Green benefits

Wiki information for the co-benefits of the Green Benefit Planner

Important information regarding the co-benefit models of the Green Benefit Planner!

Here the models used for deriving the co-benefits of increases in vegetation and water due to climate adaptation measures are described. It is important to know that the individual model results can not directly be summed up due to potential double-counting. The model inputs and results have a resolution of 10x10 meters meaning that one cell has a surface area of one square decameter (dam^2).

The following green benefits are shown in the KBS Toolbox:

- Reduction of healthcare and labour costs due to vegetation (adapted from Remme et al. 2018)
- Reduction of particulate matter (PM10) by vegetation (Adapted from Remme et al. 2018)
- Influence of vegetation & water on residential property values (Adapted from Remme et al. 2018)
- Increase in physical activity due to vegetation (Adapted from Paulin et al. 2019)
- Benefits of increased cycling for commuting purposes due to vegetation (adapted from Paulin et al., 2019)
- Carbon sequestration by vegetation (adapted from Remme et al. 2019)

Reduction of healthcare and labour costs due to vegetation (adapted from Remme et al. 2018)

Vegetation provides health benefits to people in their living environments and reduces the number of people that need to visit a doctor (Maas, 2008). Vegetation has a positive effect on air quality, stress reduction, urban cooling, concentration and physical activity, among other things (e.g. Maas, 2008 and KPMG, 2012). Vegetation in the surroundings of people's homes reduces the prevalence of multiple health risks and diseases, including respiratory diseases, migraine, diabetes, depression, neck and back pain, depression and coronary heart disease (KPMG, 2012). For this model, an aggregated methodology has been applied to assess the effect of vegetation on nine health risks (cf. the TEEB-Stad tool, see www.teebstad.nl). Table 1 and Table 2 provide an overview of the input and output maps of the co-benefit: 'reduction of healthcare and labour costs due to vegetation'.

Table 1: Input maps applied to estimate reduction of healthcare and labour costs due to vegetation.

Input	**Unit**	**Short description**	**Source**
Inhabitants	# inhabitants per dam^2	Shows the number of inhabitants per dam^2	RIVM 2017
Agricultural crop parcels	Categories for crop types	Yearly updated cadastral map of agricultural parcels with information on crop types per parcel	RVO 2013
Vegetation cover	% cover per dam^2	The percentage of a cell that is covered by vegetation (low vegetation, bushes and shrubs and trees combined)	RIVM 2017
Percentage non-green area	% non-cover per dam^2	Percentage of a cell that is not covered by vegetation (inverse of the vegetation cover map)	VITO

Build-up of the model

To determine the health effects of vegetation, the percentage of vegetation within a one km radius around every cell needs to be calculated. This can be done in two ways one calculation includes agricultural areas surrounding cities and towns, one excludes agricultural areas. The calculation is done as followed:

$$\text{PercGreenSpace}_{1\text{km}} = \sum VegetationCover, PercNonGreen$$

Where:

- 'PercGreenSpace$_{1km}$', is the percentage of vegetation within a one km radius around a cell [% vegetation cover km^{-1}].
- 'VegetationCover', is the percentage of vegetation cover in a given cell (trees, shrubs and low vegetation combined) [% vegetation cover dam^{-2}] based on the vegetation map.
- 'PercNonGreen', is the amount of area per cell that is covered by sealed surface based on the Ecosystem Unit map and the Agricultural Crop Parcels Map [% non-green dam^{-2}].

If agricultural areas are not considered in the calculation they have to be excluded from the vegetation cover maps, using the Agricultural Crop Parcels map.

The health impact of the percentage of vegetation on doctor's visits per person is based on Maas (2008) and calculated to be 0.000835 avoided doctor's visits per person per percent of vegetation. The health effects of urban green on urban areas are further determined as a function of the amount of vegetation in a one km radius around a given area of vegetation and the population density surrounding the vegetation, given the following formula:

$$\text{HealthEffects}_{vegetation} = \text{PercGreenspace}_{1km} \text{ x } \text{PopDensity}_{1km} \text{ x } \text{Healthimpact}_{vegetation}$$

Where:

- 'HealthEffects$_{vegetation}$', are the health effects of an area of vegetation [reduced doctor's visits dam $^{-2}$ yr^{-1}].
- 'PercGreenSpace$_{1km}$', is the percentage of vegetation within a one km radius around a cell [% vegetation cover dam^{-2}].
- 'PopDensity$_{1km}$', is the number of inhabitants within a one km radius around a cell [inhabitants km^{-1}], based on the inhabitants map.
- 'HealthImpact$_{vegetation}$', is the number of avoided doctor's visits per person as a result of the amount of vegetation around a home [avoided doctor's visits per person per % vegetation cover dam^{-2} yr^{-1}].

Avoided health costs due to vegetation

The monetary value of reduced healthcare costs due to vegetation in the surroundings of people's homes is calculated as followed:

$$€_{reduced\ \ healt\ hcare\ \ costs} = HealthEffects_{vegetation}\ x\ HealthCosts$$

Where:

- '€$_{\text{reduced healthcare costs}}$', is the monetary value of avoided healthcare costs [€ dam $^{-1}$ yr^{-1}];
- 'HealthEffects$_{vegetation}$', is the health effects of an area of vegetation [reduced doctor's visits dam^{-2} vegetation yr^{-1}].
- 'HealthCosts', the annual avoided health costs per patient [€ patient^{-1} yr^{-1}].

The avoided healthcare costs per patient that were applied in the TEEB Stad tool are used (2016 € values). These values are based on KPMG (2012) and the Cijfertool Kosten van Ziekten of RIVM, which values the average health costs for nine diseases that had a relation to vegetation at €868 per patient per year.

Avoided health-related labour costs due to urban green

The monetary value of reduced health-related labour costs due to vegetation in the surroundings of people's homes is calculated as followed:

$$€_{reduced\ \ labour\ \ costs} = HealthEffect_{vegetation}\ x\ HealthLabourCosts\ x\ ParticipationFactor$$

Where:

- '€$_{\text{reduced labour costs}}$', is the monetary value of avoided health-related labour costs [€ dam $^{-2}$ yr^{-1}].
- 'HealthEffects$_{vegetation}$', is the health effects of an area of vegetation [reduced doctor's visits dam^{-2} vegetation yr^{-1}].
- 'HealthLabourCosts', is the annual avoided health-related labour costs per patient [€ patient^{-1} yr^{-1}].
- 'ParticipationFactor', is the fraction of people that participate in the labour market [%].

The avoided health-related labour costs per patient that were applied in the TEEB Stad tool are used (2016 € values). These values are based on KPMG (2012) and Steenbeek et al. (2010). The costs consist of three components: absenteeism, reduced labour productivity and job losses. Average annual costs per patient were calculated to be €6,341 (€3,221 for absenteeism, €2,691 for reduced labour productivity and €429 for job loss). The participation factor was estimated to be 67% based on KPMG (2012).

Table 2: Output maps resulting from application of the 'green and healthcare model'.

Output	Unit	Short description
Amount of vegetation in a 1 km radius	% vegetation cover	The percentage of urban green in a 1 km radius around the cell
Health effects of urban green on urban living environment	Reduced doctor's visits dam^{-2} vegetation yr^{-1}	The effect a specific green area has on the reduction of doctor's visits by inhabitants in the surrounding area.
Avoided health costs due to vegetation	€ dam^{-2} yr^{-1}	The reduction of public health costs as a result of vegetation in the surroundings of homes.
Avoided health-related labour costs due to vegetation	€ dam^{-2} yr^{-1}	The reduction of labour costs due to better health of employees as a result of vegetation in the surroundings of their homes.

References

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Reduction of particulate matter (PM_{10}) by vegetation (Adapted from Remme et al. 2018)

In industrialized countries like the Netherlands, the soil, water and air are often polluted. One of the main forms of air pollution is particulate material (PM), which comes from sources such as traffic, industry and intensive livestock farming. Particulates can cause respiratory conditions, including some serious diseases. There are major scientific differences in the influence of vegetation on air quality. Recent reviews (Janhall, 2015; Abhijith et al., 2017; Baldauf, 2017) show that the impact of green infrastructure on air quality depends on the local situation. These studies show that ecosystems including trees, shrubs, lawns, and other vegetation can be of assistance in catching and retaining fine particulate matter and the purification of the air. Tables 1 and 3 provide an overview of the input and output maps of the co-benefit: 'reduction of particulate matter (PM_{10}) by vegetation'.

Table 1: Input maps applied to estimate the retention of particulate matter (PM_{10}) by vegetation.

Input	Unit	Short description	Source
LCEU map	Ecosystem unit classes	Ecosystem unit classes map for the Netherlands in 2013	CBS 2017
Concentration of PM	g m^{-3}	Concentration of PM in 2016	RIVM 2016
Trees	% cover dam^{-2}	Percentage of a cell that is covered by trees higher than 2.5 meters	RIVM 2017
Bushes and shrubs	% cover dam^{-2}	Percentage of a cell that is covered by bushes and shrubs between 1 and 2.5 meters high	RIVM 2017
Low vegetation	% cover dam^{-2}	Percentage of a cell that is covered by vegetation that is lower than 1 meter	RIVM 2017
Percentage non-green area cell	% cover dam^{-2}	Percentage of a cell that is not covered by vegetation	RIVM 2017

Build-up of the model

The deposition velocity depends on the type of vegetation and land cover. The type of vegetation is based on the maps with the percentage of trees, shrubs and low vegetation/grass. The land cover is taken from the LCEU map. The average deposition velocity of a grid cell is estimated as:

$$V_{dep} = fr_{tree}\ x\ V_{tree} + fr_{shrub}\ x\ V_{shrub} + fr_{grass}\ x\ V_{grass} + fr_{non-veg}\ x\ V_{landcover\ i}$$

$$fr_{non-veg} = 1 - (fr_{tree} + fr_{shrub} + fr_{grass})$$

Where:

- 'fr_x', is the fraction of trees, shrubs, low vegetation and non-vegetated area of a cell.
- 'V_x', is the deposition velocity of trees, shrubs, low vegetation and non-vegetated area.

The deposition velocity of trees depends on the land cover type of the LCEU map. Deposition velocity for the relevant land cover, vegetation types according De Nocker et al. (2016) are given in Table 2. For V_{tree} default a deposition velocity of 0.5 m/s for deciduous forest is assumed. Only for coniferous and mixes forest higher deposition rates are assumed of 0.7 and 0.6 m s^{-1}, respectively.

The fraction trees, shrubs and grass are maps developed by RIVM by determining the fraction of vegetation > 2.5 m, between 2.5 and 1m and < 1m, respectively. These maps are based location of vegetation as reflected in the infrared aerial photographs and the height of the vegetation based on the available LiDAR data in the Netherlands.

Table 2: Average deposition velocities for various vegetation types (De Nocker et al., 2016).

Vegetation type	**Deposition velocity (m s^{-1})**
no vegetation[1]	0.0 - 0.2
deciduous forest	0.5
coniferous forest	0.7
shrubs & bushes	0.3
meadows & grassland	0.2
arable land	0.2
Water	0.1
low natural vegetation	0.2
low-stem orchard	0.2
mixed forest	0.6

[1]The value depends on the type of land cover assigned in the LCEU map. All built-up areas in the LCEU map receive value 0.0, water and forest area 0.1 and agriculture 0.2

Next the regulation of PM is estimated according to:

$$Retention_{pm\,10} = V_{dep}\ x\ C_{pm\,10}\ x\ fr_{resuspension}\ \ x\ Unitcorrection$$

Where:

- '$Retention_{PM10}$', is the amount of PM captured by vegetation [kg dam^{-2} $year^{-1}$].
- 'V_{dep}', is average deposition velocity [m s^{-1}].
- 'C_{PM10}', is the concentration of PM [g m^{-3}].
- $fr_{resuspension}$, is the fraction of resuspension of PM [-].
- UnitCorrection, is 0.031536 to correct the units from cm s^{-1} x g m^{-3} into kg dam^{-2} $year^{-1}$

The fraction resuspension is assumed to be 0.5 for all land cover types except for water for which it is 0.0 (De Nocker et al., 2016). The concentration of PM is based on the large-scale PM maps as reported by RIVM (2017). As these large-scale concentration maps are use at a much smaller scale the concentrations in the maps are linearly smoothed over a distance of 100m.

Monetary value of PM_{10} retention by vegetation

The monetary value of air regulation is estimated for PM as followed:

$$€_{pm\,10} = Retention_{pm\,10}\,x\,ExtCosts_{pm}$$

Where:

- '$€_{PM10}$', is the monetary value [€ dam^{-2} $year^{-1}$].
- '$Retention_{PM10}$', is the retention of PM by vegetation [kg dam^{-2} $year^{-1}$].
- '$ExtCosts_{PM10}$', are the external costs of PM [€ kg^{-1}].

Milieuprijzen 2017 (CE-Delft 2017) gives a lower, central and upper value for the external costs of PM of 31.90, 44.60 and 69.10 € kg^{-1}, respectively. This value is the same for all of the Netherlands and doesn't take into account the differences in inhabitant densities. In our opinion the external costs should increase as inhabitant densities increase as has been done in earlier study of CE-Delft (2014). In this study a difference is made between metropolitan, urban and rural areas. In metropolitan areas the external costs are 223.6 € kg^{-1}, in urban areas 72.1 € kg^{-1} and in rural areas 43.7 € kg^{-1}. In order to correct for spatial discontinuities between metropolitan, urban and rural areas, a linear relation has been developed between the external costs and the population density (Figure 1):

$$ExtCost_{pm\,10} = 48.34 + 1.32\,x\,PopulationDensity$$

Where:

- '$ExtCosts_{PM10}$', are the external costs of PM [€ kg^{-1}].
- 'PopulationDensity', is the population density [inhabitants ha^{-1}].

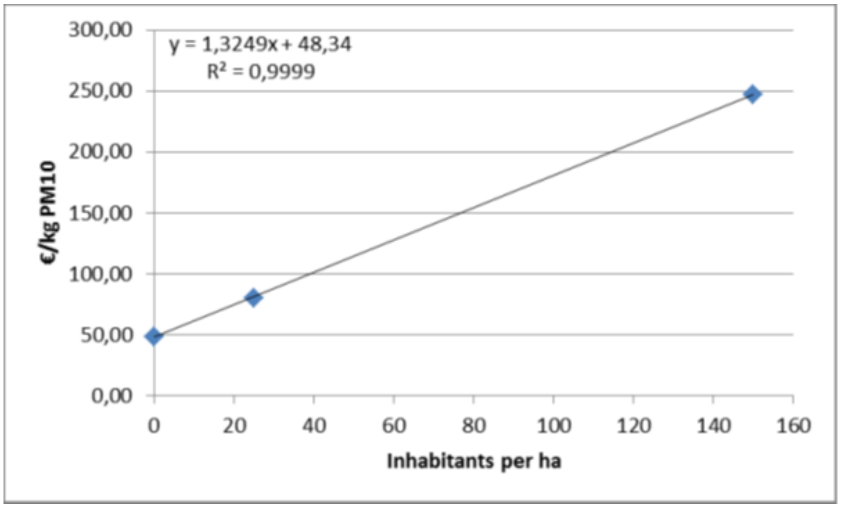

Figure 1: Linear relation between the inhabitant densities and external cost of PM

Table 3: Output map generated for the co-benefit retention of particulate matter (PM_{10}) by vegetation.

Output map	Unit	Short description
Monetary value of PM_{10} retention by vegetation	€ dam^{-2} yr^{-1}	The reduction in healthcare costs due to the retention of PM by vegetation

References

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Influence of vegetation & water on residential property values (Adapted from Remme et al. 2018)

Trees, parks, gardens and water increase the amenity of residential areas, which is reflected in property values (Czembrowski & Kronenberg 2016; Franco & MacDonald, 2017). In the Netherlands, multiple studies have been done to quantify the influence of vegetation and water on property values, for example Daams et al. 2016 and for an overview Ruijgrok et al. (2006). This model uses Luttik & Zijlstra (1997) as a main data source. The studies in the Netherlands make a distinction between two aspects, i.e. the view on green elements, parks and water, and the proximity to these elements. Tables 1 and 3 provide an overview of the input and output maps used to model the co-benefit: ‘influence of vegetation and water on residential property values’.

Table 1: Input maps applied to estimate the influence of vegetation and water on residential property values.

Input	**Unit**	**Short description**	**Source**
LCEU map	Ecosystem unit classes	Ecosystem unit classes map for the Netherlands in 2016	CBS 2017
Inhabitants	# inhabitants dam^{-2}	Shows the number of inhabitants per cell	RIVM 2017
Property Value	€	Average property value per neighbourhood 2015 (Dutch: WOZ)	CBS 2016
Vegetation	% cover dam^{-2}	Shows the percentage of a cell that is covered by vegetation (low vegetation, bushes and shrubs and trees combined).	RIVM 2017
Open Water	land use class	Selection of water classes from Top10Water	RIVM 2017
Percentage non-green area cell	% cover dam^{-2}	Percentage of a cell that is not covered by vegetation	RIVM 2017

Build-up of the model

The influence of vegetation and water on residential property values is estimated based on the

water classes in the LCEU map and the vegetation map of the Netherlands. The influence of vegetation and water on residential property value is estimated according to:

$$Influence_{vegetation\ \&water} = fr_{increase} * PropertyValue$$

Where:

- ‘$Influence_{vegetation\&water}$’, is the increased property value due to vegetation and water [€].
- ‘PropertyValue’, is the property value (so-called WOZ-value in the Netherlands) available at neighbourhood level for residential areas from the CBS for 2018.
- ‘$fr_{Increase}$’, is the fraction of increase in property value for four different types: view of a tree line, view of a park or water, proximity to a park or water and open water as given in Table 2.

Table 2: Fraction of increase in property value given different amenities of vegetation and water (Luttik & Zijlstra, 1997 and Ruijgrok, 2006).

Types of vegetation and water	Fraction of property value increase
View of a tree line	0.05
View of a park or water	0.08
Proximity to a park or water	0.06
Open water	0.12

Currently, the presence of multiple types of green or water are not accounted for. The highest fraction increase that is available is applied: open water, view on park or water, proximity to park or water respectively.

Availability of open water

The availability of open water has been defined on the topographic map that shows water areas (Top10Water). Here Top10Water is used instead of the water classes from the LCEU map because the LCEU map does not distinguish between open water and small water bodies such as ditches, canals and ponds, which is necessary for this model. Open water is available if the water area is larger than one ha and if it is within a 50m distance of a residential area (based on the map showing inhabitants).

Proximity to a park or water

The proximity of houses to a park or water has been derived from the vegetation map of the Netherlands that includes trees, bushes, flowers, plants and grass. Parks have been defined as vegetated areas larger than one ha that consist of cells with more than 60% vegetation cover. The land cover class 'water' is based on the LCEU map and can be as small as one cell of $100m^2$. The proximity to a park or water is defined as the availability (of at least one cell) of park or water within a distance of 400m.

View of a park or water

A view of a park or water has been defined in the same way as the proximity to a park or water, with the difference that the park or water should be within a distance of 30m.

Table 3: Output map generated for the co-benefit 'influence of vegetation & water on residential property values'.

Output map	**Unit**	**Short description**
Increase in property value	€	The increase in property value due to surrounding vegetation, open water and parks.

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Increase in physical activity due to vegetation (Adapted from Paulin et al. 2019)

A study conducted by Klompmaker et al. (2018) found a positive relationship between green space and outdoor physical activity within the Netherlands. The study was based on a national health survey (Public Health Monitor 2012, PHM; CBS, 2015) with 387,195 adults. Outdoor physical activity was defined as all moderate and vigorous physical activities that can be done outdoors (physical activity for commuting purposes, leisure time physical activity (walking, cycling, gardening) and outdoor sports). To measure green space. the Normalized Difference Vegetation Index (NDVI) was used. NDVI captures the density of green vegetation at a spatial resolution of 30m. Surrounding greenness was measured as the average NDVI within a circular buffer of the participant's residential address. The study found a positive relationship between green space within a buffer of 300m and the change in minutes adults engage in outdoor physical activities. Table 1 and Table 3 provide an overview of the input and output maps model for the co-benefit of 'increase in physical activity due to vegetation'.

Table 1: Input maps applied to estimate the increase in physical activity by the population due to surrounding vegetation in a 300m buffer.

Input	**Unit**	**Short description**	**Source**
Inhabitants	# inhabitants dam^{-2}	Shows the number of inhabitants per cell	RIVM (2017)
Vegetation cover	% cover dam^{-2}	The percentage of a cell that is covered by vegetation (low vegetation, bushes and shrubs and trees combined)	RIVM (2017)

Build-up of the model

To determine increase in physical activity due to vegetation, the percentage of vegetation within a 300m radius around every cell needs to be calculated. The calculation is done as followed:

$$\text{PercGreenSpace}_{300m} = \sum VegetationCover$$

Where:

- 'PercGreenSpace$_{300m}$', is the percentage of vegetation within a 300m radius around a cell [% green $300m^{-1}$].
- 'VegetationCover', is the percentage of vegetation cover in a given cell (trees, shrubs and low vegetation combined) [% vegetation cover dam^{-2}] based on the vegetation map.

Next, the increase in the amount of time spent on physical activity due to the percentage of vegetation present in each cell is determined by a look-up operation using Table 2. Percentages of vegetation cover were divided into quintiles (Table 2), where the first quintile represents the reference category. As Table 2 reveals, as the percentage of vegetation cover increases within every quintile, the minutes individuals invest in outdoor physical activities increases. Extra minutes spent on physical activity due to vegetation in each cell are determined as followed:

$$Physical\ activity_{vegetation} = Look-up_{minutes}\ (PercGreenSpace_{300m})$$

Where:

- 'Physical activity$_{vegetation}$', is the amount of additional minutes spend on physical activity due to vegetation in each cell [min].
- 'Look-up$_{minutes}$', is the look up operation performed based on Table 2, combining the amount of minutes spend on physical activity based on the percentage of vegetation cover.
- 'PercGreenSpace$_{300m}$', is the average percentage of vegetation surrounding a cell in a 300m buffer [%].

Table 2: Percentage of vegetation within a buffer of 300m and changes in the amount of minutes that individuals invest in outdoor physical activity. (Source: Klompmaker et al., 2018)

Percentage of green space (quintiles – NDVI)	Minutes extra spent on outdoor physical activity (95% CI)
40	0
45-50	3.5

51-55	9.4
53–59	18.6

Finally, the amount of increase in physical activity by the population due to surrounding vegetation is calculated as followed:

$$Physical\ activity_{min} = Physical\ activity_{vegetation}\ x\ Population$$

Where:

- 'Physical activity$_{min}$', is the amount of additional minutes spend on physical activity by the population due to vegetation in each cell [min dam^{-2}].
- 'Physical activity$_{vegetation}$', is the amount of additional minutes spend on physical activity due to vegetation in each cell [min dam^{-2}].
- 'Population', is the amount of people living in each cell [# inhabitants dam^{-2}].

Table 3: Output map generated for the co-benefit increase in physical activity due to surrounding vegetation.

Output map	Unit	Short description
Increase in time spend on physical activity	Min dam^{-2}	The increase in the amount of time spend on physical activity by the population based on the surrounding vegetation in a 300m buffer.

References

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Benefits of increased cycling for commuting purposes due to vegetation (adapted from Paulin et al., 2019)

A study conducted by Maas et al. (2008) studied the relationship between green space and cycling within the Netherlands. The study was based on a national health survey (Second Dutch National Survey of General Practice, DNSGP-2) with 4,899 people. To measure green space, the National Land Cover Classification database (LGN4) was used. LGN4 contains the dominant type of land use of each 25×25m grid cell in the Netherlands in 2001. Surrounding greenness was measured as the percentage of vegetation cover within a circular buffer of the participant's address. The study found a positive relationship between the percentage of vegetation cover within a buffer of one km and the number of minutes cycled for commuting purposes. It was found that, for every percentage increase in vegetation cover, people who cycle to work for commuting purposes will cycle 0.83 additional minutes on average (Figure 1). Moreover, people with 20% green space within a one km radius around their home cycle 120 minutes per week for commuting purposes, whereas people with 80% green space within a one km radius cycle approximately 170 minutes per week for commuting purposes. Based on this information, the intercept is estimated at 103.4 minutes per week per person (Figure 1). Table 1 and Table 2 provide an overview of the input and output maps model for the co-benefit of 'increase in cycling for commuting purposes due to vegetation'.

Table 1: Input maps applied to estimate the benefits of increased cycling to and from work due to vegetation.

Input	Unit	Short description	Source
Inhabitants	# inhabitants dam^{-2}	Shows the number of inhabitants per cell	RIVM (2017)
Vegetation cover	% cover per dam^{-2}	The percentage of a cell that is covered by vegetation (low vegetation, bushes and shrubs and trees combined)	RIVM (2017)

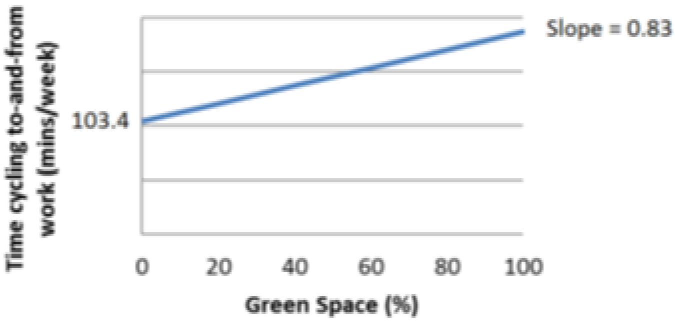

Figure 1: Relationship between the percentage of green space (vegetation cover) and the minutes people engage in cycling for commuting purposes

Build-up of the model

To determine the benefits of increased cycling to and from work due to vegetation, the percentage of vegetation within a 1km radius around every cell needs to be calculated. The calculation is done as followed:

$$\mathrm{PercGreenSpace}_{1km} = \sum VegetationCover$$

Where:

- 'PercGreenSpace$_{1km}$', is the percentage of vegetation within a 1 km radius around a cell [% vegetation cover km^{-1}].
- 'VegetationCover', is the percentage of vegetation cover in a given cell (trees, shrubs and low vegetation combined) [% vegetation cover dam^{-2}] based on the vegetation map.

Next, the amount of extra minutes cycled to and from work due to vegetation is determined for each cell as followed:

$$MinutesCycled_{inhabitants} = 103.4 + (0.83\ x\ PercGreenSpace_{1km})$$

Where:

- 'MinutesCycled$_{inhabitants}$', is the additional time spend on cycling to and from work due to vegetation by inhabitants [min $inhabitant^{-1}$ dam^{-2}].
- 'PercGreenSpace$_{1km}$', is the percentage of vegetation within a 1 km radius around a cell [% vegetation cover km^{-1}].

The total amount of extra minutes spend on cycling to and from work due to vegetation by inhabitants in each cell is determined as followed:

$$MinutesCycled_{green} = MinutesCycled_{inhabitants}\ x\ Population\ x\ (ParticipationFactor\ x\ CyclingFactor)$$

Where:

- 'MinutesCycled$_{green}$', is the additional time spend on cycling to and from work due to vegetation in each cell [min dam^{-2}].
- 'Population', is the amount of people living in each cell [# inhabitants dam^{-2}].
- 'ParticipationFactor', is the fraction of people that participate in the labour market [-].
- 'CyclingFactor', is the fraction of people that use a bicycle to travel to and from work [-].

Avoided early deaths due to increased cycling for commuting purposes

Based on the calculation obtained on cycling for commuting purposes, the number of avoided premature deaths from cycling can be calculated. This is done through the implementation of the HEAT Tool, a tool developed by the World Health Organization, which measures the effects of walking and cycling on human health (Kahlmeier et al., 2017). First the reduced risk of all-cause mortality for individuals cycling for commuting purposes is calculated according to:

$$ReducedRiskCycling = \frac{MinutesCycled_{green}}{100}\ x\ (1 - RiskMortality)$$

Where:

- 'ReducedRiskCycling', is the reduction of risk of all cause mortality for individuals that cycle for commuting purposes [-].
- '$MinutesCycled_{green}$', is the additional time spend on cycling to and from work due to green in each cell [min dam^{-2}].
- 'RiskMortality', is the relative Relative risk of mortality of cyclists against non-cyclists [-]. This has a value of 0.9 (Kelly et al., 2014).

The avoided early deaths due to cycling for commuting purposes is then calculated as followed:

$$AvoidedDeaths = \left(\frac{1}{1 - ReducedRiskCycling}\ x\ MortalityRate\ x\ Population\right) x\ (ParticipationFactor\ x\ CyclingFactor)$$

Where:

- 'AvoidedDeaths', are the avoided early deaths due to cycling for commuting purposes in each cell [avoided deaths dam^{-2}].
- 'ReducedRiskCycling', is the reduction of risk of all-cause mortality for individuals that cycle for commuting purposes [-].
- 'MortalityRate', is the mortality rate of the population [-].
- 'Population', is the amount of people living in each cell [-].
- 'ParticipationFactor', is the fraction of people that participate in the labour market [-].
- 'CyclingFactor', is the fraction of people that use a bicycle to travel to and from work [-].

To calculate the monetary benefits of cycling, the avoided deaths are multiplied with the statistical value of a life, determined by the World Health Organisation. Various estimates for the value of a statistical life exist, such as the European default values (for 2015) of €2.132 million (WHO European Region), €2.891 million (EU27 countries) or €2.877 million (EU28 countries including Croatia) can also be used. The monetary benefits of cycling for commuting purposes are calculated as followed:

$$€_{cycling} = AvoidedDeaths\ x\ VSL$$

Where:

- '$€_{cycling}$', is the monetary benefit of increased cycling for commuting purposes due to green in each cell [€ dam^{-2}].
- 'AvoidedDeaths', are the avoided early deaths due to cycling for commuting purposes in each cell [avoided deaths $cell^{-1}$].
- 'VSL', is the statistical value of a life according to the World Health Organization [€].

Table 2: Output map generated for the co-benefit of increased cycling for commuting purposes due to vegetation.

Output map	**Unit**	**Short description**
Monetary benefit of increased cycling for commuting purposes	€ dam^{-2}	The monetary benefits of increased time spend on cycling for commuting purposes due vegetation in a 1 km buffer.

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Carbon sequestration by vegetation (adapted from Remme et al. 2019)

Vegetation provides an important climate regulating service by sequestering carbon from the atmosphere and converting it into biomass. Carbon sequestration in biomass decreases the amount of carbon in the atmosphere and therefore helps to mitigate further climate change. The models indicate the potential and actual carbon sequestration in biomass and the avoided monetary damage costs based on carbon sequestration in forests and trees. Table 1 and 6 provide an overview of the input and output maps for the ecosystem service model 'carbon sequestration'.

Table 1: Input maps applied to estimate carbon sequestration by vegetation.

Input	Unit	Short description	Source
LCEU map	LCEU land use classes	Land cover class map	CBS 2016
Agricultural crop parcels	Land cover types for crops	Types of crops found on arable fields	RVO 2013
Groundwater level from the soil map*	Groundwater level in cm	Spatial information on groundwater level and soil structure to roughly 1 metre depth	Alterra 2006
BOFEK2012 map*	Soil biophysical units	Defines areas with similar soil characteristics and hydrological activity (BOFEK2012)	Alterra 2016
Min & Max Groundwater level	Groundwater level in cm	Defines maximum and minimum average groundwater levels	NHI 2016
Trees	% cover dam^{-2}	Percentage of a cell that is covered by trees higher than 2.5 meters	RIVM

*The original maps have been supplemented with data from TNO (2015), so that the maps fully cover urban areas.

Build-up of the model

Before the annual carbon sequestration by woody vegetation can be calculated the annual wood production needs to be determined. The annual wood production is calculated as followed:

$$AnnualWoodprod = AnnualIncrement \ x \ HarvestFactor \ x \ Fr_{trees} \ x \ CorrectionFactor$$

Where:

- 'AnnualWoodprod', is the annual wood production by woody vegetation [kg dam^{-2} yr^{-1}].
- 'AnnualIncrement', is the annual increment in wood of woody vegetation [kg dam^{-2} yr^{-1}].
- 'HarvestFactor', is the fraction of woody vegetation that can be harvested [-].
- 'Fr_{trees}', is the fraction of the cell that is covered by trees [-].
- 'CorrectionFactor', is the correction factor to go from kg ha^{-1} yr^{-1} to kg dam^{-2} yr^{-1}[-].

The fraction harvested (harvest factor) is based on the 6th National Forest Inventory and is estimated as: 0.373 for deciduous, 0.531 for coniferous and 0.466 for mixed forest (Schelhaas et al., 2014). The annual increment can be estimated, given specific soil texture and soil drainage groups, for different forest types (Table 2 according to Vandekerkhove et al. (2014). To determine the specific soil texture and soil drainage group maps a number of steps need to be taken that combine maps with look-up table. These steps are described below.

Soil texture

Four soil texture groups have been defined, based on the texture codes given in the map with the soil biophysical units (BOFEK2012, see Alterra 2016). These four texture groups have been grouped into two texture types: light soils and heavy soils, used for the definition of the drainage classes. Table 3 gives the reclassification of the soil types found in the map with the soil biophysical units (BOFEK2012) into eight main texture classes. Table 4 shows the reclassification of these 8 texture classes into 4 texture groups and two texture types.

Table 2: Wood increment (m^3 ha^{-1} yr^{-1}) per soil texture and drainage class combination for three forest types.

Soil texture/drainage	*Texture*	*Drainage*			
		very dry	**dry**	**moist-wet**	**wet**
Mixed forest	class/class	1	2	3	4
peat & sandy soils	1	4	6	6	5
loamy sand soils	2	5	8	8	6
(sandy) loam soils	3	3	11	10	7
(heavy) clay soils	4	3	9	10	6
Coniferous forest	class/class	very dry	dry	moist-wet	wet
peat & sandy soils	1	7	9	7	2
loamy sand soils	2	8	10	8	2
(sandy) loam soils	3	4	10	7	2
(heavy) clay soils	4	4	8	6	0
Deciduous forest	class/class	very dry	dry	moist-wet	wet
peat & sandy soils	1	4	6	6	5
loamy sand soils	2	5	8	8	6
(sandy) loam soils	3	3	11	10	7
(heavy) clay soils	4	3	9	10	6

Table 3: Reclassification of the soil classes from the BOFEK map (soil physical properties) into soil texture classes.

BOFEK Code	Texture	BOFEK Code	Texture	BOFEK Code	Texture	BOFEK Code	Texture
101	V	303	S	321	S	412	E
102	V	304	Z	322	Z	413	E
103	V	305	Z	323	Z	414	E
104	V	306	Z	324	Z	415	U
105	V	307	S	325	S	416	L
106	V	308	S	326	Z	417	L
107	V	309	Z	327	Z	418	E
108	V	310	Z	401	E	419	E
109	V	311	Z	402	E	420	E
110	V	312	S	403	E	421	E
201	U	313	S	404	U	422	U
202	E	314	S	405	U	501	E
203	V	315	S	406	L	502	L
204	V	316	S	407	E	503	U
205	Z	317	S	408	L	504	L
206	Z	318	S	409	L	505	L
301	Z	319	S	410	E	506	L
302	Z	320	Z	411	E	507	A

Table 4: Classification of soil texture classes into four texture groups and two texture types.

Texture class	**Code**	**Texture group**	**Code**	**Texture type**	**Code**
A: loam soils	1	(sandy) loam soils	3	Heavy	2
E: clay	2	(heavy) clay soils	4	Heavy	2
L: sandy loam soils	3	(sandy) loam soils	3	Heavy	2
P: light sandy loam soils	4	loamy sand soils	2	Light	1
S: loamy sand soils	5	loamy sand soils	2	Light	1

U: heavy clay soils	6	(heavy) clay soils	4	Heavy	2
V: peat	7	peat & sandy soils	1	Heavy	2
Z: sandy	8	peat & sandy soils	1	Light	1

Soil drainage

Input maps with the average minimum (GLG) and maximum (GHG) groundwater level (NHI,2006) are reclassified into nine soil drainage classes, according to Finke et al. (2010) as given in Figure 1. As the groundwater level maps do not cover the Wadden islands in the north of the Netherlands, the groundwater level from the soil map is reclassified into the same nine hydrological classes according to a reclassification table based on expert judgement (available on request). In both cases, a distinction has been made between two texture types: light soils and heavy soils as defined in Table 4. The nine drainage classes have been regrouped into four drainage groups according to Table 5 in order to estimate the annual increment.

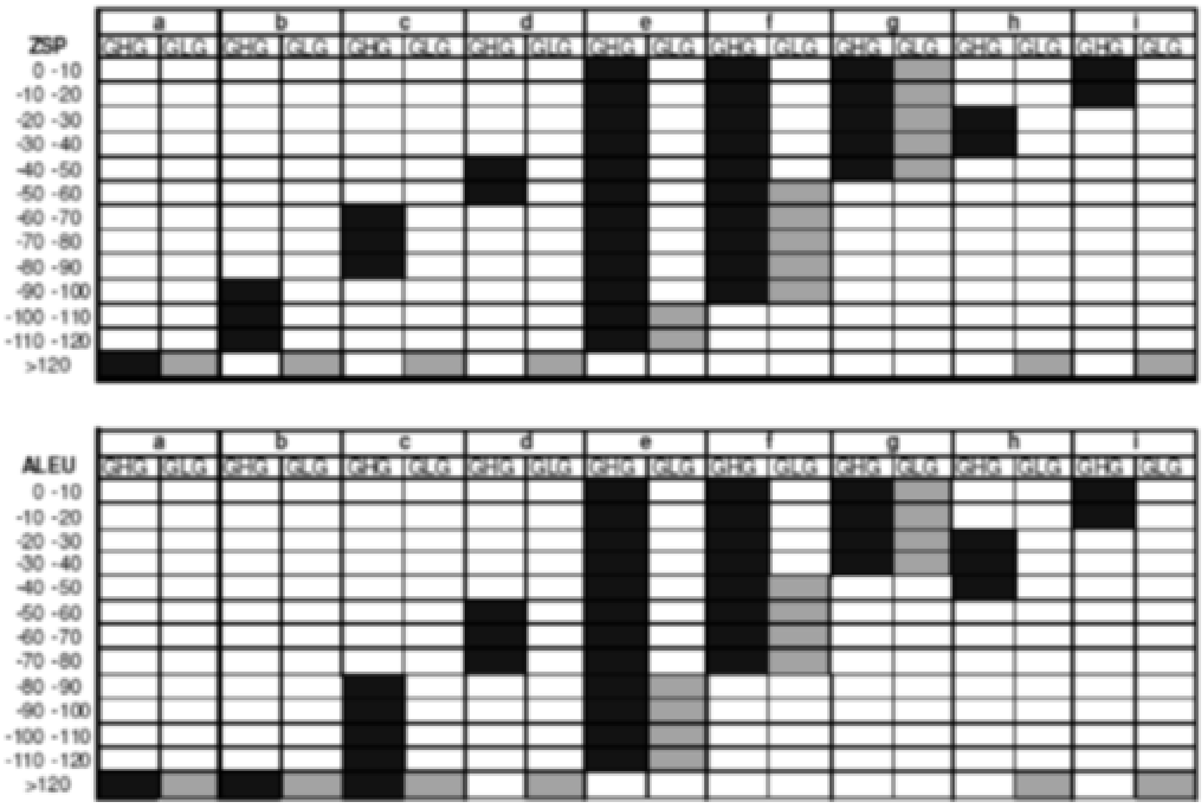

Figure 1. Definition of the average minimum (GLG, grey boxes) and maximum (GHG, black boxes) groundwater levels for the nine drainage classes for light (sandy & loamy soils) and heavy (clay & peaty) soils according to Finke et. al. (2010).

Table 5: Information from ‘Drainage group’ knowledge table necessary for reclassification.

Drainage class	**Description**	**Drainage group**	**Code**
A	excessively drained soils (very dry)	Very dry	1
B	well-drained soils (dry)	Dry	2
C	moderately well-drained soils (medium dry)	Dry	2
D	insufficiently drained soils (moderately wet)	Moist-wet	3
E	rather poorly drained soils with groundwater permanently (wet)	Moist-wet	3
F	poorly drained soils with groundwater permanently (very wet)	Wet	4
G	extremely poorly drained soils (very wet)	Wet	4
H	poorly drained soils with backwater (temporary groundwater) (very wet)	Moist-wet	3
I	rather poorly drained soils with backwater (temporary groundwater) (wet)	Wet	4

Calculating carbon sequestration by woody vegetation

Once the actual wood production is determined the carbon that is sequestered by this production can be calculated. The actual carbon sequestration in biomass is the amount of carbon that is actually sequestered by forests and trees on an annual basis. For this calculation, forested areas (as delineated by the LCEU map) and trees from the Trees map are used; all other areas are excluded from the calculation. Three LCEU forest types are used for the model: coniferous forests, deciduous forests and mixed forests. Individual trees are included as mixed forests. To determine the actual carbon sequestration in trees, information is needed on the annual increment of biomass in the tree in a certain location, the carbon density of the forest or tree and the ratio of the total biomass of a tree type (including branches, roots, etc.) compared with the stem. The annual carbon sequestration is calculated as followed:

$$AnnualCsequestration = AnnualWoodProd \ x \ BEF \ x \ C_{density} \ x \ CtoCO_2$$

Where:

- 'AnnualCsequestration', is the annual amount of carbon that is stored in forests and trees [kg dam^{-2} yr^{-1}].
- 'AnnualWoodprod', is the annual wood production by woody vegetation [kg dam^{-2} yr^{-1}].
- 'BEF', is the biomass expansion factor of a tree type. The BEF describes the expansion of the total biomass of a tree (including branches and roots) in relation to the annual increment of the stem biomass.
- '$C_{density}$', is the carbon density factor of a forest [ton C m^{-3}].
- '$CtoCO_2$', is the conversion factor between the amount of CO2 that is taken up and the amount of C that is stored.

Next, the monetary value of stored carbon can be determined by multiplying the annual amount of stored carbon with the price of a kg of stored carbon. The value is calculated as followed:

$$€_{carbon} = AnnualCsequestration \ x \ CarbonCredit$$

Where:

- '$€_{carbon}$', is the monetary value of the carbon stored by woody vegetation annually [€ dam^{-2} yr^{-1}].
- 'AnnualCsequestration', is the annual amount of carbon that is stored in forests and trees [kg dam^{-2} yr^{-1}].
- 'CarbonCredit', is the monetary value of 1 kg of stored carbon [€ kg^{-1}].

Table 6: Output maps generated for the co-benefit carbon sequestration by vegetation.

Output map	**Unit**	**Short description**
Annual wood production	kg dam^{-2} yr^{-1}	The amount of wood produced annually by woody vegetation
Annual carbon sequestration	kg dam^{-2} yr^{-1}	The amount of carbon that is stored by woody vegetation annually by uptake of CO_2.
Monetary value of stored carbon	€ dam^{-2} yr^{-1}	The monetary value of the amount of carbon that is stored annually by woody vegetation.

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Additional relevant co-benefits

Currently, seven co-benefits are calculated in the Green Benefit Planner extension in the Climate Adaptation Support Tool. These benefits are quantified both physically and monetarily. There are a number of co-benefits that cannot be quantified yet, but are important regarding climate adaptation measures (also see the CBA report[1]). Additional co-benefits that might be relevant to policy assignments are given below:

Biodiversity

At present, biodiversity cannot be quantified in the Green Benefit Planner. However, adding green and blue due to climate adaptation measures can have a positive effect on animal and plant biodiversity in municipalities. The increase in biodiversity, on its turn, can have positive effects on the delivery of other relevant co-benefits/ecosystem servicers such as pollination.

Recreation

Currently, only the increase in physical activity in green environments and the health care benefits of cycling for commuting purposes due to green are quantified. Green, however, can also contribute to other forms of recreation. These other forms of recreation are not quantified in the tool, but can be an important co-benefit to climate adaptation measures and contribute in the decision making process of applying these measures.

Social cohesion

Increasing the amount of green in the environment by means of climate adaptation measures offers possibilities for creating meeting places for local residents. This can increase the social cohesion and liveability of neighbourhoods.

Experience value

Changing the public space by means of climate adaptation measures can increase the attraction of an area, especially with ‘green’ and ‘blue’ measures. Thus, these measures can improve the experience value of the public space, which can have positive effects on local residents in and around this area.

Noise reduction

Green has a dampening effect on noise disturbance caused by traffic, for instance. The reduction in noise disturbance reduces stress of local residents that live in and around areas where ‘noise dampening’ green is implemented.

Changing subsidence / CO_2 emissions of peat

If climate adaptation measures change the ground water level in peat areas, they have an effect on the emission of CO_2 and subsidence of these peat soils.

Pollination

The implementation of green can enhance or increase the habitat for different insect species that contribute to pollination. In the last years, the numbers of these pollinators have dropped significantly, thereby threatening the production of crops and other plant species. Creating habitat for these species through climate adaptation measures can positively contribute to the survival of these species.

Increase in investment costs

The investment costs are determined by the measures that are implemented, which can differ per scenario.

Changes in management costs of green and grey

Changes in land use from grey/paved functions to green functions result in changes in management costs.

[1] https://ruimtelijkeadaptatie.nl/actueel/actueel/nieuws/2020/onderzoeken-nkwk-kbs-2019/