3.Stratospheric ozone depletion

Zoran Steinmann[1]*, Mark A.J. Huijbregts*[1]

[1] Department of Environmental Science, Radboud University Nijmegen, The Netherlands

* z.steinmann@science.ru.nl

3.1. Areas of protection and environmental mechanisms covered

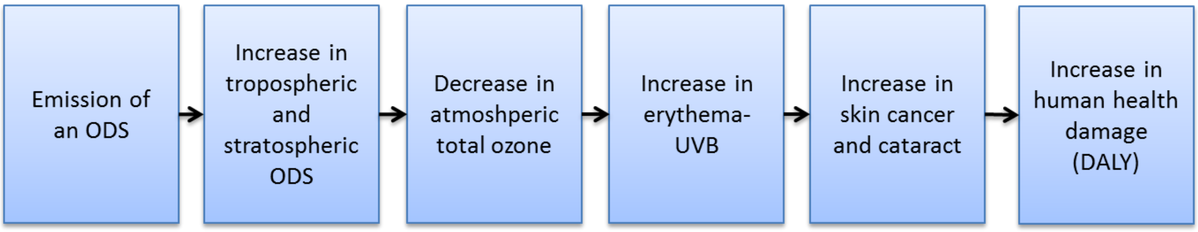

Figure 3.1: Cause-and-effect chain for emissions of ozone depleting substances (ODS) resulting in human health damage (from: Huijbregts et al. 2014)

The ozone layer in the stratosphere absorbs a large part of the harmful UV-radiation coming from the sun. In the natural situation ozone is continuously being formed and destroyed. However, a number of man-made chemicals that contain fluorine, bromine and chlorine groups, called Ozone Depleting Substances (ODS), can greatly increase the rate of destruction, leading to a reduction in the thickness of the ozone layer. With the thickness of the layer reduced, more of the UV-B radiation will reach the earth's surface. Increased exposure to UV-B radiation can lead to adverse human health effects (Figure 3.1), such as skin cancer and cataract, and effects on ecosystems. The latter are, however, not considered here, meaning that the only area of protection that is covered is human health.

3.2. Calculation of the characterization factors at endpoint level

The procedure we follow here is equal to the procedure from the latest ReCiPe report (Huijbregts et al., 2014). The World Meteorological Organization (WMO) reports the Ozone Depletion Potential (ODP) for 21 different substances (WMO, 2011) these ODPs were used for the calculation of the CFs. The ODP, as reported by the WMO, represents the amount of ozone destroyed by a substance during its entire lifetime relative to the amount of ozone destroyed by CFC-11 during its entire lifetime. Equation 3.1 shows the characterization factor CF_{end} at endpoint level. It consists of the ozone depletion potential (ODP) for substance x with time horizon TH and the effect factor EF for the reference substance CFC-11 for time horizon *TH*.

$$CF_{end,x,TH} = ODP_{x,TH} \cdot EF_{CFC-11,TH}$$

Equation 3.1

The WMO (2011) uses a semi-empirical approach to calculate the ODPs. Observational data from different air layers is used to predict the release of the bromine and chlorine groups from an ODS. Each bromine group has approximately 60 times (65 in arctic regions) more potency to destroy ozone than a chlorine group. By taking into account the release of the chlorine and bromine groups and their potencies the change in Equivalent Effective Stratospheric Chlorine (EESC) resulting from the release of 1 kg of ODS was calculated. By dividing this value by the EESC effect of CFC-11 one can calculate the ODP as follows (equation 3.2):

$$ODP_{inf,x} = \frac{\Delta EESC_x}{\Delta EESC_{CFC-11}}$$

Equation 3.2

Where the $ODP_{inf,x}$ is the ODP for an infinite time horizon for ODS *x*, $\Delta EESC_x$ and $\Delta EESC_{cfc-11}$ are the changes in EESC caused by the emission of 1 kg of ODS *x* and 1 kg of CFC-11 respectively (Equation 3.2 and description from Huijbregts et al. 2014).

The ODPs from WMO are all based on an infinite time horizon, for a 100 year time horizon a correction is needed to calculate the fraction of the bromine and chlorine that is released during the first 100 years of the lifetime. Equal to the approach followed in ReCiPe we used the equation from De Schryver et al. (2011) (equation 3.3).

$$F_t = 1 - e^{(-t-3)\cdot k}$$

Equation 3.3

Where F_t is the fraction of the total damage caused by an ODS during the first *t* years, *k* is the removal rate of the ODS (yr^{-1}) which is the inverse of the atmospheric life time and the 3 is the average time (in years) that is needed for transport from the troposphere to the stratosphere. This fraction F_t is then multiplied with $ODP_{inf,x}$ to get to the $OPD_{x,TH}$ with a finite time horizon TH.

The amount of damage caused by exposure to UV-B radiation has been quantified by Hayashi et al. (2006), a summarizing, qualitative formula of the effect factor is shown in Equation 3.4. For more details, see Hayashi et al. (2006).

$$EF = f(OLT, UVB, s, i, j, x)$$

Equation 3.4

This equation shows that the effect factor is a function of the ozone layer thickness (*OLT*), the resulting UVB radiation (*UVB*) that reaches the surface as a response to this ozone layer thickness, the season (*s*), latitudinal zone (*i*), population number of skin type (*j*) and skin cancer type (*x*) (note: damage by cataract was calculated in a similar matter, but is independent of the skin type).

The effect of EESC on ozone layer thickness was determined by historical observational data, using year 1980 as a reference year because prior to this year anthropogenic effects on ozone layer thickness were considered negligible. The effect of EESC depends on both the season as well as the latitude. Therefore Hayashi et al. (2006) used a model with latitudinal zones of degrees and four different seasons to calculate the amount of UV-B radiation that reaches the surface. The optical thickness of the ozone layer rather than the actual thickness determines the amount of direct or scattered UV-B radiation that reaches the surface. To correct for this difference, a linear regression between actual and optical thickness was used.

Three different types of skin cancer (malignant melanoma (MM), basal cell carcinoma (BCC) and squamous cell carcinoma (SCC)) were linked to UV-B radiation. The DALY concept was used to determine the severity of each of these cancers. The incidence rate of these cancers is inversely related to the amount of pigments in the skin. In order to take this into account, the percentage of people with different skin colours (white, yellow or black) was determined per longitudinal zone. The resulting damage in human health was 5.91E-04 yr/kg CFC-11 eq (for an infinite time horizon). For a 100 year time horizon this value is 10% lower (5.34 E-04 yr/kg CFC-11 eq). If the effect of cataract is also taken into account (infinite time horizon only) this factor increases to 1.34E-03 yr/kg CFC-11 eq. The resulting endpoints CFs are listed in table 3.1 for 22 ozone depleting substances.

3.3. Uncertainties

The CFs for this impact category are based on reported data from existing literature. Assessing the sensitivity of the CFs to uncertainties in the individual parameters is therefore only possible to a limited extent and is dependent on the reported data in the original reports. Uncertainties in the lifetimes as well as the estimated and projected emissions of the different ODSs are described by the WMO (2011). The resulting uncertainty in the projected total EESC is moderate, a clear downward trend in total EESC is observed and this trend is expected to continue in the future. The year at which the levels return to the national background concentration is dependent on both the future emissions as well as the projected climate change. According to the WMO scenario's it is likely that the EESC levels will continue to drop significantly within the coming 30 to 50 years, perhaps even to a level where there is hardly any expected negative impact form ODS emissions. It is not certain whether we will reach this level because of the expected increase in N_2O and uncertain developments in the future climate. Therefore impacts of long-lived substances integrated over time horizons longer than 100 years should be considered highly uncertain and it is likely that their impact is overestimated. Unfortunately no direct quantitative assessment of the uncertainty on the level of the ODPs is provided by the WMO. ODPs are uncertain both because of uncertainties in the fractional release of chlorine and bromine and the lifetime of the ODS compared to that of the reference substance CFC-11. In general the lifetimes and therefore the ODPs of the shorter lived substances are more uncertain than those of the longer lived ones, which would result in more uncertain ODPs.

Additional uncertainty is present in the damage factors. As Hayashi et al. (2006) state, a more detailed assessment of these uncertainties is required; unfortunately no quantitative estimates are provided in their publication. However, it is likely that there is model uncertainty in the models that project the increase in UV-B radiation reaching the surface, as well as in the fraction of people with different skin colours in each region and the additional cancer incidences resulting from that increased exposure to UV-B radiation. For future impacts, the projected population developments (and the distribution of people with different skin colours within those populations) are uncertain. The (implicit) assumption that this population remains stable is likely to cause an underestimation of the impact, especially in regions with a large projected population growth such as Africa.

3.4. Value choices

The different ODSs have widely varying atmospheric lifetimes, ranging from 0.8 years for CH_3Br to 1020 years for CFC-115. Therefore the CF is time-horizon dependent. The effects over the first 100 years are considered to be certain and robust. Effects in a longer time horizon are more uncertain, because of unknown future emissions as well as uncertain climate and population developments.

There is strong evidence of the link between UV radiation and skin cancer incidence. The evidence for a link with cataract is much weaker and these effects should therefore be considered to have a low robustness (Table 3.1). The mechanism by which bromine and chlorine containing substances destroy ozone is well known and understood. Nitrous oxide (N_2O) also has an ozone depleting capacity (but no bromine or chlorine groups) whether or not to include this substance should be included can be seen as a value choice. In this analysis we chose to include N_2O, as also recommended in literature (Ravishankara et al. 2010; WMO, 2011). This division of the value choices gives a CF with a high level of robustness that is equal to the Hierarchist CF in the latest ReCiPe update (Huijbregts et al., 2014), while the total CF is equal to the Egalitarian CF for all substances.

Table 3.1: Value choices in the modelling of CFs for core and extended value choices (i.e. what is added to get from core to extended vaues)

Choice category	Core	Addition in extended	Source
Time horizon	100 yr	100 yr - Infinite	De Schryver et al. (2011)
Included effects	Skin cancer	Cataract	

Table 3.2: The characterization factors for ozone depleting substances at the core level (100 year time horizon, skin cancers only) and for the extended version (infinite time horizon, additional effects of skin cancers and cataract), representing human health damage expressed as DALYs (DALY/kg ODS = y/kg ODS).

Substance	HH, core [DALY/kg ODS]	HH, extended [DALY/kg ODS]
Annex A-I		
CFC-11	5.31E-04	1.34E-03
CFC-12	3.12E-04	1.10E-03
CFC-113	3.53E-04	1.14E-03
CFC-114	1.43E-04	7.80E-04
CFC-115	3.24E-05	7.67E-04
Annex A-II		
Halon-1301	7.47E-03	2.14E-02
Halon-1211	4.66E-03	1.06E-02
Halon-2402	7.64E-03	1.75E-02
Annex B-II		
CCl4	4.75E-04	1.10E-03
Annex B-III		
CH3CCl3	9.46E-05	2.15E-04
Annex C-I		
HCFC-22	2.36E-05	5.38E-05
HCFC-123	5.91E-06	1.34E-05
HCFC-124	1.18E-05	2.69E-05
HCFC-141b	7.09E-05	1.61E-04
HCFC-142b	3.54E-05	8.07E-05
HCFC-225ca	1.18E-05	2.69E-05
HCFC-225cb	1.77E-05	4.03E-05
Annex E		
CH3Br	3.90E-04	8.88E-04
Others		
Halon-1202	1.00E-03	2.29E-03
CH3Cl	1.18E-05	2.69E-05
N2O	5.64E-06	2.29E-05

3.5. References

De Schryver, A. M., Van Zelm, R., Humbert, S., Pfister, S., McKone, T. E., & Huijbregts, M. A. (2011). Value choices in life cycle impact assessment of stressors causing human health damage. Journal of Industrial Ecology, 15(5), 796-815.

Hayashi, K., Nakagawa, A., Itsubo, N., & Inaba, A. (2006). Expanded Damage Function of Stratospheric Ozone Depletion to Cover Major Endpoints Regarding Life Cycle Impact Assessment (12 pp). The International Journal of Life Cycle Assessment, 11(3), 150-161.

Huijbregts M.A.J., Steinmann Z.J.N., Stam G., Van Zelm R. (2014). Update of emission-related impact categories in ReCiPe2008. Department of Environmental Science, Radboud University Nijmegen.

Ravishankara AR, Daniel JS, Portmann RW, 2009. Nitrous oxide (N2O): the dominant ozone-depleting substance emitted in the 21st century. Science 326,123–125.

WMO (2011) Scientific assessment of ozone depletion: 2010, Global Ozone Research and Monitoring Project-report no.52. World Meteorological Organization, Geneva