Benefito - Description of the Excel tool and user manual

Report
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CE Delft's solutions are characterised in being politically feasible, technologically sound, economically prudent and socially equitable.

Preface

We are pleased to present the Benefito tool which provides the user with a set of damage value estimates for pollutants which are most often used in environmental analyses. The tool can be seen as an extension to the Shadow Prices Handbook (CE, 2010a). While the latter source lists the values only for the Netherlands and the EU-27 average, with Benefito it is possible to obtain values pertaining to the emission of pollutants from virtually all countries in the World. One has to note that the values obtained through value transfer tools such as Benefito can only yield a first approximation of the true damage values. This is because benefit-transfers only hold in economics under very strict conditions which are not being met in practice. However, when clarifying in reports that the used values come from a benefit-transfer approach and shortly discussing the uncertainties involved, there are no formal obstacles in using these values in empirical work. The estimates are presented in Euro at the level of prices of 2008 and they refer to two years of pollution release: 2008 and 2020.

Contents

Summary

The goal of this report
This report aims to provide the user of Benefito all the information necessary to understand what is behind the values of damage costs that can be obtained from the tool. For users who are not interested in the background and methodology of these values, Annex C (User Manual, also included in the Excel tool) may be sufficient. Other users might want to check some of the methodological details - and these are broadly discussed in this report.
Yet other users might be interested in a more detailed discussion of the theoretical background or modelling of the original values obtained within the NEEDS project. These users should be referred to the Shadow Prices Handbook (CE, 2010a) and to the background documentation of the NEEDS project (http://www.needs-project.org/).

What is Benefito?
Benefito is an Excel tool developed within CE Delft accompanying the Shadow Prices Handbook (CE, 2010a). It was created with an aim to extend the set of shadow prices for the most often used pollutants (that is, classical pollutants and a selection of non-classical pollutants) to other countries than the Netherlands and the EU-27, which are the only entities used in the Handbook.

The values which constitute the basis for adjustments in Benefito are taken from the Excel tool developed within the NEEDS project, which was the last stage of the ExternE series of projects so far, completed in 2008. Especially the EU-27 emissions-weighted average values estimated within NEEDS are extensively used within Benefito for value transfer procedure (i.e. adjustment to other countries).

The full list of pollutants included in Benefito is given below:
a   Classical pollutants: NO_x, SO_2, NH_3, NMVOC, PPM_{co}, $PPM_{2.5}$.
a   Non-classical pollutants: Cd, As, Ni, Pb, Hg, Cr, Cr-VI[1], Formaldehyde, Dioxin.

Damage values within Benefito are given in Euro in prices of 2008 per tonne of a given pollutant. Two different years of release of pollutants can be chosen: 2008 and 2020.

The rationale for adjustments of damage values
Damage values for environmental pollutants have been established in various European projects, such as NEEDS. The Shadow Prices Handbook of CE Delft (CE, 2010a) has combined estimates from various projects in one coherent framework and established damage estimates for over 400 pollutants.
These estimates are available both for the Netherlands and the EU. They can be used in e.g. cost-benefit analysis or environmental impact scores. However, in some projects valuation of damages in other countries or regions may be needed. For this purpose, benefit-transfers are often used in the literature.

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[1]   With chromium, the user should note that either the values for Cr or Cr-VI should be used, otherwise double counting will occur.

The benefit-transfer method is used to estimate economic values for ecosystem services by transferring available information from studies already completed in another location and/or context. For example, values for recreational fishing in a particular lake may be estimated by applying measures of recreational fishing values from a study conducted for another lake. By determining the factors that could explain the valuation of the original lake one could transfer the damage values of this lake to the other lake by taking into account the difference in explanatory factors.

For most environmental pollutants the following factors seem to be most important (in decreasing order):
1. Income levels as damages in high income regions seem to be higher than in low income regions (in economic terms: environmental quality has a positive income elasticity).
2. Price levels as not pure income but rather the amount of goods that one can buy from this income matters for the valuation of the damages (e.g. people tend to value lost opportunity to buy things because of the damages instead of the damage itself).
3. Population density as especially human health-related impacts of pollution are more severe in densely populated areas.
4. Atmospheric conditions as both precipitation and wind have the characteristic to partly wash out (or blow away) pollution.
5. Other non-tangible aspects, such as democracy as environmental damages tend to be perceived as more damaging in open societies.

Of these four characteristics only the first three are subject to benefit-transfers in the Benefito tool. In addition specific adjustments are being made with respect to types of ecosystems.

The main mechanisms of adjustment

Within the tool, different methods of adjustment are used for different impact categories (endpoints). In the standard approach, most endpoints (except for crops) are adjusted for income level. It is also possible, however, to choose an option where the values are not adjusted for income. This seems to be a better approach for projects where equal valuation of human life and health is recommended for ethical reasons. Human health and ecosystem values are additionally adjusted for population density. These adjustments follow the logic that in more densely populated areas, the damage to human health-related to pollution is higher and also, that the aggregated values resulting from stated preferences surveys related to the sites with high biodiversity qualities are higher in areas with higher number of people. Adjustment of impacts on crops follows a different methodology, which is related to the fact that crops are subject to market transactions, so in this case Purchasing Power Parity (PPP) exchange rates are used. For ecosystems, an additional possibility of adjusting for the type of ecosystem is created.

Damage values for so-called classical pollutants (NH_3, NO_x, SO_2, PPM) have been estimated within NEEDS separately for different endpoints, therefore the outcomes are more detailed and the adjustment procedure is more complicated than for non-classical pollutants. Impacts of non-classical pollutants have been estimated within NEEDS for human health endpoint only, and this is the approach followed in Benefito (the Handbook, however, offers more extensive valuation for some non-classical pollutants).

The mechanism of Benefito for classical pollutants can be depicted using the Figure 1.
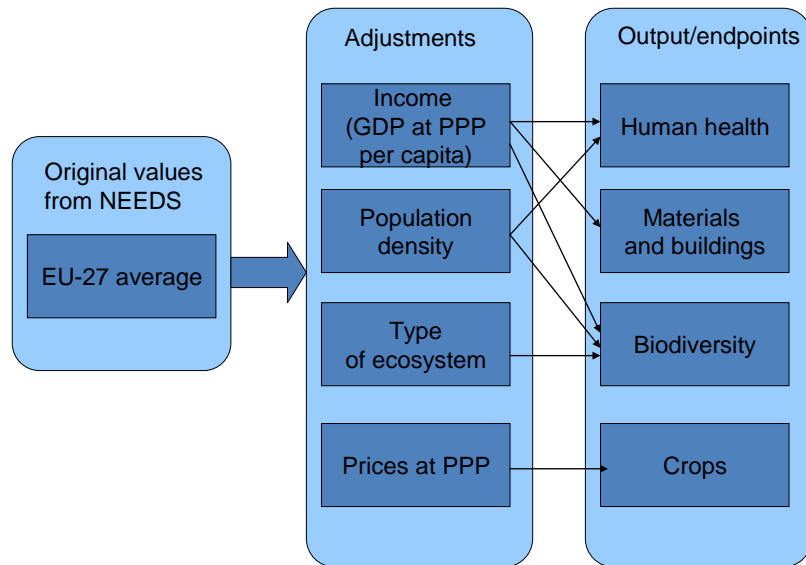
The procedure for non-classical pollutants is similar only much less complicated (see Section 3.5).

Uncertainty

The user has to keep in mind a long list of assumptions underlying the values which pop out of the Benefito tool. These assumptions create considerable uncertainty. There are two categories of uncertainty which are relevant: one is related to the values resulting from NEEDS and another is related to the procedure of value transfer. Therefore, the values which do not undergo the benefit-transfer procedure (i.e. the values for the individual EU Member States and EU-27 average) are surrounded with less uncertainty than the values which are adjusted for the countries outside the EU.

1 Introduction

1.1 Project background and purpose

Valuation of environmental damages is gaining more and more attention of policy-makers, which is reflected in an increasing number of projects performed within the society (and by CE Delft) containing an element of damage cost valuation. Estimates of so-called shadow prices[2] are needed in various socio-economic analyses such as cost-benefit analyses of investment projects, impact assessments of policy proposals and life cycle analyses.
In response to a growing demand for shadow price estimates, recently a Handbook of shadow prices has been produced by CE Delft (hereafter referred to as Handbook), commissioned by Stimular, Thermphos and the Ministry of VROM (CE, 2010a).

The Handbook of 2010 describes the methodology of estimating and weighting emissions and environmental impacts and provides an extensive set of shadow prices for the Netherlands and for the EU-27 (as an average). Some of these numbers can be used in various projects either straight away or with small adjustments (e.g. for inflation). However quite often there are projects where shadow prices are needed for specific countries within the EU, for countries outside the EU, for specific provinces within countries or for specific emission sources (e.g. transport or power-plants). While the Handbook describes in general terms the methodology of benefit-transfer[3], i.e. how to arrive at the values relevant for other countries/regions, these values are not listed in the Handbook. The Benefito tool can be seen as a supplement to the Handbook with the purpose of providing the user with damage value estimates for the specific pollutants and countries, including benefit-transfer to practically all countries in the World.

1.2 The rationale for adjustments of damage values

Damage values for environmental pollutants have been established in various European projects, such as NEEDS. The Shadow Prices Handbook of CE Delft (CE, 2010a) has combined estimates from various projects in one coherent framework and established damage estimates for over 400 pollutants.
These estimates are available both for the Netherlands and the EU-27 (average). They can be used in e.g. cost-benefit analysis or environmental impact scores. However, in some projects valuation of damages in other countries or regions may be needed. For this purpose, benefit-transfers are often used in the literature.

The benefit-transfer method is used to estimate economic values for ecosystem services by transferring available information from studies already completed in another location and/or context. For example, values for recreational fishing in a particular lake may be estimated by applying measures of recreational fishing values from a study conducted for another

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[2]   Shadow prices is a broader term covering also estimates based on prevention (abatement) costs.

[3]   Also referred to as value transfer.

lake. By determining the factors that could explain the valuation of the original lake one could transfer the damage values of this lake to the other lake by taking into account the difference in explanatory factors.

For most environmental pollutants the following factors seem to be most important (in decreasing order):
1. Income levels, as damages in high income regions seem to be higher than in low income regions (in economic terms: environmental quality has a positive income elasticity).
2. Price levels, as not pure income but rather the amount of goods that one can buy from this income matters for the valuation of the damages (e.g. people tend to value lost opportunity to buy things because of the damages instead of the damage itself).
3. Population density, as especially human health-related impacts of pollution are more severe in densely populated areas.
4. Atmospheric conditions, as both precipitation and wind have the characteristic to partly wash out (or blow away) pollution.
5. Other non-tangible aspects, such as democracy as environmental damages tend to be perceived as more damaging in open societies.

Of these four characteristics only the first three are subject to benefit-transfers in the Benefito tool. In addition specific adjustments are being made with respect to types of ecosystems. One should bear in mind that benefit-transfer by definition delivers a less accurate estimate than an original valuation study. However, benefit-transfer is often used when it is too expensive and/or there is too little time available to conduct an original valuation study, yet some measure of benefits is needed (see also Chapter 4 on uncertainty).

1.3 Relationship to other studies

Two studies of CE Delft which are directly related to Benefito have to be mentioned here: Shadow Prices Handbook (CE, 2010a) and the report Comparing Shadow Prices (CE, 2010b). The Shadow Prices Handbook presents two sets of shadow prices: one set based on damage costs (where the numbers are presented for the Netherlands and for the EU on average) and one based on abatement costs (only for the Netherlands)[4]. In addition, the Handbook presents weighting factors which allow extending the estimates to a very longlist of pollutants (for the Netherlands). The Benefito tool focuses only on damage costs and on a limited set of pollutants (for the list of pollutants see Section 2.1). Damage cost estimates in the Handbook are based on the results of the NEEDS project[5], and Benefito also draws extensively on the estimates produced within this project. The damage value estimates as calculated within NEEDS have been transferred within the Benefito, using the methodology described in Section 3, to almost all countries in the World. While comparing the Handbook and the Benefito tool, a general statement can be made that while the Handbook aims to provide shadow prices for as many substances as

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[4] To get more insight which approach is advised in which situations, the reader is referred to the Handbook.

[5] New Energy Externalities Development for Sustainability, a part of ExternE series, see http://www.needs-project.org/

feasible given the literature sources[6], the Benefito tool aims to provide damage values for as many countries as possible.

Another related project is the report Comparing Shadow Prices (CE, 2010b), where attention is given to differences between the Handbook and the IMPACT study (IMPACT, 2008). The IMPACT study focuses on damage costs related to emissions of pollutants from transport. The report summarises results of several projects and recommends to use the values from HEATCO for PPM and the values from CAFÉ CBA for other emissions.

The recommended values by the IMPACT study differ to some extent from the damage values for the same substances presented within the Handbook. The report Comparing Shadow Prices sheds light on these differences. The general conclusion to be drawn from the report Comparing Shadow Prices is that the values from the NEEDS project (used both within the Handbook and in the Benefito tool) can be used as a reliable source for emissions except PPM-related damage from the transport sector. For $PPM_{2.5}$ values related to exhaust emissions, we recommend using the estimates from the IMPACT study - a separate sheet with these values is included within the Excel worksheet containing the Benefito tool. The additional sheet gives also shadow prices for non-exhaust PPM_{10}. The estimates should not be used for maritime emissions; hopefully reliable shadow prices for this sector will be developed in future.

Regarding comparison of NEEDS and CAFÉ CBA values for NO_x, SO_2 and NMVOC, no significant differences have been found, as the methodology and indicators used in both studies are largely the same. However, because NEEDS is a more recent project including some updates in methodology, and because within NEEDS more detailed modelling of physical and chemical effects was used, the values obtained within NEEDS may be considered to represent more 'state of the art' than the values obtained within CAFÉ CBA.

It can be noted that within the Benefito tool, damage values for three different heights of release are presented and that the values for low height of release can be treated as the first approximation for valuing the effects of transport emissions, with the exception of PPM emissions. However if the user needs more detailed estimates related for example to different transport modes and local conditions, he/she should refer to the IMPACT study and/or the newest estimates if they occurred in literature.

1.4   Structure of this report

This report is organized as follows. Chapter 2 describes the scope of the Benefito, i.e. the substances, the endpoints, the countries and the height of emission. Chapter 3 deals with the methodology of adjustments. Chapter 4 describes uncertainty both related to the original values from NEEDS and to the benefit-transfer methodology. Three annexes are attached: Annex A describes in more detail how adjustments for population density in human health endpoint were made, Annex B deals in more detail with adjustments for biodiversity and Annex C contains the user manual which is also included in the Excel tool.

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[6]   The principle source for weighting which allows extension of shadow prices to a very wide range of substances is ReCiPe study (Goedkoop et al., 2009).

2 Scope

2.1 Substances

Benefito provides damage value estimates for the following pollutants:
− Classical pollutants, i.e. SO_2, NO_x, NH_3, PM and NMVOCs. These are pollutants which occur most often in various analyses.
− Non-classical pollutants, i.e. heavy metals, formaldehyde and dioxins.

For classical pollutants, damage values have been calculated within NEEDS for separate endpoints (human health, crops, materials and buildings and ecosystems). For non-classical pollutants, only human health endpoint damage has been evaluated, since the estimates related to impacts on other endpoints either do not exist or are very uncertain.

For primary particulate matter (PPM), values for two categories are estimated: particulates with diameter up to 2.5 μm ($PM_{2.5}$) and particulates with a diameter of between 2.5 and 10 μm (PM_{co} which stands for coarse particles). These two fractions are associated with different health-related impacts, where the impact of very small particles is in principle much higher. In many studies, however, a category of PM_{10} is used, which consists of both fractions: $PM_{2.5}$ and PM_{co}. Estimate of the value for PM_{10} can be made based on a weighted average of estimates for both fractions ($PM_{2.5}$ and PM_{co}), where weighting should reflect share of the more specific fractions within the more general category of PM_{10}. This share can vary depending on the region and source of emission. Based on the data on EU-27 emissions of PPMs, it has been calculated that 0.667 can be adopted as the multiplying factor to infer the damage cost for PM_{10} based from the value for $PM_{2.5}$ (CE, 2010a). This is however a very rough approximation based on average values for the EU-27.

The full list of pollutants included in Benefito is given below:

Classical pollutants:
− NO_x
− SO_2
− NH_3
− NMVOC
− PPM_{co}
− $PPM_{2.5}$

Non-classical pollutants:
- Cd
- As
- Ni
- Pb
- Hg
- Cr
- Cr-VI[7]
- Formaldehyde
- Dioxin

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[7]   With chromium, the user should note that either the values for Cr or Cr-VI should be used, otherwise double counting will occur.

It should be noted that within the Benefito Excel tool, the user has to choose one classical pollutant at a time and then he/she is able to see the values pertaining to this selected pollutant according to the four endpoints which have been evaluated within NEEDS (human health, ecosystems, crops, materials & buildings). In case of non-classical pollutants, the whole list of pollutants which were included in this group is given as default, with values related to human health endpoint only.

2.2   Time scope

Damage values within Benefito are given in Euro in prices of 2008 per tonne of a given pollutant. Two different years of release of pollutants can be chosen: 2008 and 2020. Differences in values pertaining to different years of emission are due not only to economic factors such as expected increase of GDP which leads to higher valuation but also to a different source-receptor matrix applied in modeling within the NEEDS project. Values for 2020 have been adjusted with the same GDP and population density indicators as the values for 2008, under the simplifying assumption that the relative GDP and population density of other countries as compared to the EU-27 will stay more or less the same. The user can, however, apply manual adjustments to the factors of GDP and population density.

2.3   Endpoints

The endpoints for which damage costs are estimated within Benefito are the same as in the Handbook, which follows the categories proposed within the NEEDS project. These are as follows:
–   Human health.
–   Crops.
–   Materials and buildings.
–   Biodiversity.

It should be noted that not all substances have a significant impact on all these categories of damages, for example damage values estimated for particulate matter are calculated only for human health endpoint.

2.4   Height of release

For NO_x, PPM and SO_2, different values are given for different heights of release. Three heights of release are provided: unknown, low and high. These numbers were estimated using the EcoSense model by using different sets of source-receptor matrices (SRM).

If the height of release is unknown, as is often the case in LCA data that includes all product's life cycle stages, the corresponding values of unknown height of release should be used. If the height of release is approximately known, the values referring to low height of release should be taken for emissions with a release height below 100 m, and the values referring to high height of release should be taken for emissions above 100 m. It can be suggested that for emissions from power-plants, the results according to high height of release should be used (NEEDS, 2008a).

2.5 Transport emissions

For transport, because the pollutants are released at a very low level, as the first approximation the values for low emission level can be used for all pollutants except particular matter ($PPM_{2.5}$). For PPMs, taking the values from the Benefito tool based on the NEEDS estimates calculated for industrial emissions would lead to underestimation. The impact of the PPM emissions from transport released at a very low level is higher that the impact even for low level of emissions as estimated within the NEEDS project for industrial emissions and taken over in the Benefito tool (i.e. up to a 100 meters). For transport-specific PPM emissions, a separate spreadsheet has been added to the tool. The spreadsheet contains the values calculated within the HEATCO project for $PPM_{2.5}$ exhaust emissions. In addition, the values for non-exhaust emissions of PPM_{10} are given. These shadow prices refer to 27 separate EU countries plus Norway and Switzerland and the EU-27 average. This set does not relate to maritime emissions for which reliable shadow price estimates will still have to be developed. Transport-specific values are not transferred to other countries (the procedure of adjustment would go beyond the scope of this project) but they are adjusted for inflation using the HICP indicator so that the values given originally in euro 2000 prices are expressed in 2008 prices.

The user of Benefito who is interested in more detail in transport-related emissions is advised to check the original IMPACT study, where more differentiation for some values is given (e.g. depending on the mode of transport).

2.6 Land-use changes: PDF factor adjustment

Benefito provides a possibility of adjustment for a potentially disappeared fracton (PDF) factor. PDF measures the percentage of total plant species that are likely to disappear as a result of converting land use type. By extension, it can be assumed that the damage to plants and lower organisms is also representative of the damage to populations of higher animals.

Within the NEEDS project the PDF approach has been used for assessing acidification and eutrophication impacts on ecosystems. To be able to compare and evaluate specific land-use types, the species number of a set of land use types has been standardised for 1 m^2. This absolute species number is transformed into a relative number using the regional species richness of the Swiss Lowlands as a reference. Hence, the PDF values can be interpreted as the relative decline in biodiversity caused by a land use change from Swiss Lowland use to the respective land use category (NEEDS, 2006).

Kuik et al. (2008) provide valuation of the PDF factor. The value of PDF obtained in this study equals 0.47 euro per m^2 per year for the EU-27. In the Shadow Prices Handbook this value was converted into 2008 prices using HICP inflation factors. The value in 2008 prices equals 0.55 euro per m^2 per year. Benefito provides a possibility of adjustment of this factor for population density, income and type of ecosystem. The adjustments are made according to the same methodology as the adjustments for biodiversity (see section 3.2 point 4 and Annex B).

It should be noted that the PDF factor alone is not very informative for the user whose goal is to evaluate land-use changes. PDF factor, which in Benefito is calculated per country and per type of ecosystem, can be seen as an input to the final valuation of land use changes. Additionally, a matrix with relative changes of PDF values while shifting from a given land use type to another is needed. This combination, together with the data about the surface of the land undergoing change, will allow obtaining the final valuation of a given land-use change in a given country.

2.7   Countries

The Benefito tool aims at providing damage values for all countries in the World. Altogether, 190 countries are included in the database and additionally, EU-27 is listed as a separate item.
The countries can be divided in two categories:

1. Countries for which original estimates from the NEEDS project are taken over and only adjusted for inflation up to the 2008 level of prices. These are all EU-27 countries. It can be noted that within NEEDS, estimates produced on the basis of modelling with the EcoSense model have been provided for a set of 39 countries and regions, however while constructing the Benefito tool a decision has been made to include the original estimates from NEEDS only for the EU-27 set of countries. The reason is that within NEEDS, a uniform valuation of VOLY (Value of Life Year) has been adopted for the whole domain of analysis, and in our approach we assume equal valuation of morbidity only for the European Union while values for other countries are adjusted on the basis of income differences.

2. Countries for which the estimates are created using the benefit-transfer methodology as described in Section 3. These are all countries which are not EU Member States. For these countries, the basic values to adjust from are the average EU-27 damage values.

3 The methodology of adjustments

3.1 Introduction

The methodology of adjustments varies depending on endpoints.
The adjustments in the Excel tool are possible in two variants: the basic
variant, where standard (country-average) adjustment factors such as income
and population density are used and the flexible variant, where the values of
the adjustment factors are given by the user. Both types of adjustment are
used for two groups of pollutants: classical and non-classical. Below, the
methodology in both approaches is explained.

3.2 Basic variant

In the basic variant, the following adjustments to the average values for EU-27
taken from NEEDS are made, according to the specific endpoints:

1. Human health impacts (both classical and non-classical pollutants).
   These values are adjusted for two factors:
   a Income, using the level of GDP per capita at PPP as a proxy of individual
     income. This adjustment is based on an observation from many
     valuation studies that Willingness-to-Pay values are highly depended on
     a level of income, and human health values within NEEDS are primarily
     based on WTP for increasing life-longevity due to better air quality.
     This approach is applied assuming the level of income elasticity of 0.85
     as adopted in the NEEDS project on the basis of literature review.
     We are using factors of GDP per capita at PPP for 2008 from the World
     Bank[8]. Because income elasticity estimates come as a standard from
     double-log models, the relevant transformation in order to adjust the
     values for income would take the following form: $Value_X = Value_E (Y_X / Y_E)^\beta$ where $Value_X{'}$ is the adjusted damage value for the country X,
     $value_E$ is the average damage value for the EU taken from NEEDS, Y_X is
     the income level in country X expressed as GDP per capita at PPP, Y_E is
     the average income in the EU-27 expressed as GDP at PPP per capita,
     and β is income elasticity equal to 0.85.
   b Population density as adjustment factor. Population density is a very
     important factor for assessing mortality and morbidity impacts – the
     higher the population density in a certain area, the more people are
     likely to die or get ill as a result of pollution. In adjusting for population
     density, factors from regression analysis have been used[9]. For adjusting
     human health endpoint, regression analyses were performed based on
     the values from NEEDS reported for various countries. More detailed
     methodology and adjustment factors for population density are
     described in Annex A.

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[8] World Bank statistics can be accessed at http://data.worldbank.org/indicator.

[9] Regression analyses were performed for all the pollutants included in Benefito except for Hg,
formaldehyde and dioxins for which uniform values across Europe were reported within
NEEDS. Simple regression models with only one explanatory variable, population density, have
been performed (with the dependent variables being damage values for particular
substances).

2. Impact on crops (classical pollutants only). In this category, the values are adjusted using PPP-adjusted exchange rates as reported in the World Bank statistics[10]. PPP-adjusted exchange rates measure the amount of the local currency in a given country that would purchase the same amount of market goods as one unit of the local currency in the other country. To give an illustrative example, if a given amount of pollution causes drop in crops of potatoes that is worth 1 Euro in the EU, and we want to reflect this damage value in Euro for Brazil after correcting for PPP (assuming that the same amount of pollution causes the same physical damage in Brazil), we would convert the value in the following way:

   PPP for Brazil from the World Bank statistics (for 2008) equals 1.51 in relation to US dollar which means that the goods which can be purchased for 1 USD in the US can be bought for approximately 1.51 Brazilian reals in Brazil. We need to get a PPP-adjusted exchange rate for Euro so we have to look for the PPP exchange rate of Euro to USD. The latter statistics is calculated separately for each country so in order to have an approximate value for Euro we calculated the population-weighted average of the PPP exchange rate for Euro to USD for the countries within Euro area (also based on the World Bank Statistics; it was estimated to be equal to 0.81). Thus in order to get the PPP-adjusted exchange rate for Brazilian real in comparison to Euro, we have to divide 1.51 by 0.81 – we get 1.87. This means that we need to have about 1.87 Brazilian reals to buy the same amount of goods as 1 Euro would buy on average in the Euro area. This number can be viewed also as a PPP-adjusted value of damage equal to 1 Euro according to the level of prices in Brazil and in Brazilian currency. Now we have to convert this amount back to nominal Euros, as this is a standard currency in Benefito. We do this by using a nominal exchange rate. Following this line of thought, in order to get multiplying factors for PPP-adjustment for all countries, we have taken the relevant PPP-adjusted exchange rates, divided them by the weighted average of the PPP exchange rate for Euro and then we have divided the result by the nominal exchange rate of local currency to Euro.

3. Impact on materials and buildings (classical pollutants only). Here, the values are adjusted using the level of GDP per capita at PPP as a proxy of individual income. The reason to use income rather than PPP-adjusted exchange rates, like in case of crops, is that the costs of renovations consist mostly of the costs of labor, and labor costs are related to incomes. The formula used for adjustment and the income elasticity are the same as for human health category (see point 1 above).

4. Impact on ecosystems (classical pollutants only). These values are adjusted for three factors:
   a   First, the values are adjusted using the level of GDP per capita at PPP as a proxy of individual income. The reader of this manual should notice that this is different than the NEEDS methodology suggested. In the background study by Kuik *et* al. (2008) it was shown that income is an insignificant variable explaining the variation in valuation studies. The reason to maintain an adjustment according to income in Benefito was taken on the ground that the value of the biodiversity indicator (PDF, potentially disappearing fraction) is within NEEDS derived on the basis of meta-analysis of stated preferences studies, and according to

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[10]   This and other statistics used for conversion have been obtained from http://data.worldbank.org/indicator.

scientific literature such values are highly dependent on individual income. Although Kuik *et al*. (2008) found income an insignificant variable of their meta-analysis for explaining the variation in valuation of biodiversity, it is remarkable that their original studies are all taken place in developed economies. It cannot be investigated if the same result would hold if a wider range of income would have been taken. There are two reasons, nevertheless, why we believe that income should be an important variable in explaining the valuation of biodiversity. First, it is clear that recreational values will also depend on incomes. If incomes are higher, recreational values should be considered as higher. Second, also the valuation of non-use values is most likely dependent on income. Third, Kuik *et* al. (2008) showed that the valuation of biodiversity is more or less similar to the restoration costs. As the labour is the dominant factor explaining the height of restoration costs, we would also assume that restoration costs in low income countries are generally lower. Therefore, we decided to correct the valuation of biodiversity with the income level using the general income elasticity of 0.85.

b Next, adjustment for population density is applied by using the factor from the meta-analysis of Kuik et al. (2008). Dependence of the values for damage to ecosystems from population density is related to the fact that in stated preferences surveys (and such surveys were included in the meta-analysis of Kuik et al. (2008)), the aggregate value attached to a given site with high biodiversity qualities depends on the number of people living in the vicinity of such a site. For more details see Annex B.

c This model of Kuik et al. (2008) provides also factors for adjustment for type of ecosystem. The type of the ecosystem where the pollutants are released can be taken into account, namely, if the user knows that this ecosystem is in the form of a forest, river area or coastal area, this information can be input in the model. If the user does not have such additional knowledge about the nature of the place where the pollutants are released (if it is forest, coastal or river area), he/she will get the average values for a given country with the assumption that on average, the share of natural soil and soil sensitivity to pollutants is the same as on average in the EU. More detailed methodology on adjustments based on the factors from Kuik et al. (2008) is given in Annex B.

3.3 Flexible adjustments

Additionally, within Benefito it is possible to have flexible adjustments based on the factors that are specified by the user. In this approach, the user has an option to input some of the parameters by himself/herself and the tool calculates the resulting values. These parameters are:

1. GDP at PPP per capita, which is used for adjustment of human health, materials and buildings and ecosystem values.
2. Population density, which is used for adjustment of human health and ecosystem values.

The sense of this approach is such that a country is not always the right system scale of analysis. Sometimes, cost-benefit analysis is conducted for specific regions in a country. If the user knows that in a given region income or population density differs significantly from the average, and if he knows the relevant data, the values can be adjusted accordingly. This relates both to the countries within the EU and to other countries. For other countries, the values given by the user (GDP per capita and population density) are used instead of

the average country values and applied to the EU-average. For the EU countries, the values reported within the NEEDS project for these separate countries are used and then fine-tuned with the factors given by the user. In both cases, the user is able to see the average values stored in the database of Benefito so that he/she can see how much his/her proposed values differ from the default values.

Price adjustments that are used for crops are the same for the whole country, so the tool will connect them automatically, without a possibility of fine-tuning.

3.4 No income adjustment option

In addition, the Benefito gives a possibility not to adjust for income, i.e. assume that valuation of the damages is not dependent on income. Such can be done for ethical reasons or for specific projects. For example, if we are considering international projects and we want to avoid the situation where the valuation would suggest that 'dirty industries' have to be relocated to poor countries – we could use uniform valuation of environmental aspects. So there is an option where the user can assume uniform valuation with respect to income and then no income adjustments are made (but all others, like population density and prices adjustments, are made as described in the section above). It can be assumed that without the income adjustment, the values are reflecting an average income level in the EU.

3.5 Summary of adjustments

Shadow prices for so-called classical pollutants (NH_3, NO_x, SO_2, PPM) have been estimated within NEEDS separately for different endpoints, therefore the outcomes are more detailed and the adjustment procedure is more complicated. Impacts of non-classical pollutants have been estimated for human health endpoint only and these values are adjusted for income and population density. The mechanism of Benefito for both groups of pollutants can be depicted using Figure 2 and Figure 3.

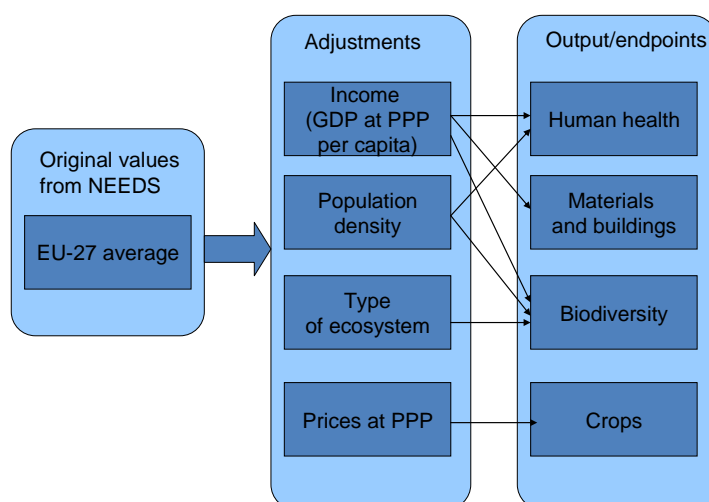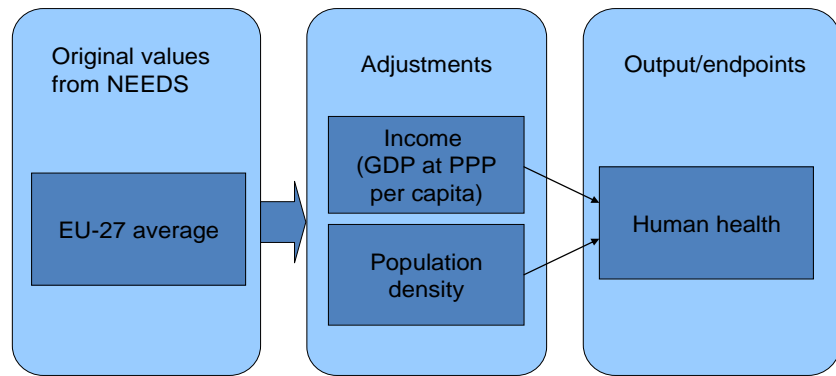**Figure 2   The mechanism of Benefito: classical pollutants**

Figure 3   The mechanism of Benefito: non-classical pollutants

4 Uncertainty

4.1 Introduction

The values in Benefito are based on the estimates resulting from the NEEDS project, where the EcoSense model was used in applying the IPA approach. These values are already associated with high uncertainty resulting from modelling and valuation methods that were used. In addition, the benefit-transfer procedure applied in Benefito adds more uncertainty. These two sources of uncertainty are shortly described below. In the last subsection we list the assumptions underlying the damage values which have to be kept in mind while applying them in various projects.

4.2 Uncertainties of the NEEDS estimates

Within NEEDS, each step of the impact pathway analysis for classical pollutants has been examined in order to estimate the uncertainties associated with the various components of the calculation. The analysis in NEEDS follows conclusions of Rabl and Spadaro (1999). Because mortality accounts for over two-thirds of the damage costs of many pollutants, the uncertainty associated with this endpoint can be viewed as a good estimate for that associated with the sum total of impacts.

The methodology for assessing uncertainty of the NEEDS estimates is based on lognormal distributions and geometric standard deviations (i.e. multiplicative confidence intervals). This choice is related to the fact that damage cost values according to the Impact Assessment Method used within the NEEDS project are a product of several factors, such as increase in concentration of a given pollutant, slope of the CRF, density of the receptors and a monetary estimate of a given endpoint.

Rabl and Spadaro (1999) show that the estimated geometric standard deviation of these damage costs equals approximately 3. According to the characteristics of lognormal distribution, this means that for classical pollutants, the true values lie, with a 68% probability, within an interval between the central value divided by three and the central value multiplied by three. Thus one can conclude that if an estimate from the Benefito tool equals, say, 15,000 and it is an original estimate taken from the NEEDS Excel tool without further adjustments for income and population density (that would be valid for EU-27 countries), a 68% confidence interval for this value would lie in between 5,000 and 45,000.

For more detailed discussion about uncertainties within NEEDS, the reader is referred to CE (2010), Annex E.

4.3   Uncertainties related to value transfer

Additional uncertainties are related to benefit-transfer. Within the Benefito, a mixed approach is used where some adjustments are made on the basis of GDP at PPP per capita ratio and some are performed as a function transfer. In a survey on transfer errors performed by Navrud (2006), average transfer error[11] in values from stated preferences survey on health-related issues performed in five countries was equal to 38%. Transfers were performed both using simple adjustments (PPP exchange rates and income ratios) and value function transfers. The author found similar evidence in literature. Therefore we can conclude that the transfer error can be expected to be at the level of approximately 40%.

4.4   The most important assumptions underlying the values

The user of Benefito should be aware of various assumptions underlying the values, which result both from the methodology of value estimation within NEEDS and from the methodology of value transfer.
Some of these assumptions are listed below.
- For value transfers outside the EU where the EU-average from NEEDS is used as a basis, it is assumed that physical and chemical reactions between the pollutants, dispersion and meteorological conditions as well as background concentration of pollutants in the countries for which the values are calculated are on average the same as for the EU-27 countries (on average).
- For these transfers it is also assumed that all other factors which are not corrected for and which can have influence on valuation, are more or less the same as in the EU-27. These factors include for example political and cultural differences.
- For the whole EU-27 it is assumed that the Value of Life Year (VOLY) used as the most important factor for valuation of mortality is uniform (and equal to 40,000 Euro in prices of 2000). This assumption comes from the NEEDS project, and the values for EU-27 are taken over to Benefito only with inflation adjustment so this assumption is preserved. For other countries, because of income level adjustments, this assumption does not hold any more unless the option 'no income adjustment' is used.
- For all income adjustments it is assumed that income elasticity equals 0.85. It is a standard assumption used within NEEDS that was proposed as an expert estimate. Various studies show however that income elasticity with respect to environmental goods may differ depending on the level of income and other characteristics of a given country.
- Population density adjustment factors for human health endpoint come from regressions which were made on the basis of damage values from NEEDS and population density data for all the countries which were included in NEEDS. Adjustments based on these regression factors are made under the assumption that relationship between population density and damage in countries outside Europe is on average the same as in Europe and that no significant differences exist regarding this relationship between countries. However one can imagine that in some countries, emission sources can be situated in relatively more densely populated

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[11]   Transfer error was defined as $TE = (WTP_T - WTP_P)/WTP_P$, where TE stands for transfer error, WTP_T is Willingness-to-Pay transferred using one of the three methods (simple value transfer, income ratio transfer and value function transfer) and WTP_P is Willingness-to-Pay estimated for a policy country.

areas than in other countries, and this difference can have influence on the resulting damage.

- For biodiversity, population density adjustment factor is taken from the study of Kuik (2008) so it is assumed that this estimate is robust in reflecting the variability of biodiversity values.
- For the year 2020, within NEEDS, a different source-receptor matrix was used in the EcoSense model than for the year 2008. This matrix reflects predictions regarding changes in emission patterns and background concentration as well as chemical reactions. This is one of the two main sources of differences between the values for 2008 and 2020. The other source is an assumption about increase of values due to increase in income: and uplift factor equal to 1.7% annually has been used, which consist of the assumed increase in GDP by 2% per year, combined with income elasticity of 0.85. The same uplift factor is used for all countries of the EU and the EU average values and consequently, it is transferred to other countries.
- No separate adjustment factors are made for the year 2020 on the basis of predictions, thus it is assumed that relative income, population density etc., of the countries for which the adjustments are made as compared with the EU-27, will stay the same as in 2008. This is of course not a very reliable assumption, e.g. the development patterns for countries like China will probably be much different from the development patterns of EU-27. However because of lack of reliable forecasts we take this simplified approach. The user can, however, use manual adjustment option so that other than default values of GDP for various countries can be used.
- It is assumed that Purchasing Power Parity factors taken from the Penn World Table and used both for income adjustments (GDP at PPP per capita) and for price adjustments (for crops) reflect well the differences in purchasing power of various countries.

4.5   Comparison with the values obtained using grid-based model

A simple model exists at CE Delft that makes a similar transformation of (human health) damage values for Europe to damage values for locations outside Europe. This model is based on fitting several population density parameters as well as a parameter for background pollution to damage estimates obtained by using the EcoSenseWeb developed at the Technical University of Stuttgart[12]. The main difference between the values reported in the NEEDS project (the basis for calculations in Benefito) and the values which can be obtained using the EcoSenseWeb is that the NEEDS values are calculated as average values for the whole country (emission-weighted averages) while via the EcoSense tool, the user can obtain values pertaining to a given location and technical parameters of the source of emissions.

The derived 'power-plant' model thus also gives values for specific locations, based on the exact population density per square degree around that location.

Such a comparison showed that the values for NO_x and SO_2 are reasonably close to each other, but for some locations there are deviations. This is particularly noticeable for smaller countries on a coast, where population density is not evenly distributed around the source. Large differences have been obtained for particulate matter emissions, where the values obtained from the power-plant model were much lower than the average country values obtained

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[12]   http://ecosenseweb.ier.uni-stuttgart.de/index.html

in Benefito. These differences may be explained by the fact that in the Benefito values, the impacts of transport emissions are also taken into account. These emissions have very high impact on human health and, if they are taken into account in the average value of damage costs, they can make this value relatively high as compared to looking at the impact of industrial source of emissions in EcoSense.

Therefore, it is recommended that for PPM damage estimates for emissions from single point sources such as power-plants or industry, preferably another tool should be used, and only as the second choice, the values from Benefito for high emissions level. In case the source of emissions is not known or mixed, the values from Benefito for 'unknown height of release' can be used. For transport PPM emissions, however, it is better to use the values reported in the IMPACT (2008) study[13]. For other substances, using the Benefito tool should not lead to high deviations (larger than about 15%) as compared to the power-plant tool.

The power-plant tool is currently based on few sample points and therefore not very robust. The EcoSense tool itself only covers Europe and some surrounding areas, thus not providing a solution for locations outside Europe. More elaborate sampling could improve the power-plant tool but this is not foreseen at the moment.

Table 1 below provides comparison of the estimates resulting from both approaches. Please note that in case of $PM_{2.5}$, the values obtained from Benefito have been adjusted with the factor equal to 0.667 resulting from application of weighted average of PPM emissions in Europe to the valuation of $PPM_{2.5}$ and PPM_{CO} from the NEEDS project – the adjusted estimate is given in parentheses. However, as explained above, the values from the Benefito tool remain a few times higher than the values obtained from the model based on EcoSenseWeb, due to inclusion of the impact of transport emissions within the Benefito values.

Table 1   **Comparison of the damage cost values obtained from Benefito and from the model based on EcoSenseWeb**

	Values obtained from Benefito		
	$PM_{2.5}$ (PM_{10} est)	NO_x	SO_2
EU-27	17,076 (11,390)	5,841	8,055
Canada	8,495 (5,666)	2,732	4,579
China	6,736 (4,493)	2,314	3,149
Namibia	1,746 (1,164)	558	954
	Values obtained from the model based on EcoSenseWeb		
	PM_{10}	NO_x	SO_2
Austria*	1,109	9,190	8,296
Alberta	942	2,297	3,131
Beijing	1,184	2,194	2,590
Windhoek	93	325	414

In Austria, a location with very low population density (near Vienna) was selected, which explains very low value for PM impact obtained from the model based on EcoSenseWeb.

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[13]   As mentioned before, the values for $PPM_{2.5}$ emissions from transport are included in a separate spreadsheet within the tool.

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Annex A Adjustments for population density

A.1 Introduction

As pollution is a non-rival good, one would expect that a higher population density results in an equiproportionately higher damage. Suppose that a certain amount of pollution A is causing damage in one square kilometer. First only one person lives in this area, suffering from damage equivalent to B. Now, if two persons start to live in this area, the total amount of damage is twice as high: 2B. However, in regression analysis this linear relationship is normally not revealed and the 'damage-elasticity' of population density is significantly below unity. This is because variation in damage estimates is due to much more factors than population density alone. The damage estimates in NEEDS give the marginal damage of one additional ton of pollution. However, this damage largely depends on threshold values, accumulation in humans, existing background concentrations, chemical reactions with other pollutants, etc.[14]

Therefore, the estimated relationship between damage and population density may not be linear and may not be equivalent to unity. A model where the damage value is dependent on a constant (capturing the other influences) and a certain factor related to population density is more appropriate.

The econometric analysis of data showed that for most pollutants, a so-called double-log model had the best fit (where both damage and population density are taken in a logarithmic form) while for one substance, and that is NMVOC, a semi-logarithmic model was chosen (where only the population variable was logged).

A.2 Coefficients and formulas

Table 2 gives information on the individual regressions that were performed for each substance. All coefficients were significant at the 1% level (results available on request). The results show in general that the fit of the model is around 30% for classical pollutants and about 60-70% for airborne heavy metals.

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[14]   In addition to this, there may be logical reasons where polluted areas are less populated than more clean areas.

Table 2   Estimated coefficients and R2

	α	ß	R2
NO$_x$	6,915327	0,30578	0,21797
SO$_2$	7,572995	0,238344	0,428711
NH$_3$	7,199164	0,370432	0,36261
PPM$_{2.5}$	8,336719	0,32167	0,352839
PPM$_{coarse}$	4,939189	0,394474	0,334274
NMVOC	0	174,8174	0,23924
Cd	11,08626	0,045464	0,602234
As	12,91613	0,048816	0,599886
Pb	12,37173	0,030077	0,606612
Ni	4,247402	0,621648	0,692085
Cr	6,161857	0,599373	0,718192
Cr-VI	7,771295	0,599373	0,718192

Note: Estimated relationship was: log(damage) = α + ßlog(Population density) except for NMVOC
where the relationship was: damage = α + ßlog(Population density).

These coefficients have been applied in the following formulas:
− For all the pollutants except NMVOC the formula resulting from transformation of the double-logarithmic equation is as follows:

$$Value_X = Value_E \ (PD_X \ / \ PD_E)^ß$$

− For VOC, because here semi-logarithmic model had the best fit, the following formula applies:

$$Value_x = Value_E + ß \ ln \ (PD_X \ / \ PD_E)$$

In the formulas, $Value_x$ is the value for a given country, $Value_E$ is the EU-27 average damage value per tonne for a given substance, PD_x is population density in a given country, PD_E is population density in the EU and ß are the coefficients indicating sensitivity of damages related to a given substance with respect to population density.

It should be noted that not all non-classical pollutants were submitted to the procedure of value transfer using the population density factors. For Hg, formaldehyde and dioxins uniform values were reported for the whole EU, therefore it was not possible to perform regression models based on this data.

Annex B Adjustments for biodiversity

B.1   Introduction

Adjustments for biodiversity are made using two approaches. First, we adjust the values from NEEDS for income using standard, country-specific averages and the method of adjustment the same as for human health endpoint. In addition, we adjust for population density and, optionally, for type of ecosystem. These two latter adjustments are based on the report of Kuik et al. (2008). Coefficients and formulas for these adjustments are given in the section below.

B.2   Coefficients and formulas

The regression equation from the model of Kuik et al. (2008) is given below:

$$\ln(VEDP) = 8.740 + 0.441 \ln(PD) + 1.070\ \mathrm{FOR} - 0.023\ RIV + 0.485\ COA - 2.010\ \mathrm{d}EDP - 0.312 \ln(AREA)$$

Where:

VEDP =   Value of Ecological Damage Potential in Euro per EDP per hectare (EDP is the same as PDF but measured per hectare);

PD =   Population density;

FOR =   Dummy variable for forest ecosystems;

RIV =   Dummy variable for river ecosystems;

COA =   Dummy variable for coastal ecosystems;

dEDP =   Change in EDP (will not be adjusted for – see explanation below)

AREA =   Size of ecosystem in hectares (will not be adjusted for – see explanation below)

For biodiversity adjustments, in addition to income adjustments, two additional factors are used: related to population density and related to the type of ecosystem. Population density has impact on the value because the meta-analysis included valuation based on stated preferences. The more people live in the vicinity of a given site, the higher the value attached to it. Population density is adjusted by taking the population density values for each country but there is also a possibility for a flexible adjustment, as described in Section 3.3 of the report.

For population density the following adjustment is made:

$$\mathrm{Value}_X = \mathrm{Value}_E\ (PD_X\ /\ PD_E)^{\beta}$$

Where PD_x is population density in a given country, D_E is population density in the EU and ß is the coefficient indicating sensitivity of damages related to ecosystems with respect to population density based on the regression equation given above, that is 0.441.

For type of ecosystem, dummy variables are used and the dependent variable is in the logarithm form. So if the region where we want to transfer the value is mostly covered by a forest and the user inputs this as a 1 in the interface, then the value will increase by e to the 1.07 power. Hence, for the forest ecosystem, Benefito multiplies the value by 2.915, for the river ecosystem by 1.023 and for the coastal ecosystem – by 1.624. Only these three types of ecosystem can be input in the model.

Annex C   User manual

C.1   Introduction

User manual is meant to be only a short set of instructions on how to use the database. Description of the methodology related to benefit-transfer and calculations of the original values from NEEDS is to be found in the main part of this report. Further information can be found in the Shadow Prices Handbook and documentation of the NEEDS project. Short version of this manual is included also in the Excel tool Benefito.

C.2   Input and output in the Benefito tool

The interface of Benefito consists of two parts: the yellow and the green part. The yellow part is devoted to the user input and the green part is devoted to presenting the results. The users who want to have the values adjusted by the tool according to the default factors and who choose for income adjustment only have to select the country, year of emission, substance and height of release. The users who want to make less standard adjustments using their own factors have to choose further options below.

C.2.1   Input

The user of Benefito has several choices available. First, he/she should select the country for which the shadow prices will be produced. It is possible to choose only one country at a time so if values for more countries are needed, the procedure has to be repeated. It is also possible in Benefito to choose EU-27 average. Subsequently, year of emission has to be chosen (2008 or 2020), the substance (NH_3, NMVOC, NO_x, PPM_{co}, PPM_{25}, SO_2) and height of emission (low, unknown or high). The user should also indicate if income adjustments should be made (this is a standard option) or not.

The user can either choose for using standard adjustments, where national average values of indicators, namely GDP per capita at PPP (based on The World Bank Statistics) and population density (based on WorldAtlas.com) are applied or he/she can choose for flexible adjustments, where own data can be proposed. GDP per capita at PPP data is used for adjusting human health impacts, materials and buildings and biodiversity. Population density is used for adjusting human health and biodiversity values. The user is able to see the default (national average) values while introducing his/her own value, so that it is possible to see the difference.

Additional possibility of flexible adjustments is created for ecosystem values. Type of ecosystem data (with options of forest, river and coastal) can be used for adjusting biodiversity impacts. If no specific type of ecosystem is chosen, the tool proposes a standard value assuming an average type of ecosystem for the EU-27.

C.2.2 Output

For classical pollutants, separate values are given for each endpoint which is relevant for the selected substance (the endpoints including human health, crops, materials and buildings, and biodiversity). For non-classical pollutants, only human health estimates are produced and presented for the whole set of pollutants in one table.