Appendix 1. Quantification and monetary valuation per ecosystem service

All data used to quantify and monetary value the ecosystem services is summarized in Fig. A1.1 and explained in detail in this appendix.

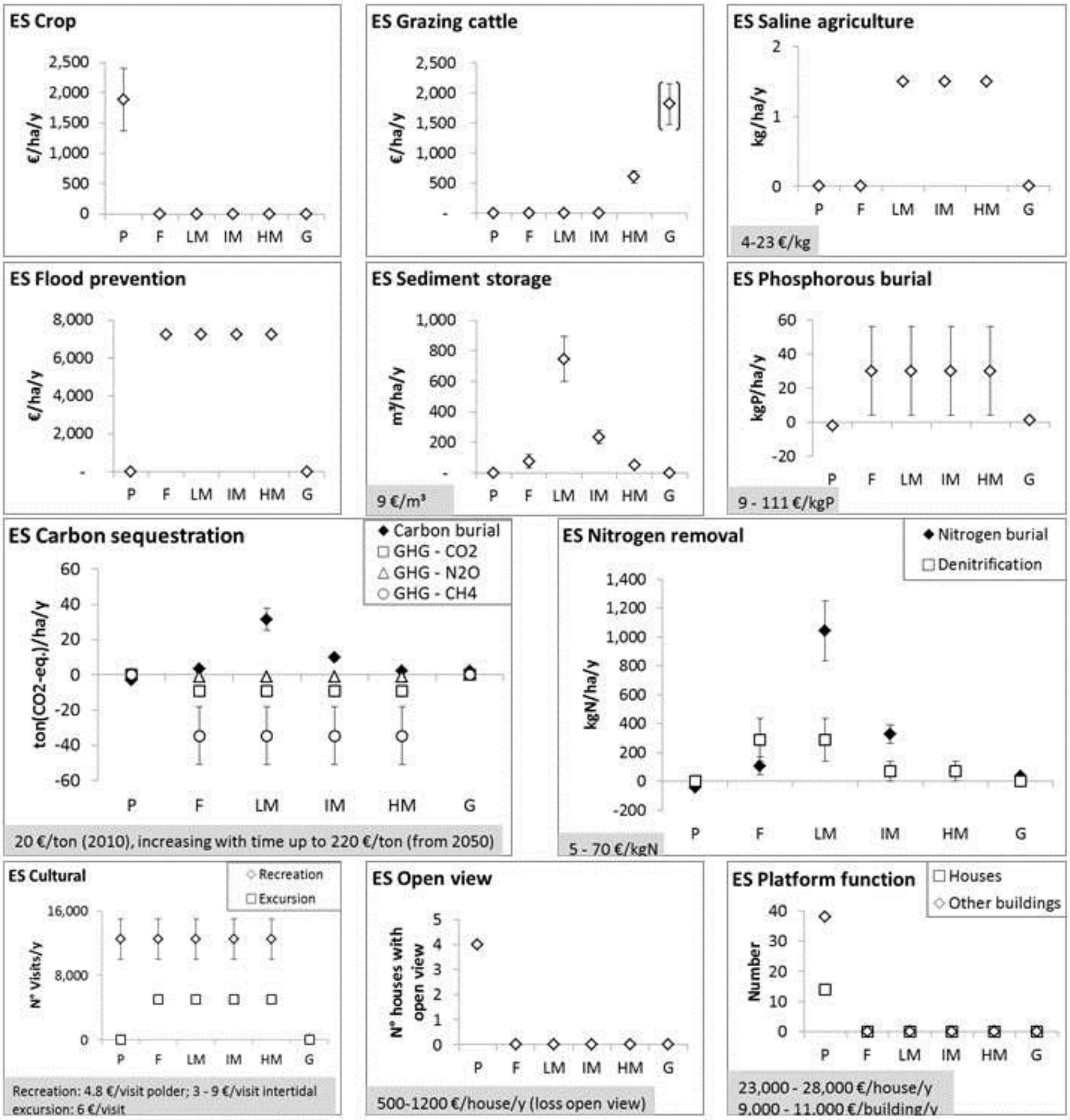

Figure A1.1. ES data for biophysical quantification and monetary valuation, for the different land uses: polder (P), mudflat (F), low marsh (LM), intermediate marsh (IM), high marsh (HM), grassland on the dike (G). Monetary values are converted to €$_{2013}$ values, the reference year, based on the Belgian consumer price index (Statbel 2014).

ES Food – crops *(CICES category: Provisioning - Nutrition - Biomass - Terrestrial plants, fungi and animals for food - Commercial crops)*

Data: The distribution of crop types in the project area is based on the Flemish map of crop types (Flanders Geographical Information Agency (FGIA/AGIV) 2007). Same crop distribution is assumed for the Dutch part of the project area. The standard gross margin (SGM) per crop type is used for the monetary valuation of food provision. This is the market price minus the variable costs related to the production (http://ec.europa.eu/agriculture/). A weighted SGM was calculated based on standard gross margin for the main crop types present in the project area (Table A1.1), excl. subsidies, data for Flanders, average 2008-2010 (Liekens et al. 2012). The weighted average SGM was converted to $€_{2013}$ values with the Belgian consumer price index (Statbel 2014): 1373 – 2402 $€_{2013}$ ha^{-1} y^{-1}. The crop benefit was not included in the net present value of the project to avoid double counting of the same cost (lost crop benefit and expropriation cost for the project), but it was included to compare the annual habitat values.

Table A1.1. Calculation weighted average Standard Gross Margin (SGM) in the project area. SGM data per crop type from (Liekens et al. 2012).

Crop type	% in the project area	SGM, €2010 ha^{-1} y^{-1} (average 2008-2010)	
		Min.	Max.
Sugar beets	12%	1,263	1,905
Potatoes	23%	1,727	4,259
Winter wheat	17%	718	1,233
Summer wheat	9%	718	1,233
Silo maize	12%	1,003	1,526
Flax	16%	788	1,414
other	11%	2,666	2,666
Weighted average	**100%**	**1,275**	**2,231**

ES Food – grazing livestock *(CICES category: Provisioning - Nutrition - Biomass - Terrestrial plants, fungi and animals for food - Land-based commercial livestock)*

Data: Grazing livestock (cattle, sheep) is a potential benefit on the high marsh. The surface of high marsh present annually changes with marsh succession, and is based on the results from the MARSED model for each scenario (Figure 2). The monetary value of livestock is the standard gross margin (SGM) for grassland and fodder land (1,245 – 1,818 € ha^{-1} y^{-1}, (Liekens et al. 2012)). Since livestock densities on a marsh are much lower, e.g. for cattle about 0.5 head ha^{-1} versus 1 to 2.5 head ha^{-1} on pastures, (Wint and Robinson 2007, Nolte et al. 2013), a monetary value of 600 € ha^{-1} y^{-1} is used. An added value for “pré-salé” meat is assumed at 10%. Discussion: Grazing livestock could also take place on the dikes, reducing the need for mowing and hence introducing grazers on the new dike will generate a double benefit: benefit from the grazers itself (100,000 € y^{-1} = 65 ha × 1,500 € ha^{-1} y^{-1}) and avoided maintenance cost for mowing (almost 60,000 € y^{-1} since a large part of the maintenance cost is for mowing). This benefit is not included to calculate the net benefits of the project since livestock grazing on the dikes was not present before the project and neither is planned.

ES Food – Saline agriculture *(CICES category: Provisioning - Nutrition - Biomass - Marine algae and animals for food - Edible plants from salt and brackish waters)*

Data: We assume that saline agriculture is possible on low, intermediate and high marshes. Saline agriculture is not the purpose of tidal marsh restoration projects, but extensive production of *Aster tripolium* (on high marshes) and *Salicornia* (on low marshes) takes place at very small scales in some projects for folkloric purposes (data Land van Saeftinghe, north of the project area: about 1.5 kg ha^{-1} y^{-1} (De Nocker et al. 2004).
Monetary data: Different market prices were found for *Aster tripolium*: from 3 € kg^{-1} (Goosen 1999) to 19 € kg^{-1} from the adjacent marsh Land van Saeftinghe (De Nocker et al. 2004), or 4 – 23 € kg^{-1} in $€_{2013}$. Market price is

not a correct monetary indicator because it includes the production cost and is hence not identifying the added value of the service. Nevertheless, it is the best data available since we were not able to find the Standard Gross Margin for *Aster tripolium* or *Salicornia*.

Discussion food provisioning: Although cropland will be lost because of the project, this does not mean that there are no possibilities for farming in the project area (livestock grazing and saline agriculture). The standard gross margin for cropland in the project area (weighted for the crop types) is comparable to the standard gross margin for grassland and fodder land, but the potential benefit of livestock grazing on a marsh is much less. Furthermore, the available area for livestock grazing after the project is limited (65 ha dike and up to 465 ha high marsh after marsh succession). The benefits of livestock grazing on the marsh and saline agriculture both depend on vegetation and hence marsh succession. This means that there is a large time gap between the lost food production from crop fields and the potential alternatives for food provision.

ES Flood prevention *(CICES category: Regulation and maintenance - Mediation of flows - Liquid flows - flood prevention)*

Data: The project is part of a larger Sigmaplan measure (Doel Prosper Hedwige polder) for which an avoided flood damage benefit of 76 million € is estimated (period 2010 and 2100, calculated based on expected flood height, damage function and replacement values) (Smets et al. 2005). Since Doel polder is not a flood control area, this benefit can be allocated entirely to Prosper and Hedwige polder, the studied project area. The annual benefit is about 3 million € y^{-1} (annuity*: n = 90 years (until 2100), i = 4 %), and per hectare: 6,700 € ha^{-1} y^{-1} (intertidal area 465 ha). This value was converted to $€_{2013}$ value with the Belgian consumer price index (Statbel 2014): 7,250 € ha^{-1} y^{-1}. This benefit last only for 90 years, until 2100.

Quantitative effect: The flood prevention benefit is an economic indicator, but flood prevention could also be quantified in biophysical terms. Data comes from the environmental impact assessment report of the project (Soresma/Antea-group et al. 2007, Oranjewoud/Antea-group and Provincie Zeeland 2013). The water storage capacity in the project area is estimated at 1.2 – 6.5 million m^3 per tide.

ES Sediment storage *(CICES category: Regulation and maintenance - Mediation of flows - Mass flow - buffering and attenuation of mass flows (transport and storage of sediments))*

Data: Sediment storage (m^3 ha^{-1} y^{-1}) is calculated by multiplying the annual sedimentation rate (m y^{-1}) by the surface unit (10,000 m^2 ha^{-1}). Annual sedimentation rates in the project area for low/intermediate/high marshes were modeled, for a time horizon of 200 years, with the MARSED model, as described, calibrated and validated for marshes along the Schelde estuary (Temmerman et al. 2004). For the mudflat habitat, not included in the MARSED model, sedimentation rate was based on the modelled sedimentation in the environmental impact assessment report of the project for which a model was used without taking into

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* Annuity: continuing payment with a fixed total annual amount. The present value (PV) of an annuity is the value of a stream of payments (R), discounted by the interest rate (i) to account for the fact that payments are being made at various moments in the future (number of years: n). Present value is linear in the amount of payments, therefore the present value for payments, or rent R is:

$$PV(i,n,R) = R \times a_{\overline{n}|i} \, , \quad a_{\overline{n}|i} = \frac{1-(1+i)^{-n}}{i} \, .$$

account the impact of vegetation (Soresma/Antea-group et al. 2007): 0.4 - 1.6 cm y^{-1}. The monetary value is calculated as the avoided cost for maintenance dredging: about 7 € m^{-3} (Broekx et al. 2011), or 8.88 $€_{2013}$ m^{-3}. Discussion: The monetary value of sediment storage is only a rough estimate because no direct link with dredging volumes is proven. It represents the value for the society to remove sediment from the system.

ES Climate regulation (CO_2-equivalent balance) *(CICES category: Regulation and maintenance - Maintenance of physical, chemical, biological conditions - Atmospheric composition and climate regulation – Carbon removal from the atmosphere by burial, correction for GHG emissions CO_2, N_2O, CH_4)*

Carbon (C) burial

Data cropland: Negative net carbon burial in croplands: between - 5 and - 2 ton CO_2-eq. ha^{-1} y^{-1}., data from Flanders (Department of environment nature and energy (LNE) 2009, Liekens 2009) and Europe (Vleeshouwers and Verhagen 2002).

Data intertidal area: Carbon burial capacity (ton CO2-eq. ha^{-1} y^{-1}) is calculated based on the annual sedimentation rate and the organic carbon content: organic C content (wt%) × sedimentation rate (cm y^{-1}) × surface (cm^2 ha^{-1}) × bulk density (kg m^{-3}) × 3.667 (conversion ton C to ton CO_2-eq.). Sediment storage per habitat type is based on the modelled sedimentation rate (see ES sedimentation storage), with a bulk density of 500 kg m^{-3} which is the average value near the project area (Temmerman et al. 2004). The 4-year (2010-2013) mean particulate organic carbon (POC) in the Schelde at the boarder measuring point (boarder between Belgium and The Netherlands, where the project is located) was used to calculate the organic carbon content (mean value 2.3%). The organic carbon content is assumed to remain constant for the long term assessment. Based on the different sedimentation rate between the five intertidal area types, we found a range from 1 to 35 tonnes CO_2-eq. ha^{-1} y^{-1}, which matches the broad range found in the literature, when habitat types are not specified (between 2 and 23 tonnes CO_2-eq. ha^{-1} y^{-1} (Middelburg et al. 1995b, Soresma/Antea-group et al. 2007, McLeod et al. 2011, Adams et al. 2012, Craft 2012). Discussion: Carbon burial is considered as a benefit since the organic carbon is stored in the soil and hence removed from the water and air. However, it is disputable if carbon burial is sustainable, since it could be remobilized easily with erosion. However, during sea level rise marshes will grow steadily with the increase in MHWL and hence the sedimentation process will be dominant (as long as sediment is available).

Data grassland: Carbon burial in grassland about 2 ton CO_2-eq. ha^{-1} y^{-1}., data from Europe (Vleeshouwers and Verhagen 2002).

Monetary data: The damage cost for CO_2-eq. is expected to increase in the future (Figure A1.2): 20 € ton(CO_2-eq.)$^{-1}$ in 2010 to 220 € ton(CO_2-eq.)$^{-1}$ in 2050 (De Nocker et al. 2010). These values are based on European models and data (Downing et al. 2005, Tol 2005, Stern 2006, Anthoff et al. 2009) and are combined with models and information from Flanders (De Nocker et al. 2010). Two methods are being used: the damage function method (doses-effect relationships) and prevention cost method (marginal reduction costs, marginal cost of management measures to prevent a 2°C increase). The resulting estimates are comparable with the results from Downing et al. (2005) and de Bruyn et al. (2010) and are within the minimum-maximum range from Kuik et al. (2009).

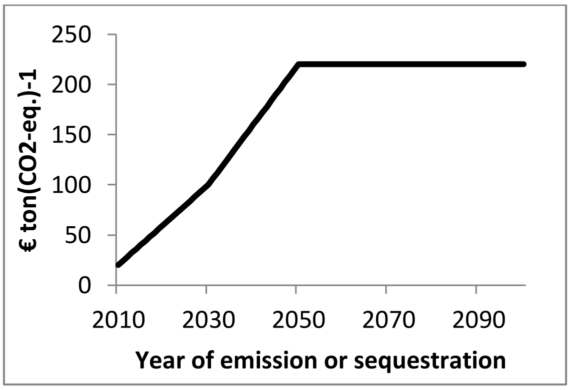

Figure A1.2. Temporal evolution in the monetary value of CO_2-eq. removal, € ton(CO_2-eq.)$^{-1}$. Data from (De Nocker et al. 2010).

Greenhouse gas emissions: CO_2, CH_4 and N_2O

Carbon in the sediment is microbially transformed to other chemical species depending on the redox state of the sediment, including two important greenhouse gases carbon dioxide (CO_2) and methane (CH_4). A third important greenhouse gas is nitrous oxide (N_2O), a by-product during nitrification and denitrification processes. All data are expressed in CO_2-equivalent and corrected for the warmth potential, CO_2:CH_4:N_2O 1:25: 298.

Data CO_2 emission cropland: The carbon released from the cropland (negative carbon burial) will be emitted as CO_2 and CH_4. The negative effect of CO_2 emission as greenhouse gas is not quantified explicitly.

Data CO_2 emission intertidal area: emission 7 - 11 ton CO_2-eq. ha^{-1} y^{-1}, data intertidal sediment at Doel (close to project area) (Middelburg et al. 1995b).

Data CO_2 emission grassland: no data found

Data CH_4 emission cropland: The carbon released from the cropland (negative carbon burial) will be emitted as CO_2 and CH_4. The negative effect of CH_4 emission as greenhouse gas is not quantified explicitly.

Data CH_4 emission intertidal area: emission 18 - 51 ton CO_2-eq. ha^{-1} y^{-1}, data intertidal sediment at Doel (close to project site) (Middelburg et al. 1995b). Since this data is from the same area as the project site, the negative relationship with salinity (methane emission less in more saline areas) is taken into account. The large range represents the natural variation caused by the many environmental factors that have an influence. This also explains why it is hard to differentiate between mudflats and marshes: on the one hand is the emission higher in anoxic conditions (in mudflats) (Jenkins et al. 2010), but on the other hand also higher in regions with rooted plants that can inject labile organic matter at depths where methanogenesis occurs (in marshes) (Abril and Borges 2005).

Data CH_4 emission grassland: no data found

Data N_2O emission cropland: no data found

Data N_2O emission intertidal area: emission 0.87 ton CO_2-eq. ha^{-1} y^{-1}, data intertidal sediment at Doel (close to project area) (Middelburg et al. 1995a).

Data N_2O emission grassland: no data found

CO_2-equivalent balance

Climate regulation (CO_2-equivalent balance) is the benefit of carbon burial corrected for emissions of greenhouse gasses (GHG) including CO_2, N_2O and CH_4. For the five sub habitats of the intertidal area, the net CO_2-equivalent balance is negative mainly due to the high negative impact from methane emission. However, in more saline areas the net carbon burial in a tidal marsh restoration area could be positive despite the large negative impact of greenhouse gas emissions (Adams et al. (2012). Due to a (slightly) negative CO_2-equivalent balance for this project, a lower or even zero monetary CO_2-equivalent value has a positive impact on the long term benefits of the project. Given the global climate problems, a higher CO_2-equivalent value can also be expected and would lead to a larger negative effect of the project. Only with a very strong increase in the CO_2-equivalent value (200 % above the expected value), the long term benefits of the project will start decreasing but will still be higher than the investment cost (Appendix 2). A similar result is found for CH_4 emission. If the CH_4 emission would be higher (200 % above the expected value), the result is much lower but still beneficial.

ES Nitrogen cycle *(CICES category: Regulation and maintenance - Mediation of waste, toxics and other nuisances - Soil and water quality - Water purification, oxygenation and nutrient regulation)*

Nitrogen (N) burial

Data cropland: Nutrient surplus from cropland in Flanders is legislated: max. - 90 kg(N) ha^{-1} y^{-1} for cropland on polder clay. However, the soil balance for agriculture in Flanders for 2011 gives a surplus of 25 - 57 kg(N) ha^{-1} y^{-1} (De Nocker et al. 2004, Platteau et al. 2014), which is better than the legal maximum nitrogen (N) surplus. The amount of 25-57 kg(N) ha^{-1} y^{-1} is used in the analysis as negative effect for cropland since this will leach to surface water. Discussion: For some effects it is disputable whether it is really a service from the ecosystem or an effect due to human interference. For example when using animal manure as fertiliser on crop fields it could be argued that the crop field treats the animal manure (resulting in avoided treatment costs and hence an ecosystem benefit from the crop field), but on the other hand using any form of fertiliser in large amounts causes nutrient pollution towards the water bodies (negative effect). In this study only the negative effect of nutrient leaching is included.

Data intertidal area: Nitrogen is removed from the water when buried in the intertidal area. N burial (kg(N) ha^{-1} y^{-1}) is calculated with sediment storage (m^3 ha^{-1} y^{-1}), bulk density (kg m^{-3}) and organic N content (wt %). Sediment storage per habitat type is based on the modelled sedimentation rate (see ES sedimentation storage), with a bulk density of 500 kg m^{-3} which is the average value near the project area (Temmerman et al. 2004). The 4-year (2010-2013) mean particulate nitrogen (PN) in the Schelde at the boarder measuring point (boarder between Belgium and The Netherlands, where the project is located) was used to calculate the organic nitrogen content (mean value 0.28%). The organic nitrogen content is assumed to remain constant for the long term assessment. Based on the different sedimentation rate between the five intertidal area types, we found a range from 45 to 1250 kg(N) ha^{-1} y^{-1}, which is a much broader range compared to the range given in the literature where the sub-habitat types are not specified (150 - 250 kg(N) ha^{-1} y^{-1}, (Middelburg et al. 1995a, Dettmann 2001, Broekx et al. 2011)). Discussion: Also for nitrogen burial it is disputable if this is a long term and sustainable benefit since it could be remobilized easily with erosion. However, during sea level rise marshes will grow steadily with the increase in MHWL and hence the sedimentation process will be dominant (as long as sediment is available).

Data grassland: Nitrogen burial ranges between 15 and 55 kg (N) ha^{-1} y^{-1} (Ruijgrok 2006, Billen et al. 2009).

Monetary value for nitrogen removal: The economic value of nitrogen removal is calculated with the shadow price: the marginal cost of a (technical) measure that would be needed to achieve the water quality target but that could be avoided due to the restoration measure. As long as the water quality target is not met, the economic value of nitrogen removal will increase rather than decrease. Since many measures to improve water quality were already taken, further measures that need to be taken today and in the future to reach the water quality targets are much more expensive. Therefore the estimate based on an international literature review is used: 5 - 65 € kg(N)$^{-1}$ (Liekens et al. 2012), or 5 - 70 € kg(N)$^{-1}$ in €$_{2013}$. Discussion: The benefit of nutrient removal depends on the demand for water quality improvement, the distance between the chemical water quality and the target for the estuary. For both nitrogen and phosphorous in the Schelde estuary, water quality does not comply with the European Water Framework Directive (Council Directive 2000/60/EC). For the long term analysis, this condition is considered to be constant and hence nutrient burial will remain a benefit. However, it is hoped that at a certain moment the water quality targets will be reached in the estuary (non-harmful level) and then nutrient removal becomes an option value (it will give a benefit in the future every time the nitrogen input increases). Before that time, it will remain an important benefit and it is also possible to argue that water quality targets will get stronger in the future rather than the opposite.

Nitrogen removal by denitrification

Data cropland: no data

Data intertidal area: Denitrification is difficult to predict, because it depends on many local conditions. A broad range between 0 and 437 kg(N) ha^{-1} y^{-1} was found, with an average of 140 kg(N) ha^{-1} y^{-1} at Doel (close to the project area) (Middelburg et al. 1995a) and an average of 107 kg(N) ha^{-1} y^{-1} for salt marshes (Broekx et al. 2011). It is important to take local values as it depends on many factors that change along the salinity gradient in estuaries, among which sediment texture, organic nitrogen content of the sediment, delivery of substrate (nitrate) and the presence of oxic/anoxic boundary layers. Based on the knowledge that denitrification is higher in un-vegetated zones compared to vegetated zones (due to the difference in inundation and hence in oxic/anoxic conditions), following values are used: 140 - 437 kg(N) ha^{-1} y^{-1} for mudflat and low marsh, and 0 - 140 kg(N) ha^{-1} y^{-1} for intermediate and high marsh. Like for nitrogen burial, also denitrification might change over the time period studied, as nitrate and organic nitrogen content in sediments might decrease over time as more water quality measures are taken.

Data grassland: no data found.

ES P-burial *(CICES category: Regulation and maintenance - Mediation of waste, toxics and other nuisances - Soil and water quality - Water purification, oxygenation and nutrient regulation)*

Data cropland: Likewise for N burial: legal maximum phosphorus (P) surplus cropland Flanders is - 3.6 kg(P) ha^{-1} y^{-1}. The soil balance for agriculture in Flanders (2011) gives a surplus of 2 kg(P) ha^{-1} y^{-1} (Platteau et al. 2014), which is better than the legal maximum phosphorus (P) surplus for cropland in Flanders (3.6 kg(P) ha^{-1} y^{-1}). The amount of 2 kg(P) ha^{-1} y^{-1} is used in the analysis.

Data intertidal area: Phosphorous is removed from the water when buried in the intertidal area. A literature review for potential P burial in saltmarshes gives a range between 4 and 56 kg(P) ha^{-1} y^{-1} (Vymazal 2007, Broekx et al. 2011, Adams et al. 2012). Discussion: Also for phosphorous burial it is disputable if this is a long term and sustainable benefit since it could be remobilized easily with erosion. However, during sea level rise marshes will grow steadily with the increase in MHWL and hence the sedimentation process will be dominant (as long as sediment is available).

Data grassland: P burial is estimated at 1.3 kg(P) ha^{-1} y^{-1} (Ruijgrok 2006).

Monetary value: Technical measures for water treatment could be avoided: value 8 - 103 € $kg(P)^{-1}$ (Liekens et al. 2012), or 8.6 - 111 € $kg(P)^{-1}$ in $€_{2013}$.

ES Recreation *(CICES category: Physical and intellectual interactions with biota, ecosystems and land-&seascapes - Natural environment suitable for non-excludable outdoor activities - Landscape for outdoor recreation)*

Data: Number of potential recreants (e.g. waking and cycling on the new dike) is assumed to remain constant before and after the project (although we assume that an intertidal area will attract more tourists and recreants from abroad). Data is derived from estimations in the adjacent Land van Saeftinghe intertidal nature area (ca. 15,000 per year) and cycle renting nearby (10,000 per year, Bike rent at Doel) (Soresma/Antea-group et al. 2007, Oranjewoud/Antea-group and Provincie Zeeland 2013). This equals to a range of 22 to 32 visits ha^{-1} y^{-1} for the 465 ha new intertidal area. The economic value for visiting a farmland is estimated at 4.8 € $visit^{-1}$ and a marine and coastal area 4.6 € $visit^{-1}$ with a range from 3 to 9 € $visit^{-1}$ (Liekens et al. 2012). These values are taken from a meta-analysis study, including the travel cost method and willingness-to-pay method to estimate the welfare value of a visit to green spaces (Bateman et al. 2014, Sen et al. 2014).

ES Excursion *(CICES category: Physical and intellectual interactions with biota, ecosystems and land-&seascapes - Natural environment suitable for non-excludable outdoor activities - Natural landscapes and species for nature experience and education)*

Data: A number of 5.000 visits to the project area in an excursion is assumed based on the excursion numbers of the adjacent Land van Saeftinghe (12,000 – 18,000 visits y^{-1}) and the fact that they have to refuse applicants to protect the area and because of shortage of guides (Soresma/Antea-group et al. 2007). The economic impact is calculated with the fee of 6 € per visitor for excursions in Land van Saeftinghe (www.hetzeeuwselandschap.nl, consulted on 4/4/2013).

ES Open view - visual intrusion *(CICES category: Physical and intellectual interactions with biota, ecosystems and land-&seascapes - Natural surroundings of build-up areas - Natural surroundings around buildings for living, working and studying)*

Data: According to the environmental impact assessment report of the project, 4 houses will be hindered by the new dike (Soresma/Antea-group et al. 2007). The economic impact of visual intrusion is the annual loss of the added value of open space (6% - 12%, (Luttik 2000)) on housing prices (mean value for Flanders: 125,000 – 150,000 € house^{-1}, (Coppens 2010)), giving a value of 500 – 1,200 €$_{2013}$ house-1 y-1 (18 y, 1.2%). This benefit only last for 18 years.

ES platform function for houses and other buildings *(Platform function for anthropogenic constructions - residential houses and other buildings)*

Data: According to the environmental impact assessment report, 14 houses and 38 other buildings has to disappear in the project area (Soresma/Antea-group et al. 2007). The economic impact is estimated with the expropriation value for the houses (375,000 € per house) and other buildings (150,000 € per house), with 10% transaction costs and +/- 10% uncertainty range (Scheltjens et al. 2013). Both benefits in the polder are not included in the net benefits of the project to calculate the net present value of the project (to avoid double counting of the same cost: lost platform function and expropriation cost for the project).

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