5. Ozone Formation

Rosalie van Zelm[1*], *Philipp Preiss*[2,3], *Thomas van Goethem*[1], *Francesca Verones*[4], *Rita Van Dingenen*[5], *Mark Huijbregts*[1]

[1] Department of Environmental Science, Radboud University Nijmegen, The Netherlands
[2] European Institute for Energy Research | EIFER, Emmy-Noether-Str. 11, 76131 Karlsruhe, Germany
[3]Institute for Energy Economics and the Rational Use of Energy, Department for Technology Assessment and Environment, Universität Stuttgart, Germany
[4] Industrial Ecology Programme and Department of Energy and Process Engineering, NTNU, Trondheim, Norway
[5]European Commission, Joint Research Centre (JRC), Environment and Sustainability (IES), Air and Climate Unit, Via Enrico Fermi, 2749, 21027 Ispra (VA), Italy
* r.vanzelm@science.ru.nl

The impact assessment method for assessing damage to human health and ecosystems due photochemical ozone formation is described based on Van Zelm et al. (2016).

5.1. Areas of protection and environmental mechanisms covered

The cause and effect pathway (Figure 5.1) of ozone formation starts with an emission of NO_x or NMVOC to the atmosphere, followed by atmospheric fate and chemistry in the air; NO_x and NMVOCs are transformed in air to ozone. Subsequently, this tropospheric ozone can be inhaled by humans or taken up by plants, leading to an increased number of mortality cases and final damage to human health, as well as disappearance of plant species and final damage to terrestrial ecosystems.

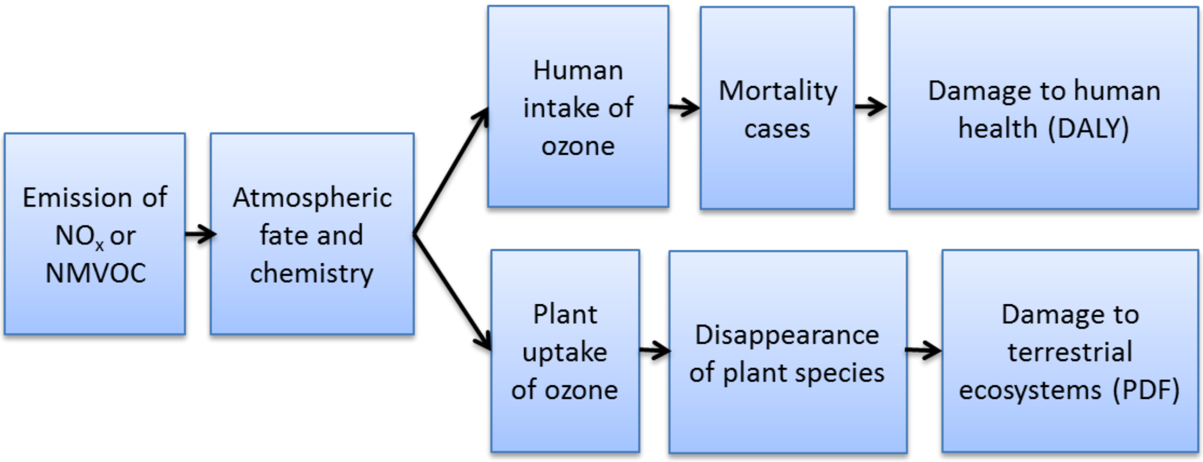

Figure 5.1: Cause and effect pathway from tropospheric ozone precursor emissions to damage to human health and terrestrial ecosystems.

The intake of a pollutant by humans is described by intake fractions (iF, in kg intake per kg emission) that quantify the relationship between an emission and intake at the population level. The environmental fate of ozone is described by fate factors (FF in ppm·hr·yr per kg emission) that quantify the relationship between an emission and subsequent concentration (Van Zelm et al. 2008). Here, a global chemical transport model was applied to determine environmental fate factors and human intake fractions for 56 emission and receptor regions. To determine human health effect factors, region-specific mortality rates, background concentrations and years of life lost were used.

Here, we included respiratory mortality due to ozone for two reasons: first, these contribute by far the most to overall disability adjusted life years, and second, for these the most up-to-date and least uncertain data related to relative risks and years of life lost are available (see e.g. Anenberg et al. 2010, Friedrich et al. 2011, Murray et al. 2012, WHO 2013).

To determine environmental impacts on terrestrial ecosystems, grid-cell specific forest and grass shares and background concentrations were used as input for plant species sensitivity distributions (Van Goethem et al. 2013a)

5.2. Calculation of the characterization factors at endpoint level

5.2.1. Human health damage

The endpoint characterization factors (CFs) for human health damage due to ozone formation caused by emitted precursor substance x in world region i ($CF_{x,i}$ in DALY·kg^{-1}) are defined as the yearly change in Disability Adjusted Life Years (DALY) of all inhabitants (dDALY in yr·yr^{-1}) due to a change in emission of substance x in source region i ($dM_{x,i}$ in kg·yr^{-1}). This CF for human health damage is composed of a dimensionless intake fraction ($iF_{x,\, i\rightarrow j}$), providing the population intake of ozone in receptor region j (in kg/yr) following an emission change of substance x in source region i (in kg/yr), an effect factor (EF_e), describing the cases of health effect *e* per kg of inhaled ozone, and a damage factor (DF_e), which describes the years of life lost per case of health effect *e*. In equation this reads:

$$CF_{x,i} = \sum_j \left(\left(iF_{x,i\rightarrow j} \right) \cdot \sum_e \left(EF_{e,j} \cdot DF_{e,j} \right) \right)$$ **Equation 5.1.**

5.2.1.1. From emission to human intake

The intake fraction is determined as the change in exposure to ozone in region j ($dEXP_j$), due to a change in emission of precursor substance x ($dM_{x,i}$). dEXP was retrieved by multiplying the change in concentration of ozone in each receptor region (dC_j) with the population (N_j) in the receptor region j and the average breathing rate per person (BR) of 4745 m^3·yr^{-1} (13 m^3·d^{-1} as recommended by USEPA (1997):

$$iF_{x,i\rightarrow j} = \frac{dEXP_j}{dM_{x,i}} = \frac{dC_j \cdot N_j \cdot BR}{dM_{x,i}}$$ **Equation 5.2.**

Population numbers (year 2005) were taken from the United Nations (2011). Since all data for the effect factor are based on the population ≥ 30 years of age, the population number was adjusted for the population share ≥ 30 years of age in 2005 (United Nations 2011) assuming no effects for younger people.

The emission–concentration sensitivities matrices for emitted precursors and relevant end pollutants (or pollutant metrics) from the global source-receptor model TM5-FASST (FAst Scenario Screening Tool for Global Air Quality and Instantaneous Radiative Forcing), based on perturbation runs with TM5 (Van Dingenen et al. 2009; Krol et al. 2005) were used to derive the change in ambient concentration of a pollutant after the emission of a precursor. TM5 is a global chemical transport model hosted by the

European Commission Joint Research Center (JRC). TM5-FASST takes into account spatial features at the emission site as well as dispersion characteristics for the whole world. In this model, the world is divided into 56 emission source regions. The regions correspond to countries or a group of countries (see Table 5.1). The TM5 model output consists of the change in concentration for each region, derived from gridded 1°×1° concentration results, following a change in emission. This change is determined by lowering the year 2000 emissions (Lamarque et al. 2010) by 20% for each of the 56 source regions sequentially. The emission-normalized differences in pollutant concentration between the unperturbed and perturbed case, aggregated over each receptor region, are stored as the emission – concentration matrix elements. This procedure was performed for both NO_x and NMVOC.

5.2.1.2. From human intake to human health damage

The human effect factor (dINC/dEXP) for health effect e caused by ozone in receptor region j, representing the change in disease incidence due to a change in exposure concentration in ambient air, was determined by dividing the concentration-response function (CRF in $m^3 \cdot yr^{-1} \cdot kg^{-1}$) by the breathing rate BR ($m^3 \cdot yr^{-1}$) (Gronlund et al. 2015) (equation 5.3):

$$EF_{e,j} = \frac{dINC_j}{dEXP_j} = \frac{CRF_{e.j}}{BR}$$ **Equation 5.3**

Region-specific CRFs were calculated as follows (equation 5.4):

$$CRF_{e,j} = \frac{(RR_e - 1) \cdot MR_{e,j}}{(RR_e - 1) \cdot C_j + 1}$$ **Equation 5.4**

where RR_e is the relative risk to obtain health effect e due to exposure to ozone (per $\mu g \cdot m^{-3}$), $MR_{e,j}$ is the mortality rate for health effect e in region j (deaths/person/yr), and C_j is the yearly average background concentration of ozone in a region ($\mu g \cdot m^{-3}$).

We followed recommendations for RRs by Anenberg et al. (2010) and Friedrich et al. (2011), who focus on the world and Europe respectively, based on North American cohort studies. The RR for respiratory mortality (1.004 per $\mu g \cdot m^{-3}$) based on data of daily 1-hr maximum ozone levels found by Jerrett et al. (2009) in an ACS cohort study of U.S. adults ≥ 30 years of age was used. Although many daily time-series epidemiology studies demonstrate short-term ozone mortality impacts (Anderson et al. 2004; Bell et al. 2005), Jerrett et al. (2009) provide the first clear evidence for long-term impacts.

Mortality rates per health effect (year 2005) were taken from the World Health Organization (WHO 2015a), and simulated background concentrations per region for the year 2000 were taken from the TM5-CTM reference run with the Lamarque et al. (2010) year 2000 reference emission scenario.

The Damage Factor $DF_{e,j}$ is defined as the Disability Adjusted Life Years (DALY) associated to the health effect e per incidence case, which were estimated per receiving region j from the world health organization (WHO) world health estimates, year 2012 (WHO 2015b):

$$DF_{e,j} = \frac{dDALY_{e,j}}{dINC_{e,j}}$$ **Equation 5.5**

For the DALY no discounting was included and uniform age weights were applied.

5.2.2. Terrestrial ecosystem damage

The endpoint characterization factors (CFs) for ecosystem damage due to ozone formation caused by emitted precursor substance x in world region i ($CF_{x,i}$ in $PDF \cdot yr \cdot kg^{-1}$) are defined as the area-integrated change in Potentially Disappeared Fraction (PDF) of forest and natural grassland species due to a change in emission of substance x in source region i ($dM_{x,i}$ in $kg \cdot yr^{-1}$). This CF for ecosystem damage is composed of a Fate Factor ($FF_{x,i \rightarrow g}$, unit: $ppm \cdot h \cdot yr \cdot kg^{-1}$), quantifying the relationship between the emission of precursor substances in region i and ozone exposure in receiving grid cell g, and an Effect Factor ($EF_{n,j}$ in $PDF \cdot ppm^{-1} \cdot h^{-1}$), quantifying the relationship between ozone exposure and the damage to natural vegetation n (forest and grassland). In equation this reads:

$$CF_{ECO,x,i} = \sum_{g} \sum_{n} \left(FF_{x,i \rightarrow g} \cdot EF_{n,g} \right) \qquad \textbf{Equation 5.6}$$

5.2.2.1. From emission to environmental concentration

To determine the ecosystem fate factor, the AOT40, i.e. the sum of the differences between the hourly mean ozone concentration and 40 ppb during daylight hours over the relevant growing season in ppm·h, was used as metric of the cumulative concentration change. The fate factor represents the sum in the change in AOT40 in grid cell g due to a change of emission of precursor x in source region i (Van Goethem et al. 2013b):

$$\mathrm{FF}_{\mathrm{x,i \rightarrow g}} = \sum_{g} \frac{\Delta AOT40_{g}}{\Delta M_{x,i}} \qquad \textbf{Equation 5.7}$$

Monthly AOT40 concentrations per unit of emission of NO_x and NMVOC were calculated on a 1°x1° resolution from hourly ozone concentrations resulting from the year 2000 reference run with TM5 chemical transport model. For the Northern Hemisphere the same growing seasons for grassland and forest were taken as was done for Europe by Van Goethem et al. (2013b), namely May till July and April till September, respectively. For the Southern Hemisphere for grassland the months November till January and for forests the months October till March were taken.

5.2.2.2. From concentration to ecosystem damage

The ecosystem effect factor (EF) was derived from Van Goethem et al. (2013b), and corrected for species density:

$$\mathrm{EF}_{\mathrm{n,g}} = \frac{\Delta PDF_{g,n}}{\Delta AOT40_{g}} \cdot A_{g,n} \cdot \frac{PRD_{g \in br}}{PR_{global}} \qquad \textbf{Equation 5.8}$$

where PRD_g is the vascular plant richness density in grid g belonging to terrestrial biogeographical region br (species/km^2), PR is the total vascular plant richness in the world (species), and $A_{g,n}$ is the area (m^2) occupied by vegetation type n in grid cell g. The effect factor was determined with data on AOT40 concentrations for which 50% reduction in productivity (EC50) was found for a number of forest or grassland species (taken from Van Goethem et al. (2013a, 2013b)). Here, we chose to use the linear ecosystem effect factor, assuming a linear change in PAF with changing AOT40 that represents the average effect between a PAF of 0.5 and 0 (Van Goethem et al. 2013b). The corresponding “AOT40 concentration per unit of yearly emission” values per grid were multiplied by the corresponding natural area of either grassland or forest (Van Zelm et al. 2016). PRD and PR were obtained from Kier et al. (2009). PR equals 315’903.

5.3. Uncertainties

The CFs were derived from emission-concentration sensitivities (dC/dM) obtained from a 20% emission perturbation. Because AOT40 is a threshold based concentration indicator, there is more uncertainty attached to it compared to the use of linear scaling concentrations (Van Dingenen et al. 2009). When a concentration is, for example, slightly above the threshold of 40 ppb and then reduced when looking at the 20% perturbation, this can have large impacts on the results. For a limited number of representative source regions the dC/dM coefficients were calculated for large perturbations of inorganic pollutants (-80%, +100%) and compared to the extrapolated 20% perturbation (Van Zelm et al. 2016). For M6M, precursor NO_x, a deviation up to 14% was seen. For AOT40, however, deviations can be large. The large deviation for AOT40 under an 80% reduction of NOx (36% average) is explained by the linear extrapolation of a threshold metric from a regime above threshold to a regime below threshold.

The negative intake fractions for ozone due to emissions of NO_x are caused by the so-called titration effect. As a result of the rapid reaction of ozone with NO to form NO_2, concentrations of ozone tend to be lower close to sources of NO emissions, such as near dense urban traffic, major highways, and industrial sources. Countries that show negative characterization factors for NO_x therefore have relatively large characterization factors for NMVOC.

5.4. Value choices

5.4.1. Time horizon

For ozone formation impacts, time horizon is not of importance as only short-living substances are involved.

5.5. Resulting characterization factors

Figure 5.2 shows the region-specific characterization factors for human health damage due to ozone precursor emissions. Lowest factors (apart from the negatives) were obtained for emissions of NMVOC in New Zealand, Australia, Indonesia, and South America, while largest factors were obtained for NOx emissions in South Asia, West-Africa, India and China. The emission weighted average for the world for NMVOC is $1.4 \cdot 10^{-1}$ yr·kton^{-1} ($8.8 \cdot 10^{-3}$ to $5.0 \cdot 10^{-1}$ yr·kton^{-1}). The emission weighted average for the world for NOx is $9.1 \cdot 10^{-1}$ yr·kton^{-1} ($-2.2 \cdot 10^{-1}$ to 5.7 yr·kton^{-1}). Negative intake fractions and thus CFs were obtained for NO_x emitted in Belgium, the Netherlands, Luxembourg, Great-Britain, and Ireland. A negative value means that the emission of NO_x leads to an overall reduction of ozone exposure.

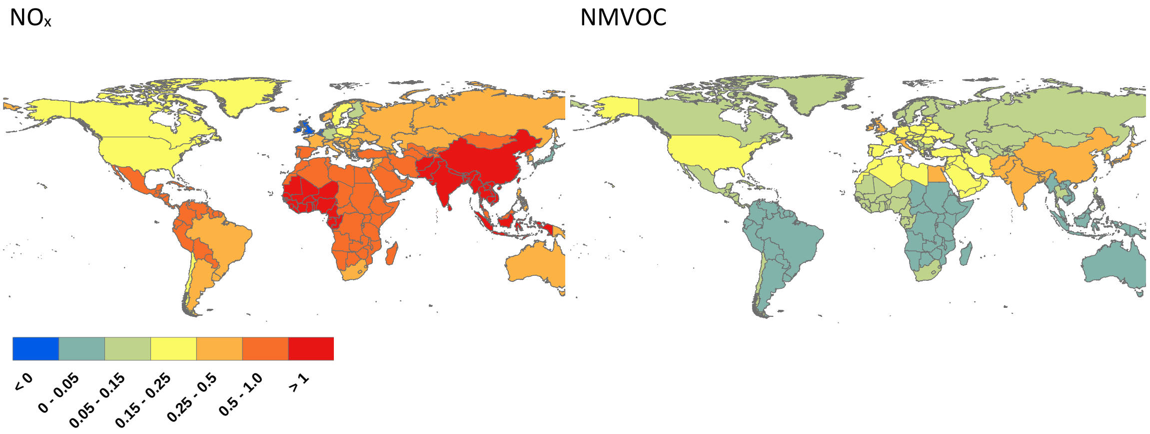

Figure 5.2.: Characterization factors for human health damage caused by ozone formation (10^{-6} DALY·kg^{-1}) (Taken from Van Zelm et al. 2016).

Figure 5.3 shows the region-specific characterization factors for ecosystem damage due to ozone precursor emissions. Lowest factors were obtained for emissions of NMVOC in New Zealand, Mongolia, and Argentina, and for NOx emissions in New Zealand, Taiwan and China. Largest factors were obtained for NOx emissions in Mid America. The emission weighted average for the world for NMVOC is $3.7\cdot10^{-16}$ PDF·yr·kg^{-1}. The emission weighted average for the world for NOx is $1.0\cdot10^{-15}$ PDF·yr·kg^{-1}.

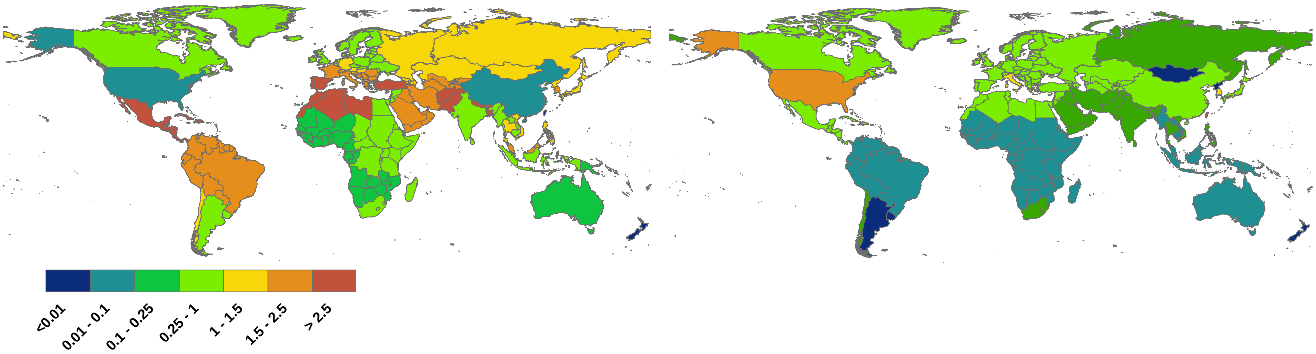

Figure 5.3.: Characterization factors for ecosystem damage caused by ozone formation (10^{-15} PDF·yr·kg^{-1}).

Table 5.1: Country-specific endpoint characterization factors for human health damage and ecosystem damage due to ozone formation.

		Human health damage (DALY·kg^{-1})		Ecosystem damage (PDF·yr·kg^{-1})	
Country	TM5 region	NO_x	NMVOC	NO_x	NMVOC
Afghanistan	RSAS	3.7E-07	5.7E-06	1.1E-16	2.9E-15
Albania	RCEU	1.4E-07	4.9E-07	4.9E-16	2.1E-15
Algeria	NOA	1.7E-07	9.9E-07	7.7E-16	4.9E-15
Angola	SAF	2.3E-08	5.8E-07	2.6E-17	1.9E-16
Argentina	ARG	3.0E-08	3.3E-07	-1.8E-17	9.5E-16
Armenia	RUS	1.4E-07	3.0E-07	4.4E-16	1.1E-15
Aruba	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Australia	AUS	1.8E-08	2.8E-07	2.4E-17	1.1E-16
Austria	AUT	1.9E-07	3.3E-07	7.7E-16	1.0E-15
Azerbaijan	RUS	1.4E-07	3.0E-07	4.4E-16	1.1E-15
Bahamas	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Bahrain	GOLF	1.6E-07	9.7E-07	2.0E-16	1.6E-15
Bangladesh	RSAS	3.7E-07	5.7E-06	1.1E-16	2.9E-15
Barbados	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Belgium	BLX	3.3E-07	-2.2E-07	6.2E-16	2.9E-16
Belize	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Benin	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Bhutan	RSAS	3.7E-07	5.7E-06	1.1E-16	2.9E-15
Bolivia	RSAM	1.6E-08	5.1E-07	2.5E-17	1.6E-15
Bosnia and Herzegovina	RCEU	1.4E-07	4.9E-07	4.9E-16	2.1E-15
Botswana	SAF	2.3E-08	5.8E-07	2.6E-17	1.9E-16
Brazil	BRA	1.8E-08	4.5E-07	5.8E-17	2.5E-15
Brunei	MYS	3.0E-08	7.0E-07	5.1E-17	1.9E-15
Bulgaria	BGR	1.5E-07	3.9E-07	5.8E-16	1.5E-15
Burkina Faso	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Burundi	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Byelarus	UKR	1.6E-07	3.4E-07	5.0E-16	9.3E-16
Cambodia	RSEA	4.4E-08	1.8E-06	9.7E-17	8.3E-16
Cameroon	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Canada	CAN	1.1E-07	2.0E-07	2.6E-16	5.9E-16
Cape Verde	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16

		Human health damage (DALY·kg^{-1})		Ecosystem damage (PDF·yr·kg^{-1})	
Country	TM5 region	NO_x	NMVOC	NO_x	NMVOC
Central African Republic	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Chad	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Chile	CHL	7.6E-08	1.8E-07	1.3E-16	1.1E-15
China	CHN	2.9E-07	1.6E-06	2.9E-16	3.9E-17
China	CHN	2.9E-07	1.6E-06	2.9E-16	3.9E-17
China, Hong Kong Special Administrative Region	CHN	2.9E-07	1.6E-06	2.9E-16	3.9E-17
Colombia	RSAM	1.6E-08	5.1E-07	2.5E-17	1.6E-15
Comoros	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Congo	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Costa Rica	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Croatia	RCEU	1.4E-07	4.9E-07	4.9E-16	2.1E-15
Cuba	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Cyprus	GRC	2.3E-07	4.4E-07	8.2E-16	2.4E-15
Czech Republic	RCZ	1.9E-07	1.6E-07	6.1E-16	6.2E-16
Democratic Republic of the Congo	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Denmark	SWE	1.5E-07	1.9E-07	4.1E-16	3.9E-16
Djibouti	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Dominican Republic	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Ecuador	RSAM	1.6E-08	5.1E-07	2.5E-17	1.6E-15
Egypt	EGY	2.5E-07	6.0E-07	2.6E-16	5.2E-16
El Salvador	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Equatorial Guinea	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Eritrea	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Estonia	POL	1.8E-07	1.8E-07	5.5E-16	6.3E-16
Ethiopia	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Fiji	PAC	1.0E-08	4.5E-07	2.0E-17	2.2E-16
Finland	FIN	1.3E-07	1.1E-07	3.6E-16	2.6E-16
France	FRA	2.4E-07	3.2E-07	8.3E-16	1.6E-15
French Guiana	RSAM	1.6E-08	5.1E-07	2.5E-17	1.6E-15
Gabon	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Gambia, The	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Georgia	RUS	1.4E-07	3.0E-07	4.4E-16	1.1E-15
Germany	RFA	2.5E-07	6.9E-08	6.3E-16	1.3E-15
Ghana	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Greece	GRC	2.3E-07	4.4E-07	8.2E-16	2.4E-15
Greenland	CAN	1.1E-07	2.0E-07	2.6E-16	5.9E-16
Grenada	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Guadeloupe	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Guatemala	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Guinea	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Guinea-Bissau	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Guyana	RSAM	1.6E-08	5.1E-07	2.5E-17	1.6E-15
Haiti	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Honduras	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Hungary	HUN	1.7E-07	2.8E-07	6.0E-16	1.1E-15
Iceland	NOR	1.2E-07	4.5E-07	3.6E-16	7.7E-16
India	NDE	4.1E-07	5.2E-06	2.1E-16	5.6E-16
Indonesia	IDN	1.8E-08	1.0E-06	2.6E-17	8.0E-16
Iran	GOLF	1.6E-07	9.7E-07	2.0E-16	1.6E-15
Iraq	GOLF	1.6E-07	9.7E-07	2.0E-16	1.6E-15
Ireland	GBR	3.2E-07	-1.6E-07	6.0E-16	3.6E-16
Israel	MEME	1.8E-07	4.9E-07	4.2E-16	9.7E-16
Italy	ITA	2.7E-07	4.6E-07	1.3E-15	1.9E-15
Ivory Coast	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Jamaica	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Japan	JPN	2.7E-07	2.3E-09	1.0E-15	1.1E-15
Jordan	MEME	1.8E-07	4.9E-07	4.2E-16	9.7E-16

		Human health damage (DALY·kg^{-1})		Ecosystem damage (PDF·yr·kg^{-1})	
Country	TM5 region	NO_x	NMVOC	NO_x	NMVOC
Kazakhstan	KAZ	1.0E-07	4.0E-07	2.8E-16	1.2E-15
Kenya	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Kuwait	GOLF	1.6E-07	9.7E-07	2.0E-16	1.6E-15
Kyrgyzstan	RIS	1.5E-07	7.0E-07	3.6E-16	2.4E-15
Laos	RSEA	4.4E-08	1.8E-06	9.7E-17	8.3E-16
Latvia	POL	1.8E-07	1.8E-07	5.5E-16	6.3E-16
Lebanon	MEME	1.8E-07	4.9E-07	4.2E-16	9.7E-16
Lesotho	RSA	1.1E-07	4.0E-07	2.0E-16	3.7E-16
Liberia	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Libya	NOA	1.7E-07	9.9E-07	7.7E-16	4.9E-15
Lithuania	POL	1.8E-07	1.8E-07	5.5E-16	6.3E-16
Luxembourg	BLX	3.3E-07	-2.2E-07	6.2E-16	2.9E-16
Macedonia	RCEU	1.4E-07	4.9E-07	4.9E-16	2.1E-15
Madagascar	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Malawi	SAF	2.3E-08	5.8E-07	2.6E-17	1.9E-16
Malaysia	MYS	3.0E-08	7.0E-07	5.1E-17	1.9E-15
Maldives	NDE	4.1E-07	5.2E-06	2.1E-16	5.6E-16
Mali	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Malta	ITA	2.7E-07	4.6E-07	1.3E-15	1.9E-15
Martinique	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Mauritania	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Mauritius	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Mexico	MEX	8.4E-08	5.8E-07	3.4E-16	1.6E-14
Moldova	UKR	1.6E-07	3.4E-07	5.0E-16	9.3E-16
Mongolia	MON	5.0E-08	5.8E-07	-2.6E-16	1.4E-15
Morocco	NOA	1.7E-07	9.9E-07	7.7E-16	4.9E-15
Mozambique	SAF	2.3E-08	5.8E-07	2.6E-17	1.9E-16
Myanmar (Burma)	RSEA	4.4E-08	1.8E-06	9.7E-17	8.3E-16
Namibia	SAF	2.3E-08	5.8E-07	2.6E-17	1.9E-16
Nepal	RSAS	3.7E-07	5.7E-06	1.1E-16	2.9E-15
Netherlands	BLX	3.3E-07	-2.2E-07	6.2E-16	2.9E-16
Netherlands Antilles	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
New Zealand	NZL	8.8E-09	6.2E-08	3.0E-18	4.5E-18
Nicaragua	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Niger	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Nigeria	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
North Korea	MON	5.0E-08	5.8E-07	-2.6E-16	1.4E-15
Norway	NOR	1.2E-07	4.5E-07	3.6E-16	7.7E-16
Oman	GOLF	1.6E-07	9.7E-07	2.0E-16	1.6E-15
Pakistan	RSAS	3.7E-07	5.7E-06	1.1E-16	2.9E-15
Panama	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Papua New Guinea	PAC	1.0E-08	4.5E-07	2.0E-17	2.2E-16
Paraguay	RSAM	1.6E-08	5.1E-07	2.5E-17	1.6E-15
Peru	RSAM	1.6E-08	5.1E-07	2.5E-17	1.6E-15
Philippines	PHL	7.2E-08	4.8E-07	2.4E-16	1.1E-15
Poland	POL	1.8E-07	1.8E-07	5.5E-16	6.3E-16
Portugal	ESP	2.2E-07	6.2E-07	9.8E-16	3.7E-15
Puerto Rico	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Qatar	GOLF	1.6E-07	9.7E-07	2.0E-16	1.6E-15
Reunion	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Romania	ROM	1.6E-07	3.8E-07	5.9E-16	1.6E-15
Russia	RUE	7.7E-08	4.7E-07	2.3E-16	1.0E-15
Russia Europe	RUS	1.4E-07	3.0E-07	4.4E-16	1.1E-15
Rwanda	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Saint Lucia	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Saint Vincent and the Grenadines	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Samoa	PAC	1.0E-08	4.5E-07	2.0E-17	2.2E-16

		Human health damage (DALY·kg^{-1})		Ecosystem damage (PDF·yr·kg^{-1})	
Country	TM5 region	NO_x	NMVOC	NO_x	NMVOC
Saudi Arabia	GOLF	1.6E-07	9.7E-07	2.0E-16	1.6E-15
Senegal	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Serbia	RCEU	1.4E-07	4.9E-07	4.9E-16	2.1E-15
Sierra Leone	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Singapore	MYS	3.0E-08	7.0E-07	5.1E-17	1.9E-15
Slovakia	RCZ	1.9E-07	1.6E-07	6.1E-16	6.2E-16
Slovenia	AUT	1.9E-07	3.3E-07	7.7E-16	1.0E-15
Solomon Islands	PAC	1.0E-08	4.5E-07	2.0E-17	2.2E-16
Somalia	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
South Africa	RSA	1.1E-07	4.0E-07	2.0E-16	3.7E-16
South Korea	COR	5.0E-07	4.1E-07	1.4E-15	1.9E-15
Spain	ESP	2.2E-07	6.2E-07	9.8E-16	3.7E-15
Sri Lanka	NDE	4.1E-07	5.2E-06	2.1E-16	5.6E-16
Sudan	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Suriname	RSAM	1.6E-08	5.1E-07	2.5E-17	1.6E-15
Swaziland	RSA	1.1E-07	4.0E-07	2.0E-16	3.7E-16
Sweden	SWE	1.5E-07	1.9E-07	4.1E-16	3.9E-16
Switzerland	CHE	2.0E-07	4.2E-07	7.1E-16	1.9E-15
Syria	MEME	1.8E-07	4.9E-07	4.2E-16	9.7E-16
Sao Tomo and Principe	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Taiwan	TWN	2.0E-07	1.0E-06	1.0E-14	-2.0E-14
Tajikistan	RIS	1.5E-07	7.0E-07	3.6E-16	2.4E-15
Tanzania, United Republic of	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Thailand	THA	5.3E-08	1.2E-06	1.3E-16	1.1E-15
Togo	WAF	1.1E-07	2.4E-06	5.6E-17	2.4E-16
Tonga	PAC	1.0E-08	4.5E-07	2.0E-17	2.2E-16
Trinidad and Tobago	RCAM	5.9E-08	6.7E-07	3.0E-16	7.2E-15
Tunisia	NOA	1.7E-07	9.9E-07	7.7E-16	4.9E-15
Turkey	TUR	1.9E-07	6.2E-07	7.5E-16	3.7E-15
Turkmenistan	RIS	1.5E-07	7.0E-07	3.6E-16	2.4E-15
Uganda	EAF	4.3E-08	9.7E-07	5.4E-17	4.3E-16
Ukraine	UKR	1.6E-07	3.4E-07	5.0E-16	9.3E-16
United Arab Emirates	GOLF	1.6E-07	9.7E-07	2.0E-16	1.6E-15
United Kingdom	GBR	3.2E-07	-1.6E-07	6.0E-16	3.6E-16
United States	USA	1.9E-07	1.9E-07	1.6E-15	8.0E-17
Uruguay	ARG	3.0E-08	3.3E-07	-1.8E-17	9.5E-16
Uzbekistan	RIS	1.5E-07	7.0E-07	3.6E-16	2.4E-15
Vanuatu	PAC	1.0E-08	4.5E-07	2.0E-17	2.2E-16
Venezuela	RSAM	1.6E-08	5.1E-07	2.5E-17	1.6E-15
Vietnam	VNM	4.3E-08	1.1E-06	1.3E-16	1.3E-15
Western Sahara	NOA	1.7E-07	9.9E-07	7.7E-16	4.9E-15
Yemen	GOLF	1.6E-07	9.7E-07	2.0E-16	1.6E-15
Zambia	SAF	2.3E-08	5.8E-07	2.6E-17	1.9E-16
Zimbabwe	SAF	2.3E-08	5.8E-07	2.6E-17	1.9E-16

Table 5.2: Continent-specific endpoint characterization factors for human health damage and ecosystem damage due to ozone formation.

	Human health damage (DALY·kg^{-1})		Ecosystem damage (PDF·yr·kg^{-1})	
Continent	NO_x	NMVOC	NO_x	NMVOC
World Weighted Average	1.4E-07	9.1E-07	3.7E-16	1.0E-15
Africa	6.4E-08	1.1E-06	9.1E-17	6.0E-16
Asia	1.9E-07	2.0E-06	3.5E-16	3.6E-16
Europe	1.6E-07	3.1E-07	4.9E-16	1.4E-15
North America	1.7E-07	1.9E-07	1.3E-15	1.4E-16
Oceania	1.7E-08	2.7E-07	2.3E-17	1.1E-16
South America	3.0E-08	4.9E-07	9.8E-17	5.2E-15

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