV4.3 above)
– Kirchengast (2021). Simple budget-based linear&floor emission reduction path modeling following Williges et al. (2021) Fairness critically conditions the carbon budget allocation across countries. Global Environ. Change in rev. (until online, available on request)</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="4">V5.
CO2 annual emissions per person [tCO_2/Person]</td><td colspan="2">Explanation: This is one of the two primary amount-of-emissions-per-person variables of GEM-EUR, the one based on annual CO_2 emissions of Europe, its countries, and the EU since 1990 (except production-based CO_2 emissions per person available from 1960). The per-person data of this variable are derived from dividing the amount-of-emissions data of Variable V3 by the respective population size data (Variable V7 below).
The SubVariables include production-based (SVs 5.1&5.3) and consumption-based (SVs 5.2&5.4) annual emissions per person measured in tons of CO_2 per person [tCO_2/Person], either up to the latest year with data (first SVs) or also including a reduction scenario to 2050 compliant with the Paris climate goals (“incl path2Paris” SVs). The relevant amount-of-emission scenarios are modeled for GCCIv1 according to a simple “linear reduction & residual floor emission path model” of Kirchengast (2021) following Williges et al. (2021) (except for SV5.3 for Austria as explained in GEM-AT). This model provides 2017-2050 paths consistent with the CO_2 budget allocated to a country (or country group) on an equal-per-person basis from a remaining 2017-2050 global CO_2 budget of 700 $GtCO_2$ with a residual-floor annual global emission of 3.5 $GtCO_2$/yr (i.e., same data as for Variable V3, just divided by the respective scenario-based population size data of Variable V7).</td></tr>
<tr><td colspan="2">GCP-Eur-UN EmDB & PopDB & WEGC Kircetal 2021</td></tr>
<tr><td>SV5.1
Production-based CO2 emissions per Person</td><td>GCP-EmDB & Eurostat-UN-PDB 2020 / WEGCupd 2021

– Friedlingstein et al. (2020). Global Carbon Budget 2020. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020
– European Environment Agency (EEA) (2020). Demographic change - Demographic balance and crude rates at national level. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_gind&lang=de
– United Nations (UN) (2020). Population Dynamics. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/</td></tr>
<tr><td>SV5.2
Consumption-based CO2 emissions per Person</td><td>GCP-EmDB & Eurostat-UN-PDB 2020 / WEGCupd 2021

– Friedlingstein et al. (2020). Global Carbon Budget 2020. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020
European Environment Agency (EEA) (2020). Demographic change - Demographic balance and crude rates at national level. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_gind&lang=de</td></tr>
</table>

		– United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV5.3 Production-based CO2 emissions per Person incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen)
		Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see also the references under SubVariable SV5.1 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
	SV5.4 Consumption-based CO2 emissions per Person incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen)
		– Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see also the references under SubVariable SV5.2 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
V6. GHG annual emissions per person [tCO_2eq/Person]	***Explanation:*** See the explanation at the beginning of the Variable V5 block above—the SubVariables of this Variable V5 are constructed in exactly the same way but based on the annual greenhouse gas (GHG) emissions of Europe, its countries, and the EU since 1990 rather than on CO_2 emissions only. The GHG emissions include all climate-relevant GHGs according to international accounting principles (also CH_4, N_2O, etc.) and are, on a per-person basis, measured in tons of CO_2 equivalent per person [tCO_2eq/Person]. The scenarios to 2050 are in this case based on a remaining 2017-2050 global GHG budget of 1000 $GtCO_2eq$ with a residual-floor annual global emission of 5 $GtCO_2eq$/yr. Compared to Variable V5, one additional amount-of-emissions-per-person SubVariable is available here for GHGs for most countries: the production-based GHG emissions per person including from land use change, which means to also count in the annual net emissions from Land Use, Land Use Change, and Forestry (LULUCF). These are negative in case the LULUCF sector acts as net sink (in which case the SV6.2 emissions are then lower than those of SV6.1).	
	EEA-EU-UN- GCP EmDB&PopDB 2020 & WEGC Kircetal 2021	
	SV6.1 Production-based GHG emissions per Person	EEA-Eurostat-UN EmDB & PopDB 2020 / WEGCupd 2021
		– European Environment Agency (EEA) – Emissions (2020). *Greenhouse gas emissions by source sector*. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en – European Environment Agency (EEA) – Demographics (2020). *Demographic change - Demographic balance and crude rates at national level*. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_gind&lang=de

		– United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV6.2 Production-based GHG emissions per Person incl from Land use change	EEA-Eurostat-UN EmDB & PopDB 2020 / WEGCupd 2021
		– European Environment Agency (EEA) – Emissions (2020). *Greenhouse gas emissions by source sector*. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en – European Environment Agency (EEA) – Demographics (2020). *Demographic change - Demographic balance and crude rates at national level*. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_gind&lang=de – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV6.3 Consumption-based GHG emissions per Person	EEA-Eurostat-UN-GCP EmDB & PopDB 2020 / WEGCupd 2021
		– European Environment Agency (EEA) – Emissions (2020). *Greenhouse gas emissions by source sector*. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en – Friedlingstein et al. (2020). *Global Carbon Budget 2020*. Earth Syst. Sci. Data, 12, 3269–3340, 2020. Online at https://doi.org/10.5194/essd-12-3269-2020 – European Environment Agency (EEA) – Demographics (2020). *Demographic change - Demographic balance and crude rates at national level*. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_gind&lang=de – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV6.4 Production-based GHG emissions per Person incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen)
		– Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR*. DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see also the references under SubVariable SV6.1 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
	SV6.5 Consumption-based GHG emissions per	WEGC/Kirc-etal 2021 (incl GCCIv1 EPClin&floor-scen)
		– Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-EUR.* DocID GCCIv1.1-GEM-EUR-Jun2021, Wegener Center,

<table>
<tr><td></td><td>Person incl path2Paris</td><td>Univ. of Graz, Austria. Online at www.gcci.earth/europe/gem (see also the references under SubVariable SV6.3 above)
– Kirchengast (2021). Simple budget-based linear&floor emission reduction path modeling following Williges et al. (2021) Fairness critically conditions the carbon budget allocation across countries. Global Environ. Change in rev. (until online, available on request)</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="6">V7.
Population size [No. of Persons]</td><td colspan="2">Explanation: This auxiliary variable of GEM-EUR provides the population size of Europe, its countries, and the EU since 1960. It expresses on an annual basis the number of residents, counted as [No. of Persons], who live in Europe, its countries, and the EU. While the annual population sizes up to the latest year with data (SV7.1) are based on population census data collected by the EEA and UN, the scenario data to 2050 (SV7.2) are drawn from the UN population dynamics database, using the “medium estimate” scenario. In this scenario the global population rises from about 7.7 to 9.7 billion over 2019 to 2050 while the European one slightly decreases from about 615 to 590 million residents (and within Europe the EU-27 from about 445 to 425 million people).</td></tr>
<tr><td colspan="2">Eurostat & UN PopDBs 2020 & WEGCupd 2021</td></tr>
<tr><td rowspan="2">SV7.1
Past-to-present population size</td><td>Eurostat & UN PopDB 2020 / WEGCupd 2021</td></tr>
<tr><td>– European Environment Agency (EEA) (2020). Demographic change - Demographic balance and crude rates at national level. European Statistical Office (Eurostat). Online at https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=demo_gind&lang=de
– United Nations (UN) (2020). Population Dynamics. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/</td></tr>
<tr><td rowspan="2">SV7.2
Scenario-based population size</td><td>UN PopDB 2020 / WEGCupd 2021</td></tr>
<tr><td>– United Nations (UN) (2020). Population Dynamics. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/</td></tr>
<tr><td colspan="3"></td></tr>
</table>

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Online at www.gcci.earth/austria/gem

GEM-AT Content and References

GEM-GHG Emissions Monitoring – Domain Austria

Version GCCIv1.1 Information Sheet on the GEM-AT Variables
Tabular List of Variables & SubVariables together with explanations and data source references

How-to-Read Template: **Format and content of the information per Variable in the Table below**

V*N*. Variable *N* Name [Unit]	***Explanation:*** brief explanation of what Variable *N* expresses and optionally (e.g., in case of an index variable in units [%]) how it is computed	
	<DataSourceShortCite V*N* string> (as cited within the chart at the GCCI data portal)	
	SV*N*.1 SubVariable *N*.1 Name	<DateSources SV*N*.1 string> (from GCCIv1 SV definitions file)
		Reference(s) to the data source(s) for SV*N*.1, incl DOIs, Weblinks, etc, as available (one or more detailed references)
	SV*N*.2 SubVariable *N*.2 Name	<DateSources SV*N*.2 string> (from GCCIv1 SV definitions file)
		Reference(s) to the data source(s) for SV*N*.2, incl DOIs, Weblinks, etc, as available (one or more detailed references)
	SV*N*.3 SubVariable *N*.3 Name	<DateSources SV*N*.3 string> (from GCCIv1 SV definitions file)
		Reference(s) to the data source(s) for SV*N*.3, incl DOIs, Weblinks, etc, as available (one or more detailed references)
	SV*N*.4 SubVariable *N*.4 Name	<DateSources SV*N*.4 string> (from GCCIv1 SV definitions file)
		Reference(s) to the data source(s) for SV*N*.4, incl DOIs, Weblinks, etc, as available (one or more detailed references)

GEM-AT Information Sheet Table: GEM-GHG Emissions Monitoring – Domain Austria

Variable (V) Name	SubVariable (SV) Name	Variable Explanation and Data Source References
V1. CO2-based climate change (CC) mitigation index [%]	***Explanation:*** This is one of the two primary index variables of GEM-AT, the one based on annual CO_2 emissions of Austria and its nine states since 1990. It indicates the success of emission reductions in any given year as a percentage against the annual-average 1990-1994 CO_2 emissions ("Em(Year *i*)" vs "AvgEm(1990-1994)"). The SubVariables include the main GCCI climate change mitigation index (SVs 1.1&1.2) as well as the production-based (SVs 1.3&1.5) and consumption-based (SVs 1.4&1.6) emission reduction indices, respectively, either up to the latest year with data (first SVs) or also including a reduction scenario to 2050 compliant with the Paris climate goals ("incl path2Paris" SVs). The scenario path data are after Kirchengast and Steininger (2020) at country level (except for SV1.6 for which the path is modeled as explained in GEM-EUR) and scaled for the state level paths in proportion to the state's emission shares of the country-total emissions in year 2019. ***Formula for the GCCI climate change mitigation index gauging emission reductions:*** *(based on the production-based emission data)* **Index(Year *i*) [%] = 100 x [Em(Year *i*) / AvgEm(1990-1994) – 1]** *Formula for the production- and consumption-based emission reduction indices:* Index(Year *i*) [%] = 100 x [Em(Year *i*) / AvgEm(1990-1994)] The main GCCI index hence expresses the level of reductions against 0 % near 1990. It indicates success for achieving percentage values below 0 % towards –100 % (climate neutrality) while it indicates failure by values that stick above 0 % or even increase. The complementary two indices rather gauge the changes against 100 % near 1990.	
	WEGC-GCCI 2021 & GCP-EmDB 2020 & UBA-EmDB 2021	
	SV1.1 GCCI CC mitigation index|CO2 emission reduction (goal -100% vs 1990-94=0%)	WEGC-GCCI/Kirc-etal 2021 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see under "Explanation" above on the index computation)
	SV1.2 GCCI CC mitigation index|CO2 emission reduction incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCI v1 ATwide&StateEPC-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem – Kirchengast and Steininger (2020). *Treibhausgasbudget für Österreich auf dem Weg zur Klimaneutralität 2040 (in German).* Wegener Center Statement 9.10.2020, Online at www.wegcenter.at/downloads/2020
	SV1.3 Production-based CO2 emission reduction index	WEGC-GCCI/Kirc-etal 2021 & UBA-EmDB 2021 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see under "Explanation" above on the index computation)

<table>
<tr><td></td><td></td><td>– Environment Agency Austria (Umweltbundesamt-UBA) (2021). Austria's National Inventory Report 2021. Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte</td></tr>
<tr><td></td><td rowspan="2">SV1.4
Consumption-based CO2 emission reduction index</td><td>WEGC-GCCI/Kirc-etal 2021 & UBA-EmDB 2021 & GCP-EmDB 2020</td></tr>
<tr><td></td><td>– Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT. DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see under "Explanation" above on the index computation)
– Environment Agency Austria (Umweltbundesamt-UBA) (2021). Austria's National Inventory Report 2021. Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte
– Friedlingstein et al. (2020). Global Carbon Budget 2020. Earth Syst. Sci. Data, 12, 3269–3340. Online at https://doi.org/10.5194/essd-12-3269-2020</td></tr>
<tr><td></td><td rowspan="2">SV1.5
Production-based CO2 emission reduction index incl path2Paris</td><td>WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 ATwide&StateEPC-scen)</td></tr>
<tr><td></td><td>– Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT. DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem
– Kirchengast and Steininger (2020). Treibhausgasbudget für Österreich auf dem Weg zur Klimaneutralität 2040 (in German). Wegener Center Statement 9.10.2020, Online at www.wegcenter.at/downloads/2020</td></tr>
<tr><td></td><td rowspan="2">SV1.6
Consumption-based CO2 emission reduction index incl path2Paris</td><td>WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 ATwide&StateEPC-scen)</td></tr>
<tr><td></td><td>– Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT. DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem
– Kirchengast (2021). Simple budget-based linear&floor emission reduction path modeling following Williges et al. (2021) Fairness critically conditions the carbon budget allocation across countries. Global Environ. Change in rev. (until online, available on request)</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="4">V2.
GHG-based climate change (CC) mitigation index
[%]</td><td colspan="2">Explanation: See the explanation at the beginning of the Variable V1 block above—the SubVariables of this Variable V2 are constructed in exactly the same way but based on the annual greenhouse gas (GHG) emissions of Austria and its nine states since 1990 rather than on the CO_2 emissions only. The GHG emissions include all climate-relevant GHGs according to international accounting principles (also CH_4, N_2O, etc.) and are measured in Million tons of CO_2 equivalent [$MtCO_2eq$] (see under Variable V4 below).</td></tr>
<tr><td colspan="2">WEGC-GCCI 2021 & UBA-AT EmDB & WEGC-EC 2020</td></tr>
<tr><td rowspan="2">SV2.1
GCCI CC mitigation index|GHG</td><td>WEGC-GCCI/Kirc-etal 2021</td></tr>
<tr><td>– Kirchengast and Kohlfürst (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet</td></tr>
</table>

	emission reduction (goal -100% vs 1990-94=0%)	*GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see under “Explanation” above on the index computation)
	SV2.2 GCCI CC mitigation index|GHG emission reduction incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 ATwide&StateEPC-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem – Kirchengast and Steininger (2020). *Treibhausgasbudget für Österreich auf dem Weg zur Klimaneutralität 2040 (in German).* Wegener Center Statement 9.10.2020, Online at www.wegcenter.at/downloads/2020
	SV2.3 Production-based GHG emission reduction index	WEGC-GCCI/Kirc-etal 2021 & UBA-AT EmDB 2020 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see under “Explanation” above on the index computation) – Environment Agency Austria (Umweltbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte
	SV2.4 Consumption-based GHG emission reduction index	WEGC-GCCI/Kirc-etal 2021 & UBA-AT EmDB 2021 & WEGC-EC 2020 – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see under “Explanation” above on the index computation) – Environment Agency Austria (Umweltbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte – Nabernegg and Steininger-EconClim (2020). Austria's consumption-based emissions updated from Steininger et al. (2018) *Austria's consumption-based greenhouse gas emissions.* Global Environ. Change, 48, 226-242. Online at https://doi.org/10.1016/j.gloenvcha.2017.11.011
	SV2.5 Production-based GHG emissions incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 ATwide&StateEPC-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem – Kirchengast and Steininger (2020). *Treibhausgasbudget für Österreich auf dem Weg zur Klimaneutralität 2040 (in German).* Wegener Center Statement 9.10.2020. Online at www.wegcenter.at/downloads/2020

	SV2.6 Consumption-based GHG emissions incl path2Paris	WEGC-GCCI/Kirc-etal 2021 (incl GCCIv1 ATwide&StateEPC-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
V3. CO2 annual emissions [$MtCO_2$]	***Explanation:*** This is one of the two primary amount-of-emissions variables of GEM-AT, the one based on annual CO_2 emissions of Austria and its nine states since 1990 (except country-total production-based CO_2 emissions being available from 1960). The SubVariables include production-based (SVs 3.1&3.3) and consumption-based (SVs 3.2&3.4) annual emissions measured in Million tons of CO_2 [$MtCO_2$], either up to the latest year with data (first SVs) or also including a reduction scenario to 2050 compliant with the Paris climate goals ("incl path2Paris" SVs). The scenario path data are after Kirchengast and Steininger (2020) at country level (except for SV3.4 for which the path is modeled as explained in GEM-EUR) and scaled for the state level paths in proportion to the state's emission shares of the country-total emissions in year 2019.	
	GCP-GlobCarbProj & UBA-AT EmDB & WEGC 2021	
	SV3.1 Production-based CO2 emissions	UBA-AT EmDB 2021 / WEGCupd 2021 – Environment Agency Austria (Umweltbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte
	SV3.2 Consumption-based CO2 emissions	UBA-AT EmDB 2021 & GCP-EmDB 2020 / WEGCupd 2021 – Environment Agency Austria (Umweltbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte – Friedlingstein et al. (2020). *Global Carbon Budget 2020.* Earth Syst. Sci. Data, 12, 3269–3340. Online at https://doi.org/10.5194/essd-12-3269-2020
	SV3.3 Production-based CO2 emissions incl path2Paris	WEGC/Kirc-etal 2021 (inclGCCIv1 ATwide&StateEPC-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see also the reference under SubVariable SV3.1 above) – Kirchengast and Steininger (2020). *Treibhausgasbudget für Österreich auf dem Weg zur Klimaneutralität 2040 (in German).* Wegener Center Statement 9.10.2020. Online at www.wegcenter.at/downloads/2020
		WEGC/Kirc-etal 2021 (incl GCCIv1 ATwide&StateEPC-scen)

	SV3.4 Consumption-based CO2 emissions incl path2Paris	– Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see also the references under SubVariable SV3.2 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
V4. GHG annual emissions [$MtCO_2eq$]	***Explanation:*** See the explanation at the beginning of the Variable V3 block above—the SubVariables of this Variable V4 are constructed in exactly the same way but based on the annual greenhouse gas (GHG) emissions of Austria and its nine states since 1990 rather than on the CO_2 emissions only. The GHG emissions include all climate-relevant GHGs according to international accounting principles (also CH_4, N_2O, etc.) and are measured in Million tons of CO_2 equivalent [$MtCO_2eq$]. Compared to Variable V3, one additional amount-of-emissions SubVariable is available here for GHGs: the production-based GHG emissions including from land use change, which means to also count in the annual net emissions from Land Use, Land Use Change, and Forestry (LULUCF). These are negative in case the LULUCF sector acts as net sink, which is the case for Austria (i.e., SV4.2 emissions lower than those of SV4.1).	
	UBA-AT EmissionsDB & WEGC 2021	
	SV4.1 Production-based GHG emissions	UBA-AT EmDB 2020 / WEGCupd 2021 – Environment Agency Austria (Umweltbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte
	SV4.2 Production-based GHG emissions incl from Land use change	UBA-AT EmDB 2020 / WEGCupd 2021 – Environment Agency Austria (Umweltbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte
	SV4.3 Consumption-based GHG emissions	UBA-AT EmDB & WEGC-EconClim 2020 / WEGCupd 2021 – Environment Agency Austria (Umweltbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte – Nabernegg and Steininger-EconClim (2020). Austria's consumption-based emissions updated from Steininger et al. (2018) *Austria's consumption-based greenhouse gas emissions.* Global Environ. Change, 48, 226-242. Online at https://doi.org/10.1016/j.gloenvcha.2017.11.011
	SV4.4 Production-based GHG emissions incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCI v1 ATwide&StateEPC-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem

		(see also the reference under SubVariable SV4.1 above) – Kirchengast and Steininger (2020). *Treibhausgasbudget für Österreich auf dem Weg zur Klimaneutralität 2040 (in German).* Wegener Center Statement 9.10.2020. Online at www.wegcenter.at/downloads/2020
	SV4.5 Consumption-based GHG emissions incl path2Paris	WEGC/Kirc-etal 2021 (incl GCCI v1 ATwide&StateEPC-scen)
		– Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see also the references under SubVariable SV4.3 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request)
V5. CO2 annual emissions per person [tCO_2/Person]	***Explanation:*** This is one of the two primary amount-of-emissions-per-person variables of GEM-AT, the one based on annual CO_2 emissions of Austria and its nine states since 1990 (except country-total production-based CO_2 emissions per person being available from 1960). The per-person data of this variable are derived from dividing the amount-of-emissions data of Variable V3 by the respective population size data of Austria and its nine states (Variable V7 below). The SubVariables include production-based (SVs 5.1&5.3) and consumption-based (SVs 5.2&5.4) annual emissions per person measured in tons of CO_2 per person [tCO_2/Person], either up to the latest year with data (first SVs) or also including a reduction scenario to 2050 compliant with the Paris climate goals ("incl path2Paris" SVs). The relevant amount-of-emission scenario path data are after Kirchengast and Steininger (2020) at country level (except for SV5.4 for which the path is modeled as explained in GEM-EUR) and scaled for the state level paths in proportion to the state's emission shares of the country-total emissions in year 2019 (i.e., same data as for Variable V3, just divided by the respective scenario-based population size data of Variable V7).	
	UBA/GCP-EmDBs & STA/UN-PopDBs 2020 & WEGC 2021	
	SV5.1 Production-based CO2 emissions per Person	UBA-AT EmDB 2021 & STATA-AT PopDB 2020 / WEGCupd 2021
		– Environment Agency Austria (Umweltbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte – Statistics Austria (2020). *Total Population 1.1.2021.* Online at https://www.statistik.at/web_en/statistics/PeopleSociety/population/index.html
	SV5.2 Consumption-based CO2 emissions per Person	UBA-AT/GCP EmDBs & STATA-AT PopDB 2020 / WEGCupd 2021
		– Environment Agency Austria (Umweltbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte – Friedlingstein et al. (2020). *Global Carbon Budget 2020.* Earth Syst. Sci. Data, 12, 3269–3340. Online at

		– https://doi.org/10.5194/essd-12-3269-2020 – Statistics Austria (2020). *Total Population 1.1.2021.* Online at https://www.statistik.at/web_en/statistics/PeopleSociety/population/index.html
	SV5.3 Production-based CO2 emissions per Person incl path2Paris	WEGC/Kirc-etal 2021 & UN PopDB (incl GCCIv1 ATw&StateEPC-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see also the references under SubVariable SV5.1 above) – Kirchengast and Steininger (2020). *Treibhausgasbudget für Österreich auf dem Weg zur Klimaneutralität 2040 (in German).* Wegener Center Statement 9.10.2020. Online at www.wegcenter.at/downloads/2020 – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV5.4 Consumption-based CO2 emissions per Person incl path2Paris	WEGC/Kirc-etal 2021 & UN PopDB (incl GCCIv1 ATw&StateEPC-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see also the references under SubVariable SV5.2 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness critically conditions the carbon budget allocation across countries.* Global Environ. Change in rev. (until online, available on request) – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
V6. GHG annual emissions per person [tCO_2eq/Person]	***Explanation:*** See the explanation at the beginning of the Variable V5 block above—the SubVariables of this Variable V5 are constructed in exactly the same way but based on the annual greenhouse gas (GHG) emissions of Austria and its nine states since 1990 rather than on the CO_2 emissions only. The GHG emissions include all climate-relevant GHGs according to international accounting principles (also CH_4, N_2O, etc.) and are, on a per-person basis, measured in tons of CO_2 equivalent per person [tCO_2eq/Person]. Compared to Variable V5, one additional amount-of-emissions-per-person SubVariable is available here for GHGs: the production-based GHG emissions per person including from land use change, which means to also count in the annual net emissions from Land Use, Land Use Change, and Forestry (LULUCF). These are negative in case the LULUCF sector acts as net sink, which is the case for Austria (i.e., SV6.2 emissions per person lower than those of SV6.1).	
	UBA-AT EmDB & STA/UN-PopDBs & WEGC 2021	
	SV6.1 Production-based GHG	UBA-AT EmDB & STATA-PopDB 2020 / WEGCupd 2021 – Environment Agency Austria (Umweltbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the

	emissions per Person	Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte – Statistics Austria (2020). *Total Population 1.1.2021.* Online at https://www.statistik.at/web_en/statistics/PeopleSociety/population/index.html
	SV6.2 Production-based GHG emissions per Person incl from Land use change	UBA-AT EmDB & STATA-PopDB 2020 / WEGCupd 2021 – Environment Agency Austria (Umwelbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte – Statistics Austria (2020). *Total Population 1.1.2021.* Online at https://www.statistik.at/web_en/statistics/PeopleSociety/population/index.html
	SV6.3 Consumption-based GHG emissions per Person	UBA-AT EmDB & STATA-PopDB & WEGC-EC 2020 / WEGCupd 2021 – Environment Agency Austria (Umwelbundesamt-UBA) (2021). *Austria's National Inventory Report 2021.* Reports on the Austrian Air Pollution Inventory (OLI). Online at https://www.umweltbundesamt.at/emiberichte – Statistics Austria (2020). *Total Population 1.1.2021.* Online at https://www.statistik.at/web_en/statistics/PeopleSociety/population/index.html – Nabernegg and Steininger-EconClim (2020). Austria's consumption-based emissions updated from Steininger et al. (2018) *Austria's consumption-based greenhouse gas emissions.* Global Environ. Change, 48, 226-242. Online at https://doi.org/10.1016/j.gloenvcha.2017.11.011
	SV6.4 Production-based GHG emissions per Person incl path2Paris	WEGC/Kirc-etal 2021 & UN-PopDB (incl GCCIv1 ATw&StateEPC-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see also the references under SubVariable SV6.1 above) – Kirchengast and Steininger (2020). *Treibhausgasbudget für Österreich auf dem Weg zur Klimaneutralität 2040 (in German).* Wegener Center Statement 9.10.2020. Online at www.wegcenter.at/downloads/2020 – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV6.5 Consumption-based GHG emissions per Person incl path2Paris	WEGC/Kirc-etal 2021 & UN-PopDB (incl GCCIv1 ATw&StateEPC-scen) – Kirchengast and Kohlfürst (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet GEM-AT.* DocID GCCIv1.1-GEM-AT-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/austria/gem (see also the references under SubVariable SV6.3 above) – Kirchengast (2021). *Simple budget-based linear&floor emission reduction path modeling* following Williges et al. (2021) *Fairness*

		critically conditions the carbon budget allocation across countries. Global Environ. Change in rev. (until online, available on request) – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
V7. Population size [No. of Persons]	***Explanation:*** This auxiliary variable of GEM-AT provides the population size of Austria and its nine states since 1960. It expresses on an annual basis the number of residents, counted as [No. of Persons], who live in the Austria and its states, respectively. While the annual population sizes up to the latest year with data (SV7.1) are based on regular population census data available from Statistics Austria and UN, the scenario-based data out to 2050 (SV7.2) are drawn from the UN population dynamics database, using the “medium estimate” scenario. In this scenario the global population rises from about 7.7 to 9.7 billion over 2019 to 2050 while the Austrian one increases marginally from about 8.9 to 9.1 million residents.	
	STAT-AT & UN PopDBs 2020 & WEGCupd 2021	
	SV7.1 Past-to-present population size	STATA PopDB & UN PopDB 2020 / WEGCupd 2021
		– Statistics Austria (2020). *Total Population 1.1.2021.* Online at https://www.statistik.at/web_en/statistics/PeopleSociety/population/index.html – United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/
	SV7.2 Scenario-based population size	UN PopDB 2020 / WEGCupd 2021
		– United Nations (UN) (2020). *Population Dynamics*. Department of Economic and Social Affairs. Online at https://population.un.org/wpp/Download/Standard/Population/

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Online at www.gcci.earth/global/cwm

CWM-GLO Content and References

CWM-Climate Warming Monitoring – Domain Global

Version GCCIv1.1 Information Sheet on the CWM-GLO Variables
Tabular List of Variables & SubVariables together with brief explanations and data source references

How-to-Read Template: **Format and content of the information per Variable in the Table below**

<table>
<tr><th colspan="3"></th></tr>
<tr><td rowspan="10">VN
Variable N
Name
[Unit]</td><td colspan="2">Explanation: brief explanation of what Variable N expresses and optionally (e.g., in case of an index variable in units [%]) how it is computed</td></tr>
<tr><td colspan="2"><DataSourceShortCite VN string> (as cited within the chart at the GCCI data portal)</td></tr>
<tr><td rowspan="2">SV<i>N</i>.1
SubVariable <i>N</i>.1
Name</td><td><DateSources SV<i>N</i>.1 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.1, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
<tr><td rowspan="2">SVN.2
SubVariable N.2
Name</td><td><DateSources SVN.2 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.2, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
<tr><td rowspan="2">SVN.3
SubVariable N.3
Name</td><td><DateSources SVN.3 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.3, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
<tr><td rowspan="2">SVN.4
SubVariable N.4
Name</td><td><DateSources SVN.4 string> (from GCCIv1 SV definitions file)</td></tr>
<tr><td>Reference(s) to the data source(s) for SVN.4, incl DOIs, Weblinks, etc, as available (one or more detailed references)</td></tr>
</table>

CWM-GLO Information Sheet Table: CWM-Climate Warming Monitoring – Domain Global

Variable (V) Name	SubVariable (SV) Name	Variable Explanation and Data Source References
V1. AHC-based global warming index [%]		***Explanation:*** This is one of the two primary index variables of CWM-GLO, the one based on global Atmospheric Heat Content (AHC) increase rates since around 1990. This increase is mainly due to anthropogenic global warming caused by the continued emission of CO_2 and other greenhouse gases (GHGs) as shown in GEM-GLO for the global emissions and countries worldwide. For a brief physical explanation of why and how this global warming unfolds see, for example, Kirchengast et al. (2021b), Section 2.1 therein (cited under SV1.1 below). The index indicates, as a percentage against the average 1980-2000 AHC decadal increase rate, how the decadal increase rate of heat energy in the atmosphere in any given center year has changed since around 1990 ("Rate(CtrYear *i*)" vs "AvgRate(1980-2000)"). The "decadal increase rate" of any center year is computed as decadally smoothed (center year ± 5 years)-linearfit to the annual observations of AHC gain since 1960 (shown as SubVariable SV4.6 of Variable V4). The SubVariables include the GCCI global warming index (SV1.1) as well as, just as a reference and for informing on the absolute reference value, the 100 %-baseline average AHC increase over 1980-2000 that amounted to 0.496 ZJ/decade (SV2.2) (1 ZJ = 10^{21} J = 1 trillion gigajoules of energy; for comparison, the world's total annual energy consumption is about 0.6 ZJ). ***Formula for the GCCI global warming index gauging atmospheric heat energy increase:*** *(based on the AHC decadal increase rate data shown in Variable V2)* **Index(CtrYear *i*) [%] = 100 x [Rate(CtrYear *i*) / AvgRate(1980-2000)]** The index hence expresses how strongly the AHC increase rate changed against 100 % around 1990. It indicates strong heat accumulation due to global warming if percentages raise high above 100 %, like in the most recent decade (center year 2015) where about 500 % indicate a five-fold increase (to 2.5 ZJ/decade), while values within 100±200 % may occur from natural variability. *Related advance info:* GCCIv1 does not yet optionally include AHC increase predictions to 2030 and projections to 2050; these are under development and will be included in follow-on versions. Furthermore, natural inter-annual to decadal AHC variations from atmosphere-ocean variability beyond El Niño Southern Oscillation (ENSO) that we currently subtract, especially from the Pacific Decadal Oscillation (PDO) and Indian Ocean Dipole (IOD), will be subtracted as well in future, further improving the index focus on tracking long-term anthropogenic warming.
	WEGC Kircetal & ERA5-JRA55-MERRA2-RADSrc 2021	
	SV1.1 GCCI global warming index|Atmospheric Heat Content (AHC) increase	WEGC-GCCI/Kircetal 2021 (bgr data WEGC CWM-DB & ERA-JRA-MERRA)
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the index computation) – Kirchengast et al. (2021b). *Carbon Management: A new approach to achieve Paris-compliant climate goals.* WEGC Research Briefs 1-2021, Wegener Center Verlag, Univ. of Graz, Austria. Online at https://doi.org/10.25364/23.2021.1 (Section 2.1 at https://unipub.uni-graz.at/obvugrveroeff/content/pageview/6047842)
	SV1.2 AHC global warming index Avg1980-2000 (100%=0.496 ZJ/decade)	WEGC-GCCI/Kircetal 2021 (bgr data WEGC CWM-DB & ERA-JRA-MERRA)
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the index computation)

<table>
<tr>
<td rowspan="4">V2.
Atmospheric Heat Content (AHC) increase [ZJ/decade]</td>
<td colspan="2">Explanation: This Variable V2 is the basis for the index variable V1 of CWM-GLO; it indicates the global Atmospheric Heat Content (AHC) increase since the 1960s. This increase is mainly due to anthropogenic global warming caused by the continued emission of CO_2 and other greenhouse gases (GHGs) as shown in GEM-GLO for the global emissions and countries worldwide. For a brief physical explanation of why and how this global warming unfolds see Kirchengast et al. (2021b), Section 2.1 therein; more details are available via Kirchengast et al. (2021c) (both cited below).
The SubVariable included is the AHC decadal increase rate since center year 1965 (SV2.1). This "decadal increase rate" is computed for any given center year as decadally smoothed (center year ± 5 years)-linearfit to the annual observations of AHC gain since 1960 (shown as SubVariable SV4.6 of Variable V4). The rates are shown in units [ZJ/decade] (1 ZJ = 10^{21} J = 1 trillion gigajoules of energy; for comparison, the world's total annual energy consumption is about 0.6 ZJ). They reach from values within 0.5±1 ZJ/decade in the early decades (mainly natural variability) to about 2.5 ZJ/decade in the most recent decade (center year 2015, i.e., applying to 2010-2020), which is a strong imprint of the recent anthropogenic global warming.
Related advance info: GCCIv1 does not yet optionally include AHC increase predictions to 2030 and projections to 2050; these are under development and will be included in follow-on versions. Furthermore, natural inter-annual to decadal AHC variations from atmosphere-ocean variability beyond El Niño Southern Oscillation (ENSO) that we currently subtract, especially from the Pacific Decadal Oscillation (PDO) and Indian Ocean Dipole (IOD), will be subtracted as well in future, further improving the focus of the variable to monitor long-term anthropogenic warming.</td>
</tr>
<tr>
<td colspan="2">WEGC Kircetal & ERA5-JRA55-MERRA2-RADSrc 2021</td>
</tr>
<tr>
<td rowspan="2">SV2.1
Atmospheric Heat Content (AHC) increase rate (decadal)</td>
<td>WEGC/Kircetal 2021 (bgr data WEGC CWM-DB & ERA-JRA-MERRA)</td>
</tr>
<tr>
<td>– Kirchengast et al. (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO. DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm
(see under "Explanation" above on the variables' computation)

– Kirchengast et al. (2021b). Carbon Management: A new approach to achieve Paris-compliant climate goals. WEGC Research Briefs 1-2021, Wegener Center Verlag, Univ. of Graz, Austria. Online at https://doi.org/10.25364/23.2021.1 (Section 2.1 at https://unipub.uni-graz.at/obvugrveroeff/content/pageview/6047842)

– Kirchengast et al. (2021c). Section 3 on AHC in von Schuckmann et al. (2020) Heat stored in the Earth system: where does the energy go?. Earth Syst. Sci. Data, 12, 2013-2041 (online at https://essd.copernicus.org/articles/12/2013/2020/#section3) and Kirchengast et al. (2019-2021) Climate trends and variability in Atmospheric Heat Content and atmosphere-ocean heat exchanges etc. IUGG 2019 Conf. Invited Pres. Montreal CA (online https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/#!sessiondetails/0000119801_0), ICGPSRO 2020 Conf. Invited Pres. Hsinchu TW, Manuscript in prep. 2021 (online link added after publication)</td>
</tr>
<tr>
<td colspan="3"></td>
</tr>
<tr>
<td>V3.
EEI-based climate change index [%]</td>
<td colspan="2">Explanation: This is the second of the two primary index variables of CWM-GLO, the one based on global Earth Energy Imbalance (EEI) increase and the related Effective Radiative Forcing (ERF) and Radiative Response Estimate (RRE) increases since around 1990. The EEI and its increase, linked to a still widening gap between the ERF and (lagging) RRE increases, occur mainly due to the ongoing anthropogenic climate change caused by the continued emission of CO_2 and other greenhouse gases (GHGs) as shown in GEM-GLO for the global emissions and countries worldwide. For a brief physical explanation of the fundamental significance of the EEI related to climate forcing (ERF) and climate response (RRE), and how global warming and climate change do consequently unfold, see Kirchengast et al. (2021b), Section 2.1 therein; more details are available via von Schuckmann et al. (2020) (both cited below).</td>
</tr>
</table>

	The SubVariables include the main GCCI climate change index based on the EEI increase (SV3.1) as well as the related ERF-based climate forcing index (SV3.2) and RRE-based climate response index (SV3.3), respectively. The main GCCI index indicates, as a percentage against the average 1988-1992 EEI decadal rates, how the decadal increase rate of energy uptake in the Earth system in any given center year has changed since around 1990 ("Rate(CtrYear *i*)" vs "AvgRate(1988-1992)"). The "decadal increase rate" of any center year is computed as five-year-smoothed (center year ± 5 years)-linearfit to the annual observations of total Earth energy uptake since 1960 (shown as SubVariable SV4.1 of Variable V4). Likewise the climate forcing and response indices are computed in the same way as percentage changes since around 1990 ("Value(CtrYear *i*)" vs "AvgValue(1988-1992)"), using the respective decadal-mean ERF and RRE datasets of Variable V11, which also contains the EEI decadal-rate dataset used. ***Formula for the GCCI climate change index gauging climate change strength via EEI increase:*** *(based on the EEI decadal increase rate data of SV11.1 of Variable V11)* **Index(CtrYear *i*) [%] = 100 x [Rate(CtrYear *i*) / AvgRate(1988-1992)]** *Formula for the ERF-based climate forcing and RRE-based climate response indices:* *(based on the ERF and RRE data of SV11.2 and SV11.3 of Variable V11)* Index(CtrYear *i*) [%] = 100 x [Value(CtrYear *i*) / AvgValue(1988-1992)] The main GCCI index hence expresses in what way the EEI changed against 100 % around 1990. It indicates strong ongoing climate change if percentages are persistently higher than 100 %, like in the last two decades higher than 150 % (more than 11 ZJ/year, or 0.7 Wm^{-2} on a per-square-meter basis, in absolute energy uptake; for comparison, the world's total annual energy consumption is currently 0.6 ZJ/year). Conversely, if the index would decrease within the next decades to below 100 % (about 0.45 Wm^{-2}), and then further to below 50 %, this would prove that the EEI is shrinking again and hence global warming slowing down, thanks to the success of Paris-compliant global emission reductions (see Kirchengast et al., 2021b; Section 2 therein). *Related advance info:* GCCIv1 does not yet optionally include EEI change predictions to 2030 and projections to 2050; these are under development and will be included in follow-on versions. Furthermore, natural inter-annual to decadal EEI variations from atmosphere-ocean variability beyond El Niño Southern Oscillation (ENSO) that we currently subtract, especially from the Pacific Decadal Oscillation (PDO) and Indian Ocean Dipole (IOD), will be subtracted as well in future, further improving the index focus on tracking anthropogenic climate change.	
	WEGC Kircetal & NOAA-NASA-ECMWF&MiscSciSrc 2021	
	SV3.1 GCCI climate change index | Earth Energy Imbalance (EEI) increase	WEGC Kircetal 2021 & vSchucketal 2020 & MiscSciSrc – Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation; and see also the further references under Variable 11/SV11.1 below that contains the data underlying this index) – Kirchengast et al. (2021b). *Carbon Management: A new approach to achieve Paris-compliant climate goals.* WEGC Research Briefs 1-2021, Wegener Center Verlag, Univ. of Graz, Austria. Online at https://doi.org/10.25364/23.2021.1 (Section 2 at https://unipub.uni-graz.at/obvugrveroeff/content/pageview/6047842) – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020
	SV3.2 Effective Radiative Forcing-based	WEGC Kircetal 2021 & NOAA & MiscSciSrc – Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.*

	climate forcing index	DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation; and see also the further references under Variable 11/SV11.2 below that contains the data underlying this index)
	SV3.3 Radiative Response Estimate-based climate response index	WEGC Kircetal 2021 & NASA-ECMWF & MiscSciSrc – Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation; and see also the further references under Variable 11/SV11.3 below that contains the data underlying this index)
V4. Earth energy uptake since 1960 [ZJ]	***Explanation:*** This Variable is the Earth energy uptake variable of CWM-GLO, the one that shows how much energy the Earth system and its main components have accumulated over time since 1960 (in units [ZJ]; 1 ZJ = 10^{21} J = 1 trillion gigajoules; for an impression of size, the world's total annual energy consumption is currently about 0.6 ZJ). This long-term energy uptake over the recent decades occurs mainly due to the ongoing anthropogenic global warming caused by the continued emission of CO_2 and other greenhouse gases (GHGs) as shown in GEM-GLO for the global emissions and countries worldwide. For a brief physical explanation of the significance of Earth's energy uptake and the associated Earth energy imbalance (EEI), and how global warming and climate change do consequently unfold, see Kirchengast et al. (2021b), Section 2.1 therein; more details are available via von Schuckmann et al. (2020) (both cited below). The SubVariables include the total global Earth energy uptake (SV4.1) as well as its contributing heat energy gain and energy uptake components from five main subsystems of the Earth system: ocean below uppermost layer (SV4.2), uppermost ocean (SV4.3), land (SV4.4), cryosphere (SV4.5), and atmosphere (SV4.6). All are provided annually as accumulated gain or uptake since around 1960 (i.e., vs. 1958-1962 average or 1960-1964 average, depending on data availability). The total energy uptake since 1960 was below 50 ZJ before 1990 but then strongly increased to values of about 300 to 430 ZJ in the most recent decade, a growth of around 13 ZJ/year (see also variable V5 below, which expresses the increase rate of this accumulated uptake). Comparing this to the world's total annual energy consumption of currently 0.6 ZJ/year, this recent increase was more than 20 times as large, mainly driven by the ongoing global warming. The accumulation will gradually start to stop only if global warming starts slowing down thanks to the success of Paris-compliant global emission reductions (see Kirchengast et al., 2021b; Section 2 therein).	
	WEGC Kircetal 2021 & vSchucketal 2020 & MiscSciSrc	
	SV4.1 Earth energy uptake (total Earth system) (vsAvg1960)	WEGC Kircetal & CWM-DB 2021 & MiscDatSrc – Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation and see also the further references under SV4.2 to SV4.6 below) – Kirchengast et al. (2021c). *Section 3 on AHC in* von Schuckmann et al. (2020) *Heat stored in the Earth system: where does the energy go?.* Earth Syst. Sci. Data, 12, 2013-2041 (online at https://essd.copernicus.org/articles/12/2013/2020/#section3) and Kirchengast et al. (2019-2021) *Climate trends and variability in Atmospheric Heat Content and atmosphere-ocean heat exchanges etc.* IUGG 2019 Conf. Invited Pres. Montreal CA (online https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/#!sessiondetails/

		0000119801_0), ICGPSRO 2020 Conf. Invited Pres. Hsinchu TW, Manuscript in prep. 2021 (online link added after publication) – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020
	SV4.2 Ocean heat content gain below UMOHC (depth>300m) (vsAvg1960)	WEGC Kircetal 2021 & vSchucketal 2020 & IAP-ORAS5
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020 – Cheng et al. (2021). *Upper ocean temperatures hit record high in 2020.* Adv. Atmos. Sci., 38, 523-530. Online at https://doi.org/10.1007/s00376-021-0447-x – Zuo et al. (2019). *The ECMWF operational ensemble reanalysis-analysis system for ocean and sea ice: a description of the system and assessment*. Ocean Sci., 15, 779-808. Online at https://doi.org/10.5194/os-15-779-2019
	SV4.3 Uppermost Ocean Heat Content (UMOHC) gain (depth 0-300m) (vsAvg1960)	WEGC Kircetal 2021 & vSchucketal 2020 & IAP-ORAS5
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Kirchengast et al. (2021c). *Section 3 on AHC in* von Schuckmann et al. (2020) *Heat stored in the Earth system: where does the energy go?.* Earth Syst. Sci. Data, 12, 2013-2041 (online at https://essd.copernicus.org/articles/12/2013/2020/#section3) and Kirchengast et al. (2019-2021) *Climate trends and variability in Atmospheric Heat Content and atmosphere-ocean heat exchanges etc.* IUGG 2019 Conf. Invited Pres. Montreal CA (online https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/#!sessiondetails/0000119801_0), ICGPSRO 2020 Conf. Invited Pres. Hsinchu TW, Manuscript in prep. 2021 (online link added after publication) – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020 – Cheng et al. (2021). *Upper ocean temperatures hit record high in 2020.* Adv. Atmos. Sci., 38, 523-530. Online at https://doi.org/10.1007/s00376-021-0447-x – Zuo et al. (2019). *The ECMWF operational ensemble reanalysis-analysis system for ocean and sea ice: a description of the system and assessment*. Ocean Sci., 15, 779-808. Online at https://doi.org/10.5194/os-15-779-2019
		vSchucketal 2020 / WEGCupd 2021

	SV4.4 Land heat content gain (vsAvg1960)	– von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020
	SV4.5 Cryospheric energy uptake (vsAvg1960)	vSchucketal 2020 / WEGCupd 2021 – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020
	SV4.6 Atmospheric Heat Content (AHC) gain (vsAvg1960)	WEGC Kircetal & CWM-DB 2021 & ERA-JRA-MERRA – Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Kirchengast et al. (2021c). *Section 3 on AHC in* von Schuckmann et al. (2020) *Heat stored in the Earth system: where does the energy go?.* Earth Syst. Sci. Data, 12, 2013-2041 (online at https://essd.copernicus.org/articles/12/2013/2020/#section3) and Kirchengast et al. (2019-2021) *Climate trends and variability in Atmospheric Heat Content and atmosphere-ocean heat exchanges etc.* IUGG 2019 Conf. Invited Pres. Montreal CA (online https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/#!sessiondetails/0000119801_0), ICGPSRO 2020 Conf. Invited Pres. Hsinchu TW, Manuscript in prep. 2021 (online link added after publication) – Gelaro et al. (2017). *The Modern-Era Retrospective Analysis for research and applications, Version 2 (MERRA-2).* J. Clim., 30, 5419-5454. Online at https://doi.org/10.1175/jcli-d-16-0758.1 – Hersbach et al. (2020). *The ERA5 global reanalysis.* Q. J. Royal Met. Soc., 146, 1999-2049. Online at https://doi.org/10.1002/qj.3803 – Japan Meteorological Agency (2013). *JRA-55: Japanese 55-year reanalysis, monthly means and variance.* Online at https://doi.org/10.5065/D60G3H5B
V5. Earth Energy Imbalance (EEI) [ZJ/year]	***Explanation:*** This is one of the two Earth Energy Imbalance (EEI) variables of CWM-GLO, the one that provides the global EEI over time since the 1960s in units [ZJ/year] ((1 ZJ = 10^{21} J = 1 trillion gigajoules of energy; for comparison, the world's total annual energy consumption is currently about 0.6 ZJ). The EEI and its increase, linked to a still widening gap between climate forcing and response (see the Explanations under Variables V4 and V11), occur mainly due to the ongoing anthropogenic climate change caused by the continued emission of CO_2 and other greenhouse gases (GHGs) as shown in GEM-GLO for the global emissions and countries worldwide. For a brief physical explanation of the fundamental significance of the EEI related to climate forcing and response, and how global warming and climate change do consequently unfold, see Kirchengast et al. (2021b), Section 2.1 therein; more details are available via von Schuckmann et al. (2020) (both cited below). The SubVariables include the total global EEI (SV3.1) as well as its contributing heat energy increase and energy uptake components from five main subsystems of the Earth system: ocean below uppermost layer (SV3.2), uppermost ocean (SV3.3), land (SV3.4), cryosphere (SV3.5), and atmosphere (SV3.6). All are provided as a decadal increase rate, which for any center year since 1965 (representing 1960-1970) is computed as five-year-smoothed (center year ± 5 years)-linearfit to the respective annual observations of energy uptake or gain since 1960 (provided as the six SubVariables of Variable V4 above). The total EEI increased from values below 7 ZJ/year before 1990 to values of about 12 to 15	

	ZJ/year in the most recent two decades. Comparing this to the world's total annual energy consumption of currently 0.6 ZJ/year, the recent EEI was more than 20 times as large, mainly driven by the ongoing global warming and climate change. It will safely shrink again only if global warming starts slowing down thanks to the success of Paris-compliant global emission reductions (see Kirchengast et al., 2021b; Section 2 therein). *Related advance info:* GCCIv1 does not yet optionally include change predictions to 2030 and projections to 2050 of EEI and its five main components; these are under development and will be included in follow-on versions. Furthermore, natural inter-annual to decadal variations in EEI and its oceanic and atmospheric components from atmosphere-ocean variability beyond El Niño Southern Oscillation (ENSO) that we currently subtract, especially from the Pacific Decadal Oscillation (PDO) and Indian Ocean Dipole (IOD), will be subtracted as well in future, further improving the indication of long-term anthropogenic climate change.	
	WEGC Kircetal 2021 & vSchucketal 2020 & MiscSciSrc	
	SV5.1 Earth Energy Imbalance (EEI) (total rate of increase)	WEGC Kircetal & CWM-DB 2021 & MiscDatSrc
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation and see also the further references under SV5.2 to SV5.6 below) – Kirchengast et al. (2021c). *Section 3 on AHC in* von Schuckmann et al. (2020) *Heat stored in the Earth system: where does the energy go?.* Earth Syst. Sci. Data, 12, 2013-2041 (online at https://essd.copernicus.org/articles/12/2013/2020/#section3) and Kirchengast et al. (2019-2021) *Climate trends and variability in Atmospheric Heat Content and atmosphere-ocean heat exchanges etc.* IUGG 2019 Conf. Invited Pres. Montreal CA (online https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/#!sessiondetails/0000119801_0), ICGPSRO 2020 Conf. Invited Pres. Hsinchu TW, Manuscript in prep. 2021 (online link added after publication) – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020
	SV5.2 Ocean heat content increase rate below UMOHC (depth>300m)	WEGC Kircetal 2021 & vSchucketal 2020 & IAP-ORAS5
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020 – Cheng et al. (2021). *Upper ocean temperatures hit record high in 2020.* Adv. Atmos. Sci., 38, 523-530. Online at https://doi.org/10.1007/s00376-021-0447-x – Zuo et al. (2019). *The ECMWF operational ensemble reanalysis-analysis system for ocean and sea ice: a description of the system and assessment*. Ocean Sci., 15, 779-808. Online at https://doi.org/10.5194/os-15-779-2019
		WEGC Kircetal 2021 & vSchucketal 2020 & IAP-ORAS5

	SV5.3 Uppermost Ocean Heat Content (UMOHC) increase rate (depth 0-300m)	– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Kirchengast et al. (2021c). *Section 3 on AHC in* von Schuckmann et al. (2020) *Heat stored in the Earth system: where does the energy go?.* Earth Syst. Sci. Data, 12, 2013-2041 (online at https://essd.copernicus.org/articles/12/2013/2020/#section3) and Kirchengast et al. (2019-2021) *Climate trends and variability in Atmospheric Heat Content and atmosphere-ocean heat exchanges etc.* IUGG 2019 Conf. Invited Pres. Montreal CA (online https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/#!sessiondetails/0000119801_0), ICGPSRO 2020 Conf. Invited Pres. Hsinchu TW, Manuscript in prep. 2021 (online link added after publication) – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020 – Cheng et al. (2021). *Upper ocean temperatures hit record high in 2020.* Adv. Atmos. Sci., 38, 523-530. Online at https://doi.org/10.1007/s00376-021-0447-x – Zuo et al. (2019). *The ECMWF operational ensemble reanalysis-analysis system for ocean and sea ice: a description of the system and assessment*. Ocean Sci., 15, 779-808. Online at https://doi.org/10.5194/os-15-779-2019
	SV5.4 Land heat content increase rate	vSchucketal 2020 / WEGCupd 2021 – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020
	SV5.5 Cryospheric energy uptake increase rate	vSchucketal 2020 / WEGCupd 2021 – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020
	SV5.6 Atmospheric Heat Content (AHC) increase rate	WEGC Kircetal & CWM-DB 2021 & ERA-JRA-MERRA – Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Kirchengast et al. (2021c). *Section 3 on AHC in* von Schuckmann et al. (2020) *Heat stored in the Earth system: where does the energy go?.* Earth Syst. Sci. Data, 12, 2013-2041 (online at https://essd.copernicus.org/articles/12/2013/2020/#section3) and Kirchengast et al. (2019-2021) *Climate trends and variability in Atmospheric Heat Content and atmosphere-ocean heat exchanges etc.* IUGG 2019 Conf. Invited Pres. Montreal CA (online https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/#!sessiondetails/0000119801_0), ICGPSRO 2020 Conf. Invited Pres. Hsinchu TW, Manuscript in prep. 2021 (online link added after publication)

		– Gelaro et al. (2017). *The Modern-Era Retrospective Analysis for research and applications, Version 2 (MERRA-2).* J. Clim., 30, 5419-5454. Online at https://doi.org/10.1175/jcli-d-16-0758.1 – Hersbach et al. (2020). *The ERA5 global reanalysis.* Q. J. Royal Met. Soc., 146, 1999-2049. Online at https://doi.org/10.1002/qj.3803 – Japan Meteorological Agency (2013). *JRA-55: Japanese 55-year reanalysis, monthly means and variance.* Online at https://doi.org/10.5065/D60G3H5B
V6. Earth Energy Imbalance (EEI) per m2 [W/m²]	***Explanation:*** This is the second of the two Earth Energy Imbalance (EEI) variables of CWM-GLO, the one that provides the global EEI over time since the 1960s in units [W/m²]. Apart from the conversion from units [ZJ/year] to units [W/m²] all SubVariables of this Variable V6 are the same as the ones of Variable V5; hence see the Explanation of Variable V5 above for further details. The conversion is implemented by dividing the (ZJ/year)-values by the Earth surface area (510.06 trillion square meters for a spherical Earth with radius 6371.0 km) and the number of seconds per year (31.558 million seconds for 365.25 days per year), yielding a conversion factor of 0.0621 (W/m2)/(ZJ/year). Such expression of energy imbalance or increase rate as the average excess power received per square meter of the global Earth surface [W/m²] is widely used in particular in connection with radiative forcing and response (see Variables V9 and V11).	
	WEGC Kircetal 2021 & vSchucketal 2020 & MiscSciSrc	
	SV6.1 Earth Energy Imbalance (EEI) (total rate of increase)	WEGC Kircetal & CWM-DB 2021 & MiscDatSrc – Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation and see also the further references under SV6.2 to SV6.6 below) – Kirchengast et al. (2021c). *Section 3 on AHC in* von Schuckmann et al. (2020) *Heat stored in the Earth system: where does the energy go?.* Earth Syst. Sci. Data, 12, 2013-2041 (online at https://essd.copernicus.org/articles/12/2013/2020/#section3) and Kirchengast et al. (2019-2021) *Climate trends and variability in Atmospheric Heat Content and atmosphere-ocean heat exchanges etc.* IUGG 2019 Conf. Invited Pres. Montreal CA (online https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/#!sessiondetails/0000119801_0), ICGPSRO 2020 Conf. Invited Pres. Hsinchu TW, Manuscript in prep. 2021 (online link added after publication) – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020
	SV6.2 Ocean heat content increase rate below UMOHC (depth>300m)	WEGC Kircetal 2021 & vSchucketal 2020 & IAP-ORAS5 – Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020

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– Cheng et al. (2021). Upper ocean temperatures hit record high in 2020. Adv. Atmos. Sci., 38, 523-530. Online at https://doi.org/10.1007/s00376-021-0447-x
– Zuo et al. (2019). The ECMWF operational ensemble reanalysis-analysis system for ocean and sea ice: a description of the system and assessment. Ocean Sci., 15, 779-808. Online at https://doi.org/10.5194/os-15-779-2019
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<tr><td></td><td>SV6.3
Uppermost Ocean Heat Content (UMOHC) increase rate (depth 0-300m)</td><td>
WEGC Kircetal 2021 & vSchucketal 2020 & IAP-ORAS5
– Kirchengast et al. (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO. DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm
(see under “Explanation” above on the variables’ computation)
– Kirchengast et al. (2021c). Section 3 on AHC in von Schuckmann et al. (2020) Heat stored in the Earth system: where does the energy go?. Earth Syst. Sci. Data, 12, 2013-2041 (online at https://essd.copernicus.org/articles/12/2013/2020/#section3) and Kirchengast et al. (2019-2021) Climate trends and variability in Atmospheric Heat Content and atmosphere-ocean heat exchanges etc. IUGG 2019 Conf. Invited Pres. Montreal CA (online https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/#!sessiondetails/0000119801_0), ICGPSRO 2020 Conf. Invited Pres. Hsinchu TW, Manuscript in prep. 2021 (online link added after publication)
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– Zuo et al. (2019). The ECMWF operational ensemble reanalysis-analysis system for ocean and sea ice: a description of the system and assessment. Ocean Sci., 15, 779-808. Online at https://doi.org/10.5194/os-15-779-2019
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Land heat content increase rate</td><td>
vSchucketal 2020 / WEGCupd 2021
– von Schuckmann et al. (2020). Heat stored in the Earth system: where does the energy go? Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020
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<tr><td></td><td>SV6.5
Cryospheric energy uptake increase rate</td><td>
vSchucketal 2020 / WEGCupd 2021
– von Schuckmann et al. (2020). Heat stored in the Earth system: where does the energy go? Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020
</td></tr>
<tr><td></td><td>SV6.6
Atmospheric Heat Content (AHC) increase rate</td><td>
WEGC Kircetal & CWM-DB 2021 & ERA-JRA-MERRA
– Kirchengast et al. (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO. DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm
(see under “Explanation” above on the variables’ computation)
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		– Kirchengast et al. (2021c). *Section 3 on AHC in* von Schuckmann et al. (2020) *Heat stored in the Earth system: where does the energy go?.* Earth Syst. Sci. Data, 12, 2013-2041 (online at https://essd.copernicus.org/articles/12/2013/2020/#section3) and Kirchengast et al. (2019-2021) *Climate trends and variability in Atmospheric Heat Content and atmosphere-ocean heat exchanges etc.* IUGG 2019 Conf. Invited Pres. Montreal CA (online https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/#!sessiondetails/0000119801_0), ICGPSRO 2020 Conf. Invited Pres. Hsinchu TW, Manuscript in prep. 2021 (online link added after publication) – Gelaro et al. (2017). *The Modern-Era Retrospective Analysis for research and applications, Version 2 (MERRA-2)*. J. Clim., 30, 5419-5454. Online at https://doi.org/10.1175/jcli-d-16-0758.1 – Hersbach et al. (2020). *The ERA5 global reanalysis.* Q. J. Royal Met. Soc., 146, 1999-2049. Online at https://doi.org/10.1002/qj.3803 – Japan Meteorological Agency (2013). *JRA-55: Japanese 55-year reanalysis, monthly means and variance.* Online at https://doi.org/10.5065/D60G3H5B
V7. GHG annual concentrations [ppm]	***Explanation***: This variable provides annual global greenhouse gas (GHG) concentrations in the atmosphere since 1960 in two forms: 1. CO_2-equivalent concentration (SV7.1), which is the concentration that CO_2 would have in the air if the total radiative forcing of all GHGs (incl. also CH_4, N_2O, etc.) would come from CO_2 only, and 2. the concentration of just CO_2, which is the main GHG that has contributed about 80 % of the radiative forcing increase since 1990 that drives global warming (see under CWM-GLO for a range of global warming-related variables, including radiative forcing). The units of parts per million [ppm], used for expressing concentrations of trace gases such as CO_2 in the air, denote the number of molecules of a trace gas per million of total air molecules. In Earth's atmosphere about 99 % of this total are made up by molecular nitrogen (N_2) and oxygen (O_2), termed the main constituents of the air.	
	NOAA 2020 & Meinetal 2017 & Etmietal 2016 & WEGC 2021	
	SV7.1 CO2-equivalent concentration (all GHGs)	NOAA 2020 & Meinsh-etal 2017 & Etmin-etal 2016 / WEGCupd 2021 – Meinshausen et al. (2017). *Historical greenhouse gas concentrations for climate modelling (CMIP6)*. Geosci. Model Dev., 10, 2057-2116. Online at https://doi.org/10.5194/gmd-10-2057-2017 – Butler and Montzka-NOAA (2020). *The NOAA Annual Greenhouse Gas Index (AGGI)*. Online at https://gml.noaa.gov/aggi/aggi.html – Etminan et al. (2016). *Radiative forcing of carbon dioxide, methane, and nitrous oxide: A significant revision of the methane radiative forcing*. Geophys. Res. Lett., 43, 12,614–12,623. Online at https://doi.org/10.1002/2016GL071930
	SV7.2 CO2 concentration (no other GHGs)	NOAA 2020 & Meinsh-etal 2017 / WEGCupd 2021 – Meinshausen et al. (2017). *Historical greenhouse gas concentrations for climate modelling (CMIP6).* Geosci. Model Dev., 10, 2057-2116. Online at https://doi.org/10.5194/gmd-10-2057-2017 – Butler and Montzka-NOAA (2020). *The NOAA Annual Greenhouse Gas Index (AGGI)*. Online at https://gml.noaa.gov/aggi/aggi.html

<table>
<tr>
<td rowspan="3">V8.
Effective radiative forcing [ZJ/year]</td>
<td colspan="2">Explanation: This is one of the two Effective Radiative Forcing (ERF) variables of CWM-GLO, the one that annually provides the global ERF since 1960 as accumulated from 1750 in units [ZJ/year] ((1 ZJ = 10^{21} J = 1 trillion gigajoules of energy; for comparison, the world's total annual energy consumption is currently about 0.6 ZJ). The ERF and its increase, driving the climate response (see the Explanations under Variables V3 and V11), occur mainly due to continued anthropogenic emission of CO_2 and other greenhouse gases (GHGs) as shown in GEM-GLO for the global emissions and countries worldwide. For a closer explanation of the main forcing components as part of the ERF see Butler and Montzka-NOAA (2020) and Smith et al. (2020) (both cited below). The SubVariables include the total global ERF (SV8.1) as well as its contributing forcings divided into five main component forcings (with the most prominent listed last): natural volcanic+solar (SV8.2), other small anthropogenic (SV8.3), anthropogenic aerosol (SV8.4), other GHGs (SV8.5), and CO_2 forcing (SV8.6), respectively. All are provided as annual values expressing the respective forcing up to the year accrued since 1750 (i.e., since preindustrial).
The total ERF increased from values near 10 ZJ/year in 1960 (since 1750) to values of about 35 to 45 ZJ/year in the most recent decade as of 2010. This forcing will gradually begin to stop only if greenhouse gas emissions are significantly reduced thanks to the success of Paris-compliant global emission reductions (see Kirchengast et al., 2021b; Section 2 therein) (cited below).</td>
</tr>
<tr>
<td colspan="2">WEGC Kircetal 2021 & NOAA 2020 & Smithetal & MiscSciSrc 2021</td>
</tr>
<tr>
<td>SV8.1
Effective radiative forcing (total) (from 1750)</td>
<td>WEGC Kircetal&CWM-DB 2021 & NOAA & Smithetal & MiscSciSrc

– Kirchengast et al. (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO. DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm
(see under "Explanation" above on the variables' computation)
– Kirchengast et al. (2021b). Carbon Management: A new approach to achieve Paris-compliant climate goals. WEGC Research Briefs 1-2021, Wegener Center Verlag, Univ. of Graz, Austria. Online at https://doi.org/10.25364/23.2021.1 (Section 2 at https://unipub.uni-graz.at/obvugrveroeff/content/pageview/6047842)
– Butler and Montzka-NOAA (2020). The NOAA Annual Greenhouse Gas Index (AGGI). Online at https://gml.noaa.gov/aggi/aggi.html
– Smith et al. (2021). Energy budget constraints on the time history of aerosol forcing and climate sensitivity. J. Geophys. Res. Atmos., 126, e2020JD033622. Online at https://doi.org/10.1029/2020JD033622
– Bond et al. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. J. Geophys. Res. Atmos., 118, 5380-5552. Online at https://doi.org/10.1002/jgrd.50171
– Checa-Garcia et al. (2018). Historical tropospheric and stratospheric ozone radiative forcing using the CMIP6 database. Geophys. Res. Lett., 45, 3264-3273. Online at https://doi.org/10.1002/2017gl076770
– Coddington et al. (2015). NOAA Climate Data Record (CDR) of Total Solar Irradiance (TSI), NRLTSI Version 2. Online at https://doi.org/10.7289/V55B00C1
– Daniel et al. (2010). Options to accelerate ozone recovery: ozone and climate benefits. Atmos. Chem. Phys., 10, 7697-7707. Online at https://doi.org/10.5194/acp-10-7697-2010
– Ghimire et al. (2014). Global albedo change and radiative cooling from anthropogenic land cover change, 1700 to 2005 based on MODIS, land use harmonization, radiative kernels, and reanalysis. Geophys. Res. Lett., 41, 9087-9096. Online at https://doi.org/10.1002/2014gl061671</td>
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		– Kovilakam et al. (2020). *The Global Space-based Stratospheric Aerosol Climatology (version 2.0): 1979-2018*. Earth Syst. Sci. Data, 12, 2607-2634. Online at https://doi.org/10.5194/essd-12-2607-2020 – Lee et al. (2021). *The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018*. Atmos. Environ., 244, 117834. Online at https://doi.org/10.1016/j.atmosenv.2020.117834 – Luo (2018). *Release Notes Stratospheric Aerosol Radiative Forcing and SAD version v4.0.0 1850-2016.* Online at ftp://iacftp.ethz.ch/pub read/luo/CMIP6 SAD radForcing v4.0.0/Release note v4.0.0.pdf (last access: 1 April 2021) – Meinshausen et al. (2017). *Historical greenhouse gas concentrations for climate modelling (CMIP6).* Geosci. Model Dev., 10, 2057-2116. Online at https://doi.org/10.5194/gmd-10-2057-2017 – Myhre et al. (2013). *Anthropogenic and Natural Radiative Forcing.* pp. 659-740. Cambridge Univ. Press, Cambridge, UK. Online at https://doi.org/10.1017/cbo9781107415324.018 – Yeo et al. (2017). *EMPIRE: A robust empirical reconstruction of solar irradiance variability*. J. Geophys. Res. Space Phys., 122, 3888-3914. Online at https://doi.org/10.1002/2016ja023733
	SV8.2 Natural volcanic+solar radiative forcing (from 1750)	WEGC Kircetal 2021 & NOAA 2021 & Luo 2018 & Yeoetal 2017
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Coddington et al. (2015). *NOAA Climate Data Record (CDR) of Total Solar Irradiance (TSI), NRLTSI Version 2*. Online at https://doi.org/10.7289/V55B00C1 – Kovilakam et al. (2020). *The Global Space-based Stratospheric Aerosol Climatology (version 2.0): 1979-2018*. Earth Syst. Sci. Data, 12, 2607-2634. Online at https://doi.org/10.5194/essd-12-2607-2020 – Luo (2018). *Release Notes Stratospheric Aerosol Radiative Forcing and SAD version v4.0.0 1850-2016.* Online at ftp://iacftp.ethz.ch/pub read/luo/CMIP6 SAD radForcing v4.0.0/Release note v4.0.0.pdf (last access: 1 April 2021) – Yeo et al. (2017). *EMPIRE: A robust empirical reconstruction of solar irradiance variability*. J. Geophys. Res. Space Phys., 122, 3888-3914. Online at https://doi.org/10.1002/2016ja023733
	SV8.3 Other (small) anthropogenic radiative forcings (from 1750)	WEGC Kircetal 2021 & Checa-Garcia-etal 2018 & MiscSciSrc
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Bond et al. (2013). *Bounding the role of black carbon in the climate system: A scientific assessment.* J. Geophys. Res. Atmos., 118, 5380-5552. Online at https://doi.org/10.1002/jgrd.50171 – Checa-Garcia et al. (2018). *Historical tropospheric and stratospheric ozone radiative forcing using the CMIP6 database.* Geophys. Res. Lett., 45, 3264-3273. Online at https://doi.org/10.1002/2017gl076770

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	SV8.4 Anthropogenic aerosol radiative forcing (from 1750)	WEGC Kircetal 2021 & Smithetal2021 – Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Smith et al. (2021). *Energy budget constraints on the time history of aerosol forcing and climate sensitivity.* J. Geophys. Res. Atmos., 126, e2020JD033622. Online at https://doi.org/10.1029/2020JD033622
	SV8.5 Further anthropogenic GHGs radiative forcing (from 1750)	WEGC Kircetal 2021 & NOAA 2020 & Meinsetal 2017 – Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Butler and Montzka-NOAA (2020). *The NOAA Annual Greenhouse Gas Index (AGGI)*. Online at https://gml.noaa.gov/aggi/aggi.html – Etminan et al. (2016). *Radiative forcing of carbon dioxide, methane, and nitrous oxide: A significant revision of the methane radiative forcing*. Geophys. Res. Lett., 43, 12,614–12,623. Online at https://doi.org/10.1002/2016GL071930 – Meinshausen et al. (2017). *Historical greenhouse gas concentrations for climate modelling (CMIP6).* Geosci. Model Dev., 10, 2057-2116. Online at https://doi.org/10.5194/gmd-10-2057-2017
	SV8.6 Anthropogenic CO2 radiative forcing (from 1750)	WEGC Kircetal 2021 & NOAA 2020 & Meinsetal 2017 – Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Butler and Montzka-NOAA (2020). *The NOAA Annual Greenhouse Gas Index (AGGI)*. Online at https://gml.noaa.gov/aggi/aggi.html – Meinshausen et al. (2017). *Historical greenhouse gas concentrations for climate modelling (CMIP6).* Geosci. Model Dev., 10, 2057-2116. Online at https://doi.org/10.5194/gmd-10-2057-2017

<table>
<tr><td colspan="3"></td></tr>
<tr><td rowspan="3">V9.
Effective radiative forcing per m2
[W/m²]</td><td colspan="2">Explanation: This is the second of the two Effective Radiative Forcing (ERF) variables of CWM-GLO, the one that provides the global ERF since 1960 as accumulated from 1750 in units [W/m²]. Apart from the conversion from units [ZJ/year] to units [W/m²] all SubVariables of this Variable V9 are the same as the ones of Variable V8; hence see the Explanation of Variable V8 above for further details.
The conversion is implemented by dividing the (ZJ/year)-values by the Earth surface area (510.06 trillion square meters for a spherical Earth with radius 6371.0 km) and the number of seconds per year (31.558 million seconds for 365.25 days per year), yielding a conversion factor of 0.0621 (W/m2)/(ZJ/year). Such expression of the ERF as an average power per square meter of the global Earth surface [W/m²] is widely used, in fact quite more commonly than the units [ZJ/year], in particular in connection with joint radiative forcing and response estimates (see Variable V11).</td></tr>
<tr><td colspan="2">WEGC Kircetal 2021 & NOAA 2020 & Smithetal & MiscSciSrc 2021</td></tr>
<tr><td>SV9.1
Effective radiative forcing (total) (from 1750)</td><td>WEGC Kircetal&CWM-DB 2021 & NOAA & Smithetal & MiscSciSrc
– Kirchengast et al. (2021). Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO. DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under “Explanation” above on the variables’ computation)
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– Bond et al. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. J. Geophys. Res. Atmos., 118, 5380-5552. Online at https://doi.org/10.1002/jgrd.50171
– Checa-Garcia et al. (2018). Historical tropospheric and stratospheric ozone radiative forcing using the CMIP6 database. Geophys. Res. Lett., 45, 3264-3273. Online at https://doi.org/10.1002/2017gl076770
– Coddington et al. (2015). NOAA Climate Data Record (CDR) of Total Solar Irradiance (TSI), NRLTSI Version 2. Online at https://doi.org/10.7289/V55B00C1
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– Lee et al. (2021). The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. Atmos. Environ., 244, 117834. Online at https://doi.org/10.1016/j.atmosenv.2020.117834
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	SV9.2 Natural volcanic+solar radiative forcing (from 1750)	WEGC Kircetal 2021 & NOAA 2021 & Luo 2018 & Yeoetal 2017
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under “Explanation” above on the variables’ computation) – Coddington et al. (2015). *NOAA Climate Data Record (CDR) of Total Solar Irradiance (TSI), NRLTSI Version 2*. Online at https://doi.org/10.7289/V55B00C1 – Kovilakam et al. (2020). *The Global Space-based Stratospheric Aerosol Climatology (version 2.0): 1979-2018*. Earth Syst. Sci. Data, 12, 2607-2634. Online at https://doi.org/10.5194/essd-12-2607-2020 – Luo (2018). *Release Notes Stratospheric Aerosol Radiative Forcing and SAD version v4.0.0 1850-2016.* Online at ftp://iacftp.ethz.ch/pub read/luo/CMIP6 SAD radForcing v4.0.0/Release note v4.0.0.pdf (last access: 1 April 2021) – Yeo et al. (2017). *EMPIRE: A robust empirical reconstruction of solar irradiance variability*. J. Geophys. Res. Space Phys., 122, 3888-3914. Online at https://doi.org/10.1002/2016ja023733
	SV9.3 Other (small) anthropogenic radiative forcings (from 1750)	WEGC Kircetal 2021 & Checa-Garcia-etal 2018 & MiscSciSrc
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under “Explanation” above on the variables’ computation) – Bond et al. (2013). *Bounding the role of black carbon in the climate system: A scientific assessment.* J. Geophys. Res. Atmos., 118, 5380-5552. Online at https://doi.org/10.1002/jgrd.50171 – Checa-Garcia et al. (2018). *Historical tropospheric and stratospheric ozone radiative forcing using the CMIP6 database.* Geophys. Res. Lett., 45, 3264-3273. Online at https://doi.org/10.1002/2017gl076770 – Daniel et al. (2010). *Options to accelerate ozone recovery: ozone and climate benefits.* Atmos. Chem. Phys., 10, 7697-7707. Online at https://doi.org/10.5194/acp-10-7697-2010 – Ghimire et al. (2014). *Global albedo change and radiative cooling from anthropogenic land cover change, 1700 to 2005 based on MODIS, land use harmonization, radiative kernels, and reanalysis.* Geophys. Res. Lett., 41, 9087-9096. Online at https://doi.org/10.1002/2014gl061671 – Lee et al. (2021). *The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018*. Atmos. Environ., 244, 117834. Online at https://doi.org/10.1016/j.atmosenv.2020.117834

		– Myhre et al. (2013). *Anthropogenic and Natural Radiative Forcing.* pp. 659-740. Cambridge Univ. Press, Cambridge, UK. Online at https://doi.org/10.1017/cbo9781107415324.018
	SV9.4 Anthropogenic aerosol radiative forcing (from 1750)	WEGC Kircetal 2021 & Smithetal2021
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Smith et al. (2021). *Energy budget constraints on the time history of aerosol forcing and climate sensitivity.* J. Geophys. Res. Atmos., 126, e2020JD033622. Online at https://doi.org/10.1029/2020JD033622
	SV9.5 Further anthropogenic GHGs radiative forcing (from 1750)	WEGC Kircetal 2021 & NOAA 2020 & Meinsetal 2017
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Butler and Montzka-NOAA (2020). *The NOAA Annual Greenhouse Gas Index (AGGI)*. Online at https://gml.noaa.gov/aggi/aggi.html – Etminan et al. (2016). *Radiative forcing of carbon dioxide, methane, and nitrous oxide: A significant revision of the methane radiative forcing*. Geophys. Res. Lett., 43, 12,614–12,623. Online at https://doi.org/10.1002/2016GL071930 – Meinshausen et al. (2017). *Historical greenhouse gas concentrations for climate modelling (CMIP6).* Geosci. Model Dev., 10, 2057-2116. Online at https://doi.org/10.5194/gmd-10-2057-2017
	SV9.6 Anthropogenic CO2 radiative forcing (from 1750)	WEGC Kircetal 2021 & NOAA 2020 & Meinsetal 2017
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Butler and Montzka-NOAA (2020). *The NOAA Annual Greenhouse Gas Index (AGGI)*. Online at https://gml.noaa.gov/aggi/aggi.html – Meinshausen et al. (2017). *Historical greenhouse gas concentrations for climate modelling (CMIP6).* Geosci. Model Dev., 10, 2057-2116. Online at https://doi.org/10.5194/gmd-10-2057-2017
V10. Global surface air temperature [°C]	***Explanation:*** This is the global surface air temperature (GSAT) variable of CWM-GLO that is included in form of annual-mean GSAT data since 1960. These are contained in its SubVariable SV10.1 as temperature change data relative to preindustrial, constructed from state-of-the-art GSAT datasets, with most weight given to the recent HadCRUT5 data of Morice et al. (2021). Following the latter study, "preindustrial" is taken to be the 1850-1900 average which was found a close proxy to the time period around 1750 as is used as preindustrial reference in the effective radiative forcing (ERF) data (see Variables V8 and V9). The GSAT data are used as a product with a best estimate climate feedback parameter (α_{FP}; set to 1.4 Wm^{-2}/K) in order to obtain a radiative response estimate (RRE) as included in Variable 11	

	(SubVariable V11.2) as well as the related index Variable V3 (SubVariable V3.3). For a brief physical explanation on how the climate forcing (ERF) and climate response (RRE) act together, and are related in their difference to the EEI, see Kirchengast et al. (2021b), Section 2.1 therein.	
	WEGC Kircetal 2021 & HadCRUT5-NASAGIST4-ERA5T	
	SV10.1 Global surface air temperature change (vs Preindustrial)	WEGC Kircetal 2021 & HadCRUT5-NASAGIST4-ERA5T
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Kirchengast et al. (2021b). *Carbon Management: A new approach to achieve Paris-compliant climate goals.* WEGC Research Briefs 1-2021, Wegener Center Verlag, Univ. of Graz, Austria. Online at https://doi.org/10.25364/23.2021.1 (Section 2.1 at https://unipub.uni-graz.at/obvugrveroeff/content/pageview/6047842) – Morice et al. (2021). *An updated assessment of near-surface temperature change from 1850: The HadCRUT5 data set*. J. Geophys. Res. Atmos., 126, e2019JD032361. Online at https://doi.org/10.1029/2019jd032361 – GISTEMP Team (2021). *GISS Surface Temperature Analysis (GISTEMP), version 4. NASA Goddard Institute for Space Studies*. Online at https://data.giss.nasa.gov/gistemp/ – Lenssen et al. (2019). *Improvements in the GISTEMP uncertainty model*. J. Geophys. Res. Atmos., 124, 6307-6326. Online at https://doi.org/10.1029/2018jd029522 – Hersbach et al. (2020). *The ERA5 global reanalysis.* Q. J. Royal Met. Soc., 146, 1999-2049. Online at https://doi.org/10.1002/qj.3803
V11. Forcing-Response-Imbalance estimates [W/m²]	***Explanation:*** This is the variable of CWM-GLO that collects the estimates of the global Earth Energy Imbalance (EEI) increase and the related Effective Radiative Forcing (ERF) and Radiative Response Estimate (RRE) increases since the 1960s. The EEI and its increase, linked to a still widening gap between the ERF and (lagging) RRE increases, occur mainly due to the ongoing anthropogenic climate change caused by the continued emission of CO_2 and other greenhouse gases (GHGs) as shown in GEM-GLO for the global emissions and countries worldwide. For a brief physical explanation of the fundamental significance of the EEI related to climate forcing (ERF) and climate response (RRE), and how global warming and climate change do consequently unfold, see Kirchengast et al. (2021b), Section 2.1 therein; more details are available via von Schuckmann et al. (2020) (both cited below). The SubVariables include the global EEI (SV11.1) as well as the related global ERF (SV11.2) and RRE (SV11.3) estimates, respectively. The fourth SubVariable (SV11.4) shows for completeness the difference between the forcing and response estimates (i.e., between SV11.2 an SV11.3), which roughly corresponds to the EEI (up to some natural variability in the EEI due to its estimation from Earth system-internal heat gain and energy uptake data). The ERF estimates are constructed for the purpose here without the intermittent and episodic natural volcanic and the small solar forcing terms, in order to focus on the anthropogenic forcing (due to the decadal-mean construction this makes a small difference only, however). The EEI expresses the decadal increase rate of energy uptake in the Earth system in any center year shown. It is computed as five-year-smoothed (center year ± 5 years)-linearfit to the annual observations of total Earth energy uptake since 1960 (i.e., it is equal to SubVariable SV4.1 of Variable V4). Similarly, the ERF and RRE estimates are computed as (center year ± 5 years)-moving-averages; the former based on the annual total anthropogenic ERF data of Variable V9, the latter as the product of a best-estimate total climate feedback parameter (α_{FP}; 1.4 Wm^{-2}/K)	

	and the global surface air temperature (GSAT) change data of Variable V10. The Forcing-minus-Response estimate (SV11.4) confirms, from its overall consistency with the EEI estimate (SV11.1), the best-estimate value of the feedback parameter.	
	WEGC Kircetal 2021 & ERF-RRESAT-EEI MiscSciSrc	
	SV11.1 Earth Energy Imbalance (EEI) observation (decadal)	WEGC Kircetal 2021 & vSchucketal 2020 & MiscSciSrc
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Kirchengast et al. (2021b). *Carbon Management: A new approach to achieve Paris-compliant climate goals.* WEGC Research Briefs 1-2021, Wegener Center Verlag, Univ. of Graz, Austria. Online at https://doi.org/10.25364/23.2021.1 (Section 2.1 at https://unipub.uni-graz.at/obvugrveroeff/content/pageview/6047842) – Kirchengast et al. (2021c). *Section 3 on AHC in* von Schuckmann et al. (2020) *Heat stored in the Earth system: where does the energy go?.* Earth Syst. Sci. Data, 12, 2013-2041 (online at https://essd.copernicus.org/articles/12/2013/2020/#section3) and Kirchengast et al. (2019-2021) *Climate trends and variability in Atmospheric Heat Content and atmosphere-ocean heat exchanges etc.* IUGG 2019 Conf. Invited Pres. Montreal CA (online https://www.czech-in.org/cmPortalV15/CM_W3_Searchable/iugg19/#!sessiondetails/0000119801_0), ICGPSRO 2020 Conf. Invited Pres. Hsinchu TW, Manuscript in prep. 2021 (online link added after publication) – von Schuckmann et al. (2020). *Heat stored in the Earth system: where does the energy go?* Earth Syst. Sci. Data, 12, 2013-2041. Online at https://doi.org/10.5194/essd-12-2013-2020 – Cheng et al. (2021). *Upper ocean temperatures hit record high in 2020.* Adv. Atmos. Sci., 38, 523-530. Online at https://doi.org/10.1007/s00376-021-0447-x – Gelaro et al. (2017). *The Modern-Era Retrospective Analysis for research and applications, Version 2 (MERRA-2).* J. Clim., 30, 5419-5454. Online at https://doi.org/10.1175/jcli-d-16-0758.1 – Hersbach et al. (2020). *The ERA5 global reanalysis.* Q. J. Royal Met. Soc., 146, 1999-2049. Online at https://doi.org/10.1002/qj.3803 – Japan Meteorological Agency (2013). *JRA-55: Japanese 55-year reanalysis, monthly means and variance.* Online at https://doi.org/10.5065/D60G3H5B – Zuo et al. (2019). *The ECMWF operational ensemble reanalysis-analysis system for ocean and sea ice: a description of the system and assessment*. Ocean Sci., 15, 779-808. Online at https://doi.org/10.5194/os-15-779-2019
	SV11.2 Effective radiative forcing (decadal) (from 1750)	WEGC Kircetal 2021 & NOAA 2020 & Smithetal & MiscSciSrc
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation)

		– Butler and Montzka-NOAA (2020). *The NOAA Annual Greenhouse Gas Index (AGGI)*. Online at https://gml.noaa.gov/aggi/aggi.html – Smith et al. (2021). *Energy budget constraints on the time history of aerosol forcing and climate sensitivity.* J. Geophys. Res. Atmos., 126, e2020JD033622. Online at https://doi.org/10.1029/2020JD033622 – Bond et al. (2013). *Bounding the role of black carbon in the climate system: A scientific assessment.* J. Geophys. Res. Atmos., 118, 5380-5552. Online at https://doi.org/10.1002/jgrd.50171 – Checa-Garcia et al. (2018). *Historical tropospheric and stratospheric ozone radiative forcing using the CMIP6 database.* Geophys. Res. Lett., 45, 3264-3273. Online at https://doi.org/10.1002/2017gl076770 – Ghimire et al. (2014). *Global albedo change and radiative cooling from anthropogenic land cover change, 1700 to 2005 based on MODIS, land use harmonization, radiative kernels, and reanalysis.* Geophys. Res. Lett., 41, 9087-9096. Online at https://doi.org/10.1002/2014gl061671 – Lee et al. (2021). *The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018*. Atmos. Environ., 244, 117834. Online at https://doi.org/10.1016/j.atmosenv.2020.117834 – Meinshausen et al. (2017). *Historical greenhouse gas concentrations for climate modelling (CMIP6).* Geosci. Model Dev., 10, 2057-2116. Online at https://doi.org/10.5194/gmd-10-2057-2017 – Myhre et al. (2013). *Anthropogenic and Natural Radiative Forcing.* pp. 659-740. Cambridge Univ. Press, Cambridge, UK. Online at https://doi.org/10.1017/cbo9781107415324.018
	SV11.3 Radiative response estimate (decadal) (from 1750)	WEGC Kircetal 2021 & HadCRUT5-NASAGIST4-ERA5T
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm (see under "Explanation" above on the variables' computation) – Morice et al. (2021). *An updated assessment of near-surface temperature change from 1850: The HadCRUT5 data set*. J. Geophys. Res. Atmos., 126, e2019JD032361. Online at https://doi.org/10.1029/2019jd032361 – GISTEMP Team (2021). *GISS Surface Temperature Analysis (GISTEMP), version 4. NASA Goddard Institute for Space Studies*. Online at https://data.giss.nasa.gov/gistemp/ – Lenssen et al. (2019). *Improvements in the GISTEMP uncertainty model*. J. Geophys. Res. Atmos., 124, 6307-6326. Online at https://doi.org/10.1029/2018jd029522 – Hersbach et al. (2020). *The ERA5 global reanalysis.* Q. J. Royal Met. Soc., 146, 1999-2049. Online at https://doi.org/10.1002/qj.3803
	SV11.4 Forcing-minus-Response imbalance estimate (decadal)	WEGC Kircetal 2021 & CWM-DB & MiscDatSrc
		– Kirchengast et al. (2021). *Graz Climate Change Indicators (GCCI) Content and References Information Sheets—InfoSheet CWM-GLO.* DocID GCCIv1.1-CWM-GLO-Jun2021, Wegener Center, Univ. of Graz, Austria. Online at www.gcci.earth/global/cwm

		(see under "Explanation" above on the variables' computation; and see the SV11.2 and SV11.3 references above on the forcing and response estimates themselves)