International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

Interim Report **IR-03-047**

The Effects of Traffic on Human Health of Local Residents

Arjen Meijer (ameijer@ivam.uva.nl)

Approved by

Leen Hordijk (hordijk@iiasa.ac.at)
Director

November 12, 2004

Contents

Abstract

In this study, a model is proposed to evaluate the local human health damage caused by (changes in) road traffic on a particular road. These damages are due to global health effects occurring due to the traffic life cycle, as assessed in standard life cycle assessments, and to exposure of local residents to noise and outdoor pollutants originating from road traffic on the road considered. The results of this model were compared with the global human health damage occurring in the life cycle of both traffic and dwellings.

The fate factor calculation for pollutants is based on the Dutch CAR model, which relates traffic densities to pollutant concentrations at the façade of dwellings, and on an indoor airflow and exposure model. The effect and damage factors for pollutants are derived from the Eco-Indicator 99 methodology. For noise, the calculation of the fate, effect and damage factor is derived from a methodology developed by the Swiss Agency for the Environment, Forests and Landscape SAEFL to integrate the human health effects of noise due to road traffic in life cycle assessments.

It appears that for someone living in a dwelling along a street local health damage due to changes in road traffic situations may be of the same order of magnitude as the human health damage associated with the life cycle of dwellings as calculated by standard LCA methodologies. Compared to the human health damage occurring in the life cycle of vehicles as calculated by standard LCA procedures, the local human health damage may be two to three orders of magnitude larger. The local human health effects due to (changes in) road traffic situations thus cannot be neglected when carrying out life cycle assessments of dwellings or complete residential areas.

For the road studied, the magnitude of the effect of a decrease in road traffic density on the human health are smaller when the initial number of cars per hour is smaller than 50 or when the distance of the façade to the road axis is more than eight meter. This is because for noise levels there are thresholds to impact.

In the future, the improvement of the model, the addition of the effects of other means of transport and the assessment of real neighbourhoods might be carried out.

Acknowledgments

I would like express my gratitude to Prof. Dr. Edgar Hertwich, previously staff member of the General Research Project (Sustainable Consumption) of the International Institute for Applied Systems Analysis (IIASA) and now professor at the Norwegian University of Science and Technology (NTNU), for his supervision, excellent feedback and comments on this study.

I would also like to thank Dr. Klaus Hubacek, Ecological Economist from the School of the Environment at the University of Leeds, United Kingdom and affiliated with the General Research Project (Sustainable Consumption) of IIASA, Prof. Dr. Lucas Reijnders, professor at the department of Environmental Sciences of the Universiteit van Amsterdam, and Dr. Mark Huijbregts, associate professor at the department of Environmental Sciences of the University of Nijmegen, for their valuable feedback on my work.

The finances for this research were made available by the Netherlands Organisation for Scientific Research (NWO).

And finally, I would like to thank my office mates Takuya Hara and Katarina Korytarova, the other participants of the Young Scientists Summer Program (YSSP), the other staff members of IIASA and Margaret Traber, the YSSP coordinator, for the wonderful mixture of research, recreation and international contacts I have experienced during the YSSP in the summer of 2003.

Arjen Meijer

About the Authors

Arjen Meijer received his Masters in Environmental Sciences in 1999 at the University of Nijmegen, The Netherlands. In 2000, he started his PhD study at the department of Environmental Sciences of the Universiteit van Amsterdam, The Netherlands.

The goal of his research is the improvement of the environmental assessment of dwellings based on life cycle assessment, by among other things the incorporation of the indoor environment. Furthermore, he will compose a dwelling with maximum practicable efforts to reduce the environmental impact and compare it with a reference dwelling in order to examine to what extend the environmental impact of dwellings can be decreased reasonably.

In 2003, he participated in the Young Scientists Summer Program (YSSP) at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria. Under the supervision of Prof. Dr. Edgar Hertwich, he conducted a research on the local human health effects of road traffic at the General Research Project, Sustainable Consumption.

The effects of traffic on human health of local residents

Arjen Meijer

Chapter 1: Introduction

Sustainable building is getting increasing attention. Especially in view of energy saving, sustainable material consumption and human health, measures are taken to decrease the environmental impact of buildings.

One of the problems that occur in the process of designing a sustainable dwelling is to determine what measures have a lower environmental impact than others, especially when conflicts occur, like when energy-saving measures cause higher material inputs. One way to compare the environmental effects of measures, sets of measures or even total buildings in a quantitative way is to use life cycle assessment (LCA). In an LCA, a product or service is assessed from the cradle (the winning of raw materials) to the grave (waste management). Several impact categories can be taken into account, like human health damage, ecosystem damage as a result of acidification or eutrophication, or resource depletion.[1,2]

There are several LCA methodologies for dwellings, of which Eco-Quantum is an example.[3] Although the wide-ranging environmental effects are well described, local effects like the human health of local residents are not included. In most LCAs, local effects are not described because of the generic character of the methodology. But for dwellings, health effects associated with indoor exposure to radon, particulate matter (PM_{10}) and formaldehyde are in the same order of magnitude as health effects due to outdoor pollution associated with the dwelling life cycle.[4] Thus for dwellings, it is important to take the local health aspects into account.

In a study performed by Meijer *et al.*, the damage to human health of indoor pollutants originating from building materials, like volatile organic compounds and radon, has been determined.[4,5] In dwellings, there are also other sources of health damage, like radon exhaled from the soil, traffic pollutants and traffic noise. In this study, the health effects of noise and pollutants (substances) originating from road traffic are regarded.

Traffic has negative environmental impacts. Therefore, measures are advocated ranging from better public transport services in the district to car-free neighbourhoods. The effects of these measures, however, have not been included in the LCA of dwellings yet.

The goal of this research is the integration of the environmental impacts of traffic in life cycle assessment of dwellings. These impacts are global health effects occurring in the traffic life cycle as calculated by standard LCA procedures, and the quality of life due to exposure to noise and several pollutants originating from traffic sources.

It is impossible to assess all effects of all traffic categories in this research. Therefore, the following boundaries are applied to this research:

- Only the environmental effects of motorized road vehicles are included in this research. Effects of e.g. trains and airplanes are not included.
- Only the health effects of noise and pollutants are assessed in this research. Effects of e.g. traffic accidents are not included.
- Only certain human health effects are assessed. This is explained in the description of the methodology.

The assessed situations are simple. Accumulation of pollutants in a valley location, effects of strong winds and other uncommon effects are not taken into account in this study. Also noise reflection is not taken into account.

The wide-ranging effects occurring in the traffic life cycle can be calculated using standard life cycle assessment methodologies.[1,2] Therefore, this methodology is not dealt with in this research. The results of this assessment can be found in several LCA databases.[6]

In Chapter 2, the methodology is described. First, the use of impact scores is outlined and the human health effects are listed. Then the determination of the emissions and the calculation of the fate factor, effect factor and damage factor are given for noise and pollutants.

The results of the research are given in Chapter 3. The relation between health impact and distance to the road is determined, as well as the effects of lower car use. The local and global health effects of traffic are compared, and the health effects of traffic are compared with the other health effects occurring in the life cycle of dwellings.

The methodology and the results are discussed in Chapter 4. The model restrictions, uncertainties in the model and missing data are dealt with. Finally, the conclusions are drawn and recommendations for further research are given in Chapter 5.

Chapter 2: Methodology

2.1 Calculation procedure

In the LCA methodology, characterisation factors are used to calculate the combined environmental impact of products or services occurring in the life cycle of a product. The impact score of a product or service p can be calculated as follows:[7]

$$IS_p = \sum_x M_{x,p} \cdot Q_x \qquad (1)$$

where IS_p is the impact score for product or service p (e.g. disability adjusted lost years per kg product ($DALY \cdot kg_p^{-1}$) or per (additional) vehicle kilometre ($DALY \cdot km_v^{-1}$)); $M_{x,p}$ is the emission of substance x from product or service p (e.g. $kg_x \cdot kg_p^{-1}$, $kg_x \cdot km_v^{-1}$ or $dB(A) \cdot km_v^{-1}$); and Q_x is the characterisation factor of substance x (e.g. $DALY \cdot kg_x^{-1}$ or $DALY \cdot dB(A)$).

As the calculations regard damage to human health, the characterisation factors can be calculated as follows:[1]

$$Q_x = F_x \cdot \sum_k E_{x,k} \cdot D_{x,k} \qquad (2)$$

where F_x is the fate factor of substance x (-); $E_{x,k}$ is the effect factor of substance x for human health impact category k (e.g. cancer cases$\cdot kg^{-1}$ absorbed substance x or cases of sleep disturbance$\cdot dB(A)^{-1}$); and $D_{x,k}$ is the damage factor of substance x for human health impact category k ($DALY \cdot case^{-1}$).

The calculation of the fate factors for pollutants is derived from the CAR model[9] and from an indoor airflow and exposure model.[5] The CAR model (Calculation of Air pollution from Road traffic) has been developed by TNO to calculate the air quality at and along roads. The calculation of the effect and damage factors for pollutants is described in the Eco-Indicator 99 methodology.[1] For noise, the calculation of the fate factor, effect factor and damage factor is derived from a Swiss methodology to integrate the human health effects of road traffic noise in life cycle assessments.[8]

In section 2.2, the health effects of pollutants (substances) and noise are listed. In section 2.3, the calculation of the emissions is described. In sections 2.4, 2.5 and 2.6, the calculation of respectively the fate factor, the effect factor and the damage factor for both pollutants and noise is given.

2.2 Health effects

2.2.1 Health effects of pollutants

In the Eco-indicator 99 methodology, the health damages of pollutants are divided in several categories distinguished by cause: [1]

- carcinogenic effects;
- respiratory effects;
- climate change;
- ionizing radiation;
- ozone layer depletion.

In this research, only the first two cases are regarded because of the local nature of them. Additionally, other non-carcinogenic effects like teratogenic effects are taken into account when data are available.[5]

2.2.2 Health effects of noise

There are several health effects that have been associated with exposure to high noise levels:[8]

- Interference with communication like conversation, listening to music and interference with more intellectually demanding tasks;
- Sleep disturbances;
- Cardiovascular and physiological effects;
- Hearing damage;
- Psychological disturbances of various kinds;
- Effects of nuisance like aggressiveness, depression and irritability.

Only the first two effects are taken into account in this research, together with heart attacks. The other effects are left out of the research, either because they have no relevance to road-traffic noise (e.g. because the noise levels are too low to induce hearing damage), or there are too little data available due to unclear cause-effect relationships.[8]

2.3 Emissions

2.3.1 Pollutants

In this research, impacts on residents along a road due to pollution generated by vehicles on the road considered are calculated and differences therein associated with differences in traffic.

The emission of pollutants by vehicles depends on several factors like the vehicle category, vehicle speed, fuel, brand, age, speed, road slope, wind speed and wind direction. It is impossible to include all factors in the model. Therefore, an average emission per vehicle category and per speed category is used. These averages are different for different countries, because of different occurrences of vehicle categories and of different fuel preferences.

The vehicle categories considered are described in Table 1. The speed categories are described in Table 2.

Table 1: Description of vehicle categories[9]

Vehicle category	Description
Motorcycles	Motorcycles on two wheels, possibly with sidecar
Light motor vehicles	Motor vehicles on three or more wheels and not in the other vehicle categories
Medium-weighed motor vehicles	All busses and unarticulated vehicles equipped with one rear axle with four tires
Heavy motor vehicles	Articulated motor vehicles and motor vehicles with double rear axles other than busses

Table 2: Description of speed categories[9]

Speed category	Average speed ($km \cdot h^{-1}$)
Highway	100
Countryside road	44
Continuous flowing town traffic	26
Normal town traffic	19
Obstructed town traffic	13

In Table 3, the emission factors of the different vehicle categories per speed category are given for the Dutch situation in 2002.[9]

The total emission of vehicles on a certain road per meter for the duration of the traffic situation can be calculated as follows:

$$M_x = T \cdot \sum_c MF_{x,c} \cdot VD_c \qquad (3)$$

where M_x is the emission of pollutant x by traffic ($kg \cdot m^{-1}$) for the duration of the traffic situation; T is the duration of the traffic situation (h); $MF_{x,c}$ is the emission factor for pollutant x by vehicle category c ($kg \cdot m^{-1} \cdot vehicle^{-1}$); and VD_c is the vehicle density of vehicle category c ($vehicle \cdot h^{-1}$).

Table 3: Emission factors ($kg \cdot m^{-1} \cdot vehicle^{-1}$)[9]

Vehicle category	Speed category	NO_x	PM_{10}	CO	SO_2	Benzene	Benzo[a] pyrene
Light motor vehicles	Highway	$7.4 \cdot 10^{-7}$	$5.1 \cdot 10^{-8}$	$1.9 \cdot 10^{-6}$	$9.0 \cdot 10^{-9}$	$7.8 \cdot 10^{-9}$	$7.0 \cdot 10^{-13}$
Light motor vehicles	Countryside road	$5.5 \cdot 10^{-7}$	$6.0 \cdot 10^{-8}$	$2.4 \cdot 10^{-6}$	$1.0 \cdot 10^{-8}$	$1.3 \cdot 10^{-8}$	$1.3 \cdot 10^{-12}$
Light motor vehicles	Continuous flowing town traffic	$7.2 \cdot 10^{-7}$	$9.4 \cdot 10^{-8}$	$4.5 \cdot 10^{-6}$	$1.3 \cdot 10^{-8}$	$2.6 \cdot 10^{-8}$	$2.6 \cdot 10^{-12}$
Light motor vehicles	Normal town traffic	$7.9 \cdot 10^{-7}$	$1.1 \cdot 10^{-7}$	$5.4 \cdot 10^{-6}$	$1.5 \cdot 10^{-8}$	$3.1 \cdot 10^{-8}$	$3.1 \cdot 10^{-12}$
Light motor vehicles	Obstructed town traffic	$8.7 \cdot 10^{-7}$	$1.3 \cdot 10^{-7}$	$6.4 \cdot 10^{-6}$	$1.7 \cdot 10^{-8}$	$3.6 \cdot 10^{-8}$	$3.6 \cdot 10^{-12}$
Medium-weighed motor vehicles	Highway	$6.5 \cdot 10^{-6}$	$2.6 \cdot 10^{-7}$	$1.4 \cdot 10^{-6}$	$5.3 \cdot 10^{-8}$	$1.1 \cdot 10^{-8}$	$9.4 \cdot 10^{-12}$
Medium-weighed motor vehicles	Countryside road	$5.9 \cdot 10^{-6}$	$3.2 \cdot 10^{-7}$	$1.4 \cdot 10^{-6}$	$5.1 \cdot 10^{-8}$	$1.6 \cdot 10^{-8}$	$1.4 \cdot 10^{-11}$
Medium-weighed motor vehicles	Continuous flowing town traffic	$6.8 \cdot 10^{-6}$	$4.2 \cdot 10^{-7}$	$2.0 \cdot 10^{-6}$	$6.3 \cdot 10^{-8}$	$2.7 \cdot 10^{-8}$	$2.3 \cdot 10^{-11}$
Medium-weighed motor vehicles	Normal town traffic	$7.2 \cdot 10^{-6}$	$4.6 \cdot 10^{-7}$	$2.2 \cdot 10^{-6}$	$6.8 \cdot 10^{-8}$	$3.1 \cdot 10^{-8}$	$2.7 \cdot 10^{-11}$
Medium-weighed motor vehicles	Obstructed town traffic	$9.5 \cdot 10^{-6}$	$6.0 \cdot 10^{-7}$	$2.9 \cdot 10^{-6}$	$8.2 \cdot 10^{-8}$	$4.3 \cdot 10^{-8}$	$3.8 \cdot 10^{-11}$
Heavy motor vehicles	Highway	$1.1 \cdot 10^{-5}$	$2.7 \cdot 10^{-7}$	$1.2 \cdot 10^{-6}$	$7.0 \cdot 10^{-8}$	$8.0 \cdot 10^{-9}$	$6.9 \cdot 10^{-12}$
Heavy motor vehicles	Countryside road	$1.1 \cdot 10^{-5}$	$3.5 \cdot 10^{-7}$	$2.1 \cdot 10^{-6}$	$8.2 \cdot 10^{-8}$	$1.8 \cdot 10^{-8}$	$1.6 \cdot 10^{-11}$
Heavy motor vehicles	Continuous flowing town traffic	$1.3 \cdot 10^{-5}$	$4.0 \cdot 10^{-7}$	$2.7 \cdot 10^{-6}$	$1.0 \cdot 10^{-7}$	$2.7 \cdot 10^{-8}$	$2.4 \cdot 10^{-11}$
Heavy motor vehicles	Normal town traffic	$1.4 \cdot 10^{-5}$	$4.2 \cdot 10^{-7}$	$2.9 \cdot 10^{-6}$	$1.1 \cdot 10^{-7}$	$3.0 \cdot 10^{-8}$	$2.7 \cdot 10^{-11}$
Heavy motor vehicles	Obstructed town traffic	$1.8 \cdot 10^{-5}$	$5.3 \cdot 10^{-7}$	$3.8 \cdot 10^{-6}$	$1.3 \cdot 10^{-7}$	$4.2 \cdot 10^{-8}$	$3.7 \cdot 10^{-11}$

2.3.2 Noise

Noise levels are on a logarithmic scale. The noise level is calculated for a certain traffic situation, taking into account the number of cars per hour and the average speed. This is outlined in the description of the fate factor calculation. In this methodology, only the noise of car engines and wheel-to-pavement contact are taken into account. House vibrations and rattles are left out of the assessment.

2.4 Fate factors

2.4.1 *Pollutants*

The calculation of the fate factor for pollutants emitted by road vehicles exists of three parts: the fate factor from the vehicle emission to the outside façade of the dwelling, the fate factor from outside to inside the dwelling and the fate factor from the entrance of the pollutants to the adsorption by the inhabitants of the dwelling. The last two fate factors are different for several compartments in the dwelling (see Figure 1). This is reflected in formula (4):

$$F_x = F_{x,ef} \cdot \sum_a F_{x,fi,a} \cdot F_{x,ii,a} \quad (4)$$

where F_x is the fate factor for pollutant x emitted by road traffic (m); $F_{x,ef}$ is the fate factor for pollutant x from emission source to the façade of the dwelling ($s \cdot m^{-2}$); $F_{x,fi,a}$ is the fate factor for pollutant x from the façade of the dwelling to the indoor air of compartment a ($m^3 \cdot s^{-1}$); and $F_{x,ii,a}$ is the fate factor for pollutant x from the indoor air in compartment a to the inhabitants of the dwelling (-). This pathway is given schematically in Figure 1. It is assumed that the affected dwellings are all the same.

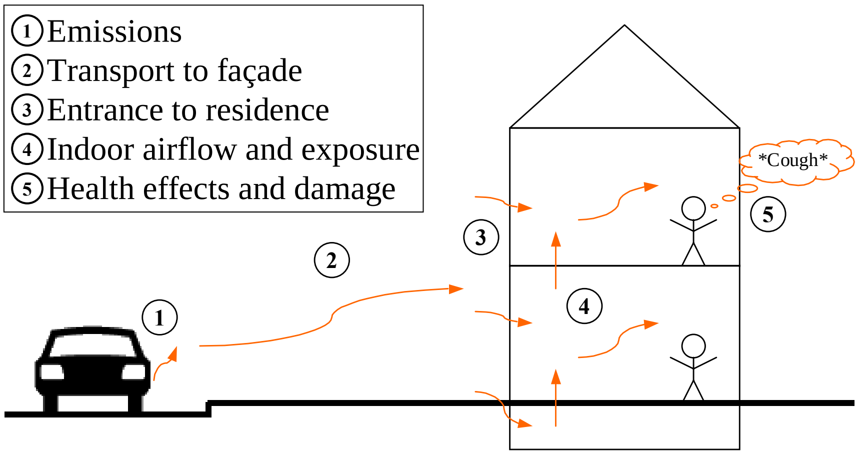

Figure 1: Pollutant transport route

The fate factor $F_{x,ef}$ for pollutant x from the vehicle emission to the façade of the dwelling is derived from the CAR model.[9] With this semi-empirical model, it is possible to calculate the concentration of several traffic pollutants at the façade of dwellings along a certain road from the emission factors (in $g \cdot km^{-1} \cdot vehicle^{-1}$) of the traffic at that road. The CAR model provides for several years (including future estimates) emission factors and meteorological data for past years, unfavourable years (with low wind speeds) and 10-year averaged values. Recent validation proved that the CAR model complies with the demands made on it by Dutch air quality regulations.[10]

The fate factor $F_{x,ef}$ can be calculated as follows:[9]

$$F_{x,ef} = \theta \cdot CF_t \cdot CF_m \quad (5)$$

where is the dilution factor (-); CF_t is the tree factor (-); and CF_m is the regional meteorological conversion factor ($s \cdot m^{-2}$). The dilution factor can be calculated as follows:

$$\theta = a \cdot S^2 + b \cdot S + c \qquad (6)$$

where *a*, *b*, and *c* are dilution parameters (respectively m^{-2}, m^{-1} and dimensionless); and *S* is the distance from the road axis to the façade of the dwelling (m).

The dilution parameters *a*, *b* and *c* are dependent of the road type. The road types are given in Table 4.[9] Road type 1 seldom occurs in neighbourhoods, and the calculation of the dilution factor is different for this road type. Therefore, this road type is left out of the model.

The dilution parameters belonging to the different road types are given in Table 5.[9]

Table 4: Description of the road types[9]

Road type	Characteristics
1	Open terrain, incidental building or trees
2	Other roads
3a	Buildings at both sides of the road; distance of road axis to façade is smaller than three times and larger than 1.5 times building height
3b	Buildings at both sides of the road; distance of road axis to façade is smaller than 1.5 times building height
4	Buildings at one side of the road; distance of road axis to façade is smaller than three times building height

Table 5: Dilution parameters per road type[9]

Road type	Parameter *a* (m^{-2})	Parameter *b* (m^{-1})	Parameter *c* (-)
2	$3.1 \cdot 10^{-4}$	$-1.82 \cdot 10^{-2}$	0.33
3a	$3.25 \cdot 10^{-4}$	$-2.05 \cdot 10^{-2}$	0.39
3b	$4.88 \cdot 10^{-4}$	$-3.08 \cdot 10^{-2}$	0.59
4	$5.00 \cdot 10^{-4}$	$-3.16 \cdot 10^{-2}$	0.57

The tree factor CF_t is given in Table 6.

Table 6: Description of the tree factors[9]

Tree factor	Description
1	No or some trees
1.25	One or more rows of trees with distance smaller than 15 meter between each tree and gaps between the tree crowns
1.5	The tree crowns touch each other and span at least one third of the road width

The regional meteorological conversion factor CF_m is given in the CAR model.[9] In this study, the Dutch 10-year averaged data are used, which are weighed over the regions where these data are applied. This yields a value of 1.22 $s \cdot m^{-2}$.[9]

The fate factor $F_{x,fi,a}$ for pollutant *x* from the façade of the dwelling to the indoor air in compartment *a* can be calculated as:

$$F_{x,fi,a} = f_{oa} \cdot CF_{r,x,a} \qquad (7)$$

where f_{oa} is the air entrance rate from the outdoor air to compartment *a* ($m^3 \cdot s^{-1}$); and $CF_{r,x,a}$ is the fraction of pollutant *x* present in the inflow that enters compartment *a* (-).

The air entrance rate f_{oa} is calculated in an indoor air model for the Dutch standard dwelling.[5] The values are given in Table 7. In this study, it is assumed that the fraction of the pollutants that enters the dwelling is 1.

The fate factor $F_{x,ii,a}$ for pollutant *x* from the indoor air in compartment *a* to the inhabitants of the dwelling can be calculated as follows:[5]

$$F_{x,ii,a} = \frac{IR}{f_{e,a}} \cdot N \qquad (8)$$

where *IR* is the inhalation rate of humans ($m^3 \cdot y^{-1}$); $f_{e,a}$ is the effective outgoing airflow for an emission to compartment *a* ($m^3 \cdot y^{-1}$); and *N* is the number of persons living in the examined neighbourhood (-).

The effective outgoing airflow $F_{x,ii,a}$ is the weighed sum of the airflows leaving all compartments. It reflects the pollutant transport between the compartments and the time fraction the residents spend in the compartments. The detailed calculation is carried out using an indoor air and exposure model.[5] For a situation with two residents living in a Dutch standard dwelling, spending 50% of their lifetime in the first floor and 30% in the second floor, the results are given in Table 7.

Table 7: **Airflows from outdoor air to indoor air and indoor fate factors for the three compartments in the Dutch standard dwelling**[5]

Compartment	Airflow from outdoor air to indoor air ($m^3 \cdot y^{-1}$)	Indoor fate factor (-)
Crawl space	$1,3 \cdot 10^6$	$8.4 \cdot 10^{-6}$
First floor	$2,8 \cdot 10^5$	$1.7 \cdot 10^{-2}$
Second floor	$1,4 \cdot 10^5$	$2.1 \cdot 10^{-2}$

2.4.2 Noise

The calculation of the fate factor for noise exists of two parts. First, the noise levels at the façade of the dwelling have to be calculated for the compared situations. Then the noise levels are compared with the thresholds values for the noise levels under which a change in noise level has no effect on the human health. These thresholds vary per health effect.[8]

The average noise level during daytime at 1 meter from the road axis due to road traffic can be calculated as follows:[8]

$$LAeq_r = 10\log(10^{0.1\cdot(E_c+10\log(N_c))} + 10^{0.1\cdot(E_t+10\log(N_t))}) \qquad (9)$$

where $LAeq_r$ is the average sound pressure level during daytime at 1 meter from the road axis (dB(A)); E_c is a car-specific parameter (-); N_c is the number of cars per hour (h^{-1}); E_t is a truck-specific parameter (-); and N_t is the number of trucks per hour (h^{-1}).

The car- and truck-specific parameters can be calculated as follows:[8]

$$E_c = Max\left[(12.8 + 19.5^{\log(V_c)}), (45 + 0.8 \cdot (0.5^i - 2))\right] \qquad (10)$$

$$E_t = Max\left[(34 + 13.3^{\log(V_t)}), (56 + 0.6 \cdot (0.5^i - 1.5))\right] \qquad (11)$$

where V_c is the average car speed ($km \cdot h^{-1}$); i is the road slope (%); and V_t is the average truck speed ($km \cdot h^{-1}$).

There are two restrictions regarding the use of formulae (9), (10) and (11): the road surface must be asphalt and the number of vehicles per hour must be the same in both directions.[8]

In order to calculate the noise level during daytime at the façade, the following formula can be used:

$$LAeq_f = LAeq_r - \left[3 \cdot \left({}^2\log(S)\right)\right] \qquad (12)$$

where $LAeq_f$ is the average sound pressure level during daytime at the façade of the house (dB(A)).

It is assumed that the noise levels during night-time are 9 dB(A) lower than the noise levels during daytime.[8]

The lower and upper threshold values of noise levels at the façade of the dwelling for the considered health effects are given in Table 8.[8] Changes in noise level that are between these threshold values are characterized by a linear dose-response relationship. It is uncertain whether the linear dose-response relationship for noise is also valid for noise level values above the upper threshold value, but the traffic intensity must be very high to generate noise levels that high.

The threshold values for noise levels at the façade of the dwelling are valid for average conditions. When additional noise reducing measures are taken, the thresholds values for noise levels will be lower. This can be reflected in the model by subtracting a certain value from the calculated noise levels at the façade of the dwelling.

Table 8: Lower and upper threshold values for noise levels at the façade of the dwelling having health impacts[8]

Human health impact category	Lower threshold value (dB(A))	Upper threshold value (dB(A))
Communication disturbances	55	70
Sleep disturbances	46	61
Heart attacks during daytime	65	76
Heart attacks during night-time	55	66

2.5 Effect factors

2.5.1 Pollutants

The methodology to calculate effect factors for pollutants in the indoor air regarding carcinogenic and non-carcinogenic, non-respiratory effects is taken from Meijer *et al*.[5] The effect factors for respiratory effects of traffic pollutants are calculated according to the Eco-Indicator 99 methodology.[1,11] All effect factors are calculated in the hierarchist perspective, as recommended in the Eco-Indicator 99 methodology.[1]

The effect factors for carcinogenic and respiratory effects of pollutants are derived from the respective unit risk factors, an estimate of the probability that an individual will develop a disease when exposed to a pollutant at a certain ambient concentration for the individual’s life. The effect factors for non-carcinogenic, non-respiratory effects of pollutants are derived from no observed effect levels (NOELs) or lowest observed effect levels (LOELs).

The calculated effect factors are given in Table 9. For respiratory effects, only effects due to primary pollutants are taken into account; the rate of formation of the secondary pollutant ozone from NO_x and volatile organic carbons mixtures is insignificant at short distances. For reasons of clarity, only the combined effect and damage factors for respiratory effects are given in Table 9.

Table 9: Calculated effect and damage factors for traffic-related impact categories

Impact category	Health effect	Effect factor (cases·kg^{-1} or cases·dB(A)$^{-1}$)	Damage factor (DALY·cases^{-1})
Benzo[a]pyrene	Carcinogenic	260	16
Benzene	Carcinogenic	0.018	17
	Non-carcinogenic	3.7	0.067
CO	Respiratory	- [a]	0[a,b]
NO_2	Respiratory	- [a]	0[a,b]
PM_{10}	Respiratory	- [a]	64[a]
SO_2	Respiratory	- [a]	0.95[a]
Noise	Communication disturbances	0.05	1.5
	Sleep disturbances	0.034	1.3
	Heart attacks during daytime	$6.2 \cdot 10^{-5}$	0.0054
	Heart attacks during night-time	$6.0 \cdot 10^{-5}$	10

[a] For respiratory effects, only the sum of the effect and damage factors per disease are given. The details of the calculations are given in the DALY methodology[11]
[b] Only characterized for egalitarian perspective[11]; see also discussion

2.5.2 Noise

For the calculation of the effect factors for traffic noise, data from epidemiological researches have been used.[8,12,13] The effect factors for communication disturbances, sleep disturbances and heart attacks can be calculated by:

$$E_{n,k} = \beta_k \cdot N \qquad (13)$$

where $E_{n,k}$ is the effect factor of human health impact category k due to an increase in noise level (cases·dB(A)$^{-1}$); and $_k$ is the dose-response slope for human health impact category k (cases·dB(A)$^{-1}$).

The calculated effect factors are given in Table 9.[8]

2.6 Damage factors

In this research, human health damages are expressed in disability adjusted life years (DALY).[14] With the DALY methodology, it is possible to express human health damages in terms of equivalent life losses:

$$D_{x,k} = \sum_d \left(w_d \cdot YLD_{d,k} \right) + YLL_k \qquad (14)$$

where $D_{x,k}$ is the damage factor of substance x for human health impact category k (y, equivalent to DALY); w_e is the severity factor for disease d (-); $YLD_{d,k}$ is the number of years living disabled due to disease d as a result of human health impact category k (y); and YLL_k is the number of years of life loss due to premature death as a result of human health impact category k (y).

There are several advantages of the use of DALYs as an endpoint for human health damages.[1] First, the DALYs of different human health impact categories can be added e.g. one DALY due to irritation is considered as serious as one DALY due to cancer. Second, DALYs include the number of individuals affected, the duration of the disease and the severity of the disease. Third, it is a transparent methodology, and social preferences can be adapted easily.

2.6.1 Pollutants

The determination of the damage factors for pollutants has been outlined by Hofstetter.[11] The values for the damage factors are given in Table 9. All damage factors are given for the hierarchist perspective, as recommended in the Eco-Indicator 99 methodology.[1]

2.6.2 Noise

The damage factors for the health effects of noise are calculated for the several health effects. In general, the damage factor is calculated according to formula (15):

$$D_{n,k} = w_k \cdot d_k \qquad (15)$$

where w_k is the disability weight of human health impact category k (DALY·y^{-1}), and d_k is the average duration of human health impact category k (y·case^{-1}).

The disability weights for communication and sleep disturbances were determined by a group of 64 members of the medical staff of SUVA (the Swiss Accident Insurance Institute). This group is considered well suited, because in their jobs they deal with comparing health effects.[8] The averages of the disability weights that these professionals determined are given in Table 10.[8]

Table 10: Disability weights and duration of disease of noise-related health impacts[8]

Impact category	Disability weight (-)	Average duration of health impact (y)	Reference
Communication disturbances	0.033	46.7[a]	8
Sleep disturbances	0.055	23.3[a]	8
Heart attacks fatal	1	10[b]	14
Heart attacks non-fatal	0.044	0.122	8,14

[a] Assuming a duration of the situation of 70 years; daytime is 16 hours; nighttime is 8 hours
[b] Years of life lost

Because not all heart attacks are fatal, a distinction should be made between fatal heart attacks and non-fatal heart attacks. It is assumed that a constant fraction of the heart attacks is fatal. The disability weight and duration of the diseases have been determined by WHO and are given in Table 10.[8,14] The calculated damage factors are given in Table 9.[8]

Chapter 3: Results

Calculations have been carried out for a virtual situation with one house at a certain distance from a road with a certain traffic density. The following assumptions are used unless stated otherwise:

No noise-decreasing measures have been taken;

There is no background noise;

The pavement is default asphalt;

The road slope is 0 %;

There are no trees along the road, so the tree factor is zero;

The speed category is ‘Normal town traffic’;

The average car speed is equal to the reference speed for speed category ‘Normal town traffic’, i.e. 19 $km \cdot h^{-1}$;[9]

The number of vehicles per hour at the road is the same in both directions;

In average residential areas, trucks are not common. The number of trucks is set to a value of 1 h^{-1}. This number does not change when the number of cars per hour changes;

The human health damage due to traffic noise and pollutants has been calculated for one dwelling with two inhabitants. They spend 50% of their lifetime in the first floor and 30% in the second floor. This assumption has no impact on the relative results;

The considered dwelling is the Dutch standard dwelling;[3,5,15]

The duration of the situation is for 70 years.

3.1 Distance to road axis

Because of the lower threshold values in the noise dose-response curve, at a certain distance from the road axis the human health damage decreases sharply. This distance is different for different reductions in car density in the beginning and final situations. To show the magnitude of this effect, the total decrease of human health damages have been calculated for several distances and several reductions in car density. The results are depicted in Figure 2.

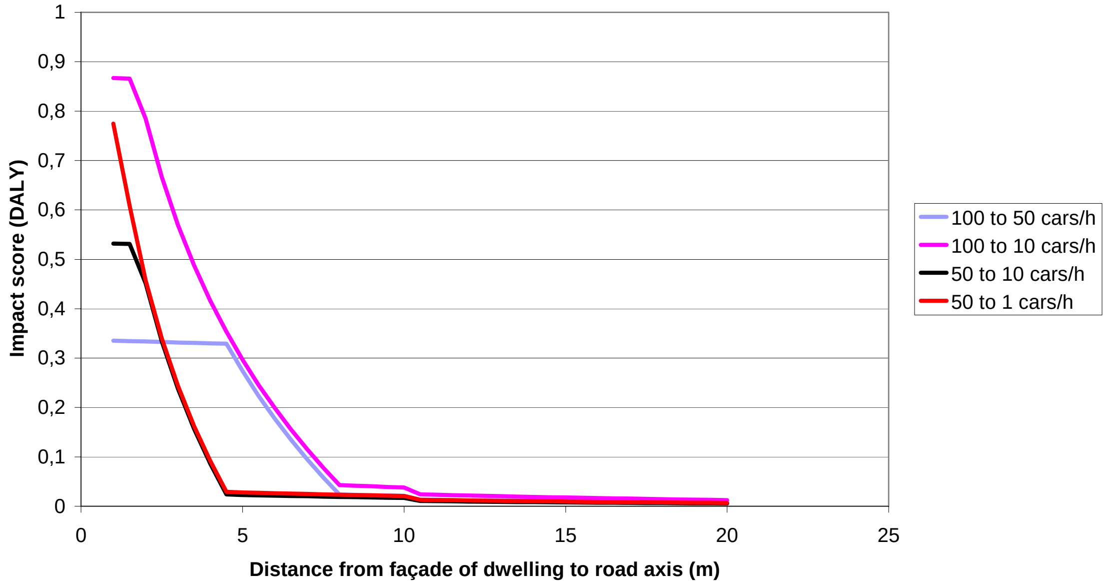

Figure 2: **Decrease of health damage (in DALY) due to traffic vs. distance of the façade of the dwelling to the road axis for several reductions in car density**

The graph in Figure 2 for the situation where the number of cars per hour decreases from 100 h^{-1} to 10 h^{-1} is split up per human health impact category (communication disturbances, sleep disturbances and respiratory effects of PM_{10}, which are the dominant health impact categories) in Figure 3.

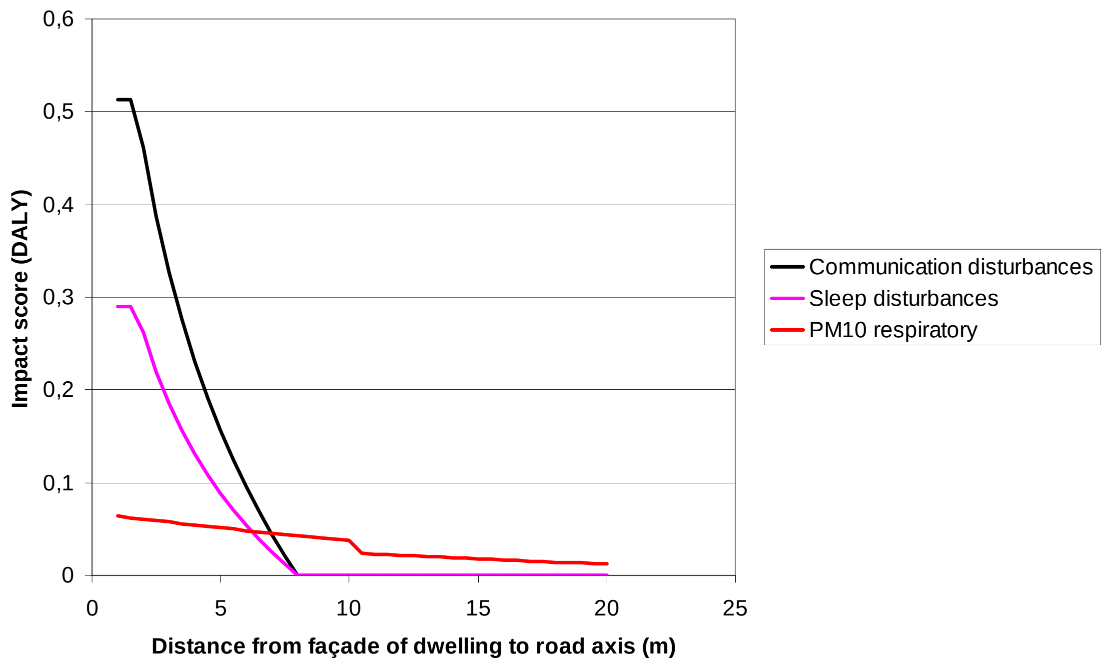

Figure 3: **Health damages due to traffic for the situation where the number of cars per hour decreases from 100 h^{-1} to 10 h^{-1}**

For communication and sleep disturbances, the first flat part of the graphs can be explained by the facts that the difference in noise levels is constant and that both the old and the new noise level are between the lower and upper noise level impact thresholds (see Table 8). The decrease in human health damage at somewhat longer distance from the road axis reflects the fact that the new noise level is lower than the lower noise level impact threshold for communication and sleep disturbances; the difference in impact drops to zero as the noise level at 100 cars·h^{-1} also approaches the lower threshold.

For human health damage due to respiratory effects of PM_{10}, the graph shows a slight decline. The steeper part of the graph can be explained by the fact that the distance to the road becomes so large compared to the height of the houses that the road type changes from type 3b to type 3a and the dilution parameters in the model change. The curves for human health damages due to the other substances given in Table 9 show a similar behaviour, but with lower values.

3.2 Traffic density

To see the influence of measures to reduce car use, the decrease of human health damage due to traffic is compared for situations with several differences in traffic density, given that the distance of the façade of the dwelling to the road axis is five meters.

The results of the comparison are given in Table 11.

Table 11: Decrease in human health damage due to a decrease in traffic density, given that the distance of the façade of the dwelling to the road axis is five meters (DALY)

Initial number of cars per hour	Final number of cars per hour					
	50		10		1	
	Total	Per car	Total	Per car	Total	Per car
100	$2.7 \cdot 10^{-1}$	$5.5 \cdot 10^{-3}$	$3.0 \cdot 10^{-1}$	$3.3 \cdot 10^{-3}$	$3.0 \cdot 10^{-1}$	$3.1 \cdot 10^{-3}$
50	-	-	$2.3 \cdot 10^{-2}$	$5.7 \cdot 10^{-4}$	$2.8 \cdot 10^{-2}$	$5.7 \cdot 10^{-4}$
10	-	-	-	-	$5.2 \cdot 10^{-3}$	$5.7 \cdot 10^{-4}$

The magnitude of the effect of a decrease in car density on the human health damage decreases when the initial car density decreases. This is because the initial noise level is higher above the lower impact threshold for noise when the initial car density is higher. When the initial noise level is below the lower threshold for noise, a decrease in car density results only in a decrease in human health damage due to pollutants, which is linear proportional to the decrease in car density.

3.3 Impacts of changes in speed limits

Another measure to decrease the nuisance of traffic is the establishment of lower speed limits. The noise levels and the car emissions become lower as a result of this measure.

The average speed at a road is not equal to the speed limit, because the road might not give the driver the opportunity to drive the maximum speed and there are cars stopping or being parked. The assumed average speeds are given in Table 12.

Table 12: Speed limits and assumed average speeds

Speed limit ($km \cdot h^{-1}$)	Average speed ($km \cdot h^{-1}$)
50	40
40	36
30	27
20	18

The effects of lower speed limits on human health damage, given that the distance of the façade of the dwelling to the road axis is five meters, are given in Table 13.

Table 13: Effect of decreased speed limits on human health, given that the distance of the façade of the dwelling to the road axis is five meters (DALY)

Number of cars per hour	Speed limit change ($km \cdot h^{-1}$)				
	50 → 40	50 → 30	50 → 20	40 → 30	40 → 20
100	$2.2 \cdot 10^{-1}$	$2.9 \cdot 10^{-1}$	$2.9 \cdot 10^{-1}$	$7.1 \cdot 10^{-2}$	$7.1 \cdot 10^{-2}$
50	$2.1 \cdot 10^{-1}$	$2.2 \cdot 10^{-1}$	$2.2 \cdot 10^{-1}$	$1.1 \cdot 10^{-2}$	$1.1 \cdot 10^{-2}$
10	0	0	0	0	0

The human health damage does not change for situations with 10 cars per hour. The reason is that the values given in Table 13 only reflect the changes in human health damage due to the lower noise level, and the average noise level is below the lower threshold values for situations with 10 cars per hour. Changes in human health damage due to pollutants are not reflected in the calculations, because the CAR model uses speed categories instead of average speeds for the calculation of health impacts due to pollutants. The speed category remains the same, because in all cases there is no flowing or stagnating traffic.

3.4 Comparison with global health damages of traffic

To get an idea of the importance of the local human health damage due to road traffic, this is compared to the human health damage occurring in the life cycle of a car driving a certain (average) distance.

In 1997, 93 billion vehicle kilometres were driven by car in the Netherlands.[16] In the same year, there were 0.96 movements of vehicle drivers per day.[16] Assuming a constant population of 16 million people in the Netherlands, it can be calculated that each ride of a car is on average 17 kilometres long.

The human health damage occurring in the life cycle of a car driving 1 kilometre is $3.1 \cdot 10^{-7}$ DALY.[6] Multiplying this value with the average ride length, the decrease in car density and the duration of the situation yields the decrease in human health damage occurring in the life cycle of car traffic as calculated by standard LCA procedures.

In Table 14, the total human health damage due to local exposure to traffic noise and pollutants is given for several reductions in traffic densities, given that the distance of the façade of the dwelling to the road axis is five meters. The human health damage occurring in the life cycle of road traffic as calculated by standard LCA procedures is given in the same table for the number of vehicle kilometres that are not driven when the traffic density is reduced.

Table 14: Total human health damage due to local health effects compared to total human health damage occurring in the life cycle of road traffic and of the dwelling as calculated by standard LCA procedures, given that the distance of the façade of the dwelling to the road axis is five meters

Change in traffic density ($cars \cdot h^{-1}$)	Human health damage (DALY)			
	Local	Wide range vehicle life cycle[a]	Fraction of vehicle life cycle[b]	Fraction of dwelling life cycle[b]
100-50	$-2.7 \cdot 10^{-1}$	$2.6 \cdot 10^{-4}$	110000 %	107 %
100-10	$-3.0 \cdot 10^{-1}$	$4.6 \cdot 10^{-4}$	64000 %	116 %
100-1	$-3.0 \cdot 10^{-1}$	$5.1 \cdot 10^{-4}$	59000 %	118 %
50-10	$-2.3 \cdot 10^{-2}$	$2.1 \cdot 10^{-4}$	11000 %	9.0 %
50-1	$-2.8 \cdot 10^{-2}$	$2.5 \cdot 10^{-4}$	11000 %	11 %
10-1	$-5.2 \cdot 10^{-3}$	$4.6 \cdot 10^{-5}$	11000 %	2.0 %

[a] Values calculated for the number of vehicle kilometres that are not driven when the traffic density is reduced
[b] Absolute values of local DALYs used in calculations

The human health damage due to local effects of traffic is two to three orders of magnitude higher than the human health damage occurring in the life cycle of road traffic as calculated by standard LCA procedures.

3.5 Comparison with dwelling life cycle

To get an idea of the importance of the local human health damage due to road traffic, this is also compared to the human health damage occurring in the life cycle of the dwelling itself. The considered dwelling is the Dutch standard dwelling.[3,5,15] Human health damages due to indoor pollutants emitted from building materials are not taken into account.

The outdoor human health damage occurring in the life cycle of the standard dwelling as calculated by standard LCA procedures is 0,26 DALY.[3,5,15] The proportion of the human health damage due to local effects of traffic and the human health damage occurring in the life cycle of the dwelling as calculated by standard LCA procedures is given in Table 14.

When the number of cars per hour in the initial situation is 100 cars$\cdot$$h^{-1}$, the human health damage due to local effects of traffic and the human health damage occurring in the life cycle of the dwelling as calculated by standard LCA procedures are in the same order of magnitude. When the number of cars per hour in the initial situation is 50 or lower, the human health damage due to local effects of traffic is one or two orders of magnitude lower than the human health damage occurring in the life cycle of the dwelling as calculated by standard LCA procedures.

Chapter 4: Discussion

4.1 Model restrictions

In this study, a model is proposed with which it is possible to calculate the human health damage due to the local effects of traffic. However, there are some restrictions in the application of this model.

First, only the effects of road traffic are taken into account. The effects of other means of transport like railroad traffic, ships and airplanes are not assessed in this model.

Second, the model can only calculate the decrease of human health damage in a comparison of situations, not on a per-car or per-vehicle-kilometre base. This makes it hard to compare the results of this model with the results of other life cycle assessments, because the functional unit in the latter are usually a number of cars or vehicle kilometres. For the application of this model in the life cycle assessment of dwellings, this is not an obstacle. But it might be annoying for the users of the model that they have to recalculate the fate factors for each traffic situation.

Third, the actual average vehicle speed is not fully taken into account for the calculation of human health damage due to pollutants. In the CAR model, traffic situations are divided in speed categories, classified to road type (highway, countryside roads and town traffic). The emission of pollutants is therefore less exact. The decrease in maximum speed in a neighbourhood has no effect on the calculated human health damage due to traffic pollutants, thus causing an overestimation or underestimation of the change in human health effects, according to the average speed of the traffic.[17]

Fourth, accumulation of pollutants in a valley location, effects of strong winds and other uncommon characteristics at a location are not taken into account in this study.

Finally, this model calculates only the human health effects due to a change, e.g. a decrease in car use. But when people do not use their cars, they will use other means of transport like bikes, busses and trains. The local health effects of bikes are nil, but the human health effects of bus and train use cannot be neglected, although they are lower than the health effects of equivalent car use. It is possible to calculate the local health effects of bus use, but this is not done for the calculations executed in this study. The health effects of train use are not dealt with in this research. This leads to an overestimation of the human health effects of a decrease in road traffic use.

4.2 Uncertainties

The model proposed in this research is in an early stage of the development. There is little experience in the assessment of local health effects in life cycle assessment. Furthermore, there are few field data available about the local human health damages due to road traffic that are directly related to traffic density. Therefore, there are many uncertainties in the model parameters and thus in the results. With increasing availability of field data, the model can be adjusted to these data and thus the uncertainties will be reduced.

Based on expert judgement, one can predict that the division of the average vehicle speed in several speed categories for the calculation of the fate factor of pollutants causes large uncertainties in the model results. Also, the use of averages for traffic densities, noise levels and pollution emissions is a source of uncertainties. Finally, in the calculation of the effect and damage factors, uncertainties are present, because in epidemiological data the variance in data is large.

However, it cannot be said that despite the uncertainties in the model, the results of the model will change so radically that for example the human health effects of a reduction in car use will be negative.

4.3 Missing data

There are a few missing data in this research, although the best available data have been used. First, the precise relationship between vehicle speed and pollutant emissions is unknown. There are some individual data on this relationship, but because of the parabolic shape of the speed-emission curves, it is hard to calculate the average emissions for a certain average speed.[17]

Furthermore, only a limited number of pollutants are taken into account in this model. The combustion gases of road vehicles consist of a mixture of numerous substances. However, only the health effects of the substances mentioned in Table 3 are taken into account in this model. This leads to an underestimation of the calculated human health damages. This resulting error is likely to be low, because the pollutants mentioned in Table 3 form the major part of the pollutants that are considered relevant to health.[18]

Moreover, the effect and damage factors for human health damage due to respiratory effects of carbon monoxide and nitrogen dioxide are zero, because the health effects related to exposure to these substances are characterized only for the egalitarian perspective. However, a preliminary calculation shows that when the human health damage due to respiratory effects of carbon monoxide and nitrogen dioxide emitted by cars is calculated in the egalitarian perspective, this health damage is about 7 per cent of the human health damage due to health impacts of the pollutants given in Table 9 emitted by cars in the hierarchist perspective.

There are also no data available of the effect and damage factors for human health damage due to non-respiratory effects of carbon monoxide, nitrogen dioxide, particulate matter (PM_{10}) and sulphur dioxide and due to non-carcinogenic effects of benzo[a]pyrene.

Chapter 5: Conclusions and further research

5.1 Conclusions

In this study, a model is proposed to evaluate the health damage to local residents due to changes in road traffic situations and the results are compared with the global human health damage due to both traffic and dwellings as calculated by standard LCA procedures. When taking into account the uncertainties, missing data and model restrictions mentioned in Chapter 4, the following conclusions can be drawn:

It appears that for someone living in a dwelling along a street local health damage due to changes in road traffic situations may be of the same order of magnitude as the human health damage associated with the life cycle of dwellings as calculated by standard LCA methodologies. Compared to the human health damage occurring in the life cycle of road traffic as calculated by standard LCA methodologies, the local human health damage may be two to three orders of magnitude larger. The local human health effects due to (changes in) road traffic situations thus cannot be neglected when carrying out life cycle assessments of dwellings or complete residential areas.

The total human health damage due to road traffic decreases greatly for a situation with 50 or fewer cars per hour or when the dwelling is built at a distance to the road axis of more than eight meter. This is because the noise level at the façade drops below the lower threshold for communication and sleep disturbances, so the effective noise level decrease drops to zero. This implies that when complete residential areas are assessed, only roads nearby the dwellings need to be taken into account. This does not hold for highways because of the high noise levels and pollution emissions and the range of noise and pollutant transport.

When the number of cars per hour drops, the human health damage due to traffic drops as well. However, when the initial number of cars per hour is 100, the decrease in human health damage is higher than when the initial number of cars per hour is 50 or lower. This is because the initial noise level is higher above the lower threshold for noise when the initial car density is higher.

When the speed limit is lowered, the human health damage due to traffic drops as well. However, when the number of cars per hour is 10 or lower, the human health damage does not change on lowering the speed limit.

5.2 Further research

The model presented in this study is a first step in the integration of local health effects due to traffic in the life cycle assessment of dwellings. The next step might be the addition of missing data and the reduction of the uncertainties in the model parameters. The exact vehicle speed might be introduced in the fate factor calculation for pollutants as well. Also the health effects of other means of transport like railroad transport might be included in the model to get an idea of the magnitude of the rebound effect.

When the model gives satisfying results, instead of imaginary neighbourhood situations, real neighbourhoods or residential areas that are in a design state might be assessed with this model. One way to do this is to implement the model in a geographical information system (GIS) environment, so that the map of the neighbourhood could be introduced and the results can be presented as maps as well. In this way, the comparison of traffic situations in a neighbourhood could be carried out in a way compatible with the life cycle assessment of dwellings.

References

[1] Goedkoop, M. & R. Spriensma, 1999. The Eco-Indicator 99; A damage oriented method for Life Cycle Impact Assessment; Methodology report & Annex. Pré Consultants, Amersfoort, The Netherlands.

[2] Guinée, J.B., M. Gorree, R. Heijungs, G. Huppes, R. Kleijn, A. de Koning, A. Wegener Sleeswijk, S. Suh, H.A. Udo de Haes, J.A. de Bruijn, R. van Duin & M.A.J. Huijbregts, 2001. Life cycle assessment: An operational guide to the ISO standards. Centre of Environmental Sciences, Leiden, The Netherlands. http://www.leidenuniv.nl/cml/

[3] Mak, J.P., D.A. Anink, L.G.M. Kortman, E. Lindeijer & H. van Ewijk, 1996. Eco-Quantum, Eindrapport: Ontwerp van een rekenmethode voor de kwantitatieve bepaling van de milieubelasting van een gebouw. Rapportnummer 727, W/E Adviseurs, Gouda, The Netherlands.

[4] Meijer, A., L. Reijnders & M.A.J. Huijbregts, 2002. Human health damage due to indoor pollutants in life cycle impact assessment. In: H. Levin (ed.), Indoor Air 2002: Proceedings of the 9th International Conference on Indoor Air Quality and Climate, Vol. 4, Indoor Air 2002, Santa Cruz, California, United States, pp 947-952.

[5] Meijer, A., Huijbregts, M.A.J. & L. Reijnders, 2003. Human health damages due to indoor pollutant sources in life cycle impact assessment of dwellings. To be published.

[6] IVAM, 2001. IVAM LCA Database 3.0. IVAM Environmental Research: Amsterdam, The Netherlands.

[7] Heijungs, R. & P. Hofstetter, 1996. Definition of terms and symbols. In: H.A. Udo de Haes, Towards a methodology for life cycle impact assessment. Society of Environmental Toxicity and Chemistry Europe, Belgium.

[8] Müller-Wenk, R., 2002. Attribution to road traffic of the impact of noise on health. Environmental Series No. 339. Swiss Agency for the Environment, Forests and Landscape, Bern, Switzerland.

[9] Teeuwisse, S., 2003. Handleiding bij software pakket CAR II versie 2.0. TNO-rapport R 2003/118, TNO, Apeldoorn, The Netherlands.

[10] Velzen, K. van & M. Crank, 2003. Nauwkeurigheid van CAR II. RIVM, Bilthoven, The Netherlands. To be published

[11] Hofstetter, P., 1998. Perspectives in life cycle impact assessment: a structured approach to combine models of the technosphere, ecosphere and valuesphere. Kluwer Academic Publishers, Boston, United States.

[12] Oliva, C., 1998. Belastungen der Bevölkerung durch Flug- und Strassenlärm, Berlin, Germany.

[13] Ising, H., 2000. Das Herzinfarktrisiko aufgrund von Verkehrslärm im Vergleich zu Krankheitsrisiken durch Luftverschmutzung, speech at 9th Conference on Traffic Noise, Dresden, Germany.

[14] Murray, C.J.L. & A.D. Lopez, 1996. The Global Burden of Disease. WHO, World Bank and Harvard School of Public Health, Boston, United States.

[15] Novem, 1999. Referentiewoningen 98. Novem nr. DV1.2.171 99.02, Novem, Sittard, The Netherlands.

[16] CBS, 2003. StatLine. Centraal Bureau voor de Statistiek, Voorburg/Heerlen, The Netherlands. Internet: http://statline.cbs.nl

[17] Jensen, S.S., 1995. Driving patterns and emissions from different types of roads. The Science of the Total Environment 169 (1-3): 123-128.

[18] ETH, 1994. Okoinventare für Energiesysteme. Laboratorium für Energiesysteme, ETH, Zürich, Switserland.