FIRE COST v 1.0

Users guide

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Executive summary

The FireCost software was developed to enable the estimation of economic impact of forest fires, assisting in the prediction of the economic impact of forest fires, and for the comparison of the efficiency of alternative fire management scenarios.

Three different models were developed for the assessment of economic impacts of forest fires. The three models differ in complexity, data needs, and precision of damage assessment estimations.

The quick assessment model is the simplest, and its aim is to provide a first estimate of the possible range of economic damages caused by a forest fire. The lower bound of the provided damage estimate is based on forest replacement costs and the upper range on people's willingness to pay to protect an additional hectare of a forest.

The intermediate model for forest fire damage assessment provides estimates based on established lists of values for a number of forest goods and services, and fire suppression costs. The goods and services included are timber, non-wood forest products, recreation and carbon sequestration.

The detailed assessment model is more precise and flexible as the previous models, so it can be better adjusted to the case specific situation. For example, the user can select all the important damages caused by the forest fire. On the other hand, it requires more input data that has to be provided by the user. Nevertheless, the model also provides a number of predefined price lists for different forest goods and services.

The model for the evaluation of economic efficiency of fire management measures is a tool to compare two or more fire management alternatives. The model can be used for prediction (*ex ante*) To specify a management alternative the user has to specify which fire management measures are performed (prevention, fire suppression and restoration), when and in what extent, and what would be the potential damages if a fire would occur. The model is based on the Cost-Benefit Analysis and it provides the net present value of a certain management alternative.

The software can be downloaded at http://fireintuition.efi.int/firecost.fire.

Contents

1 General description

FireCost software enables the estimation of economic damages caused by a forest fire and to evaluate the efficiency of different fire management alternatives.

1.1 Assessment of economic impacts of forest fires

Three different models were developed for the assessment of economic impacts of forest fires (figure 1.1). The three models differ in complexity, data needs, and precision of damage assessment estimations
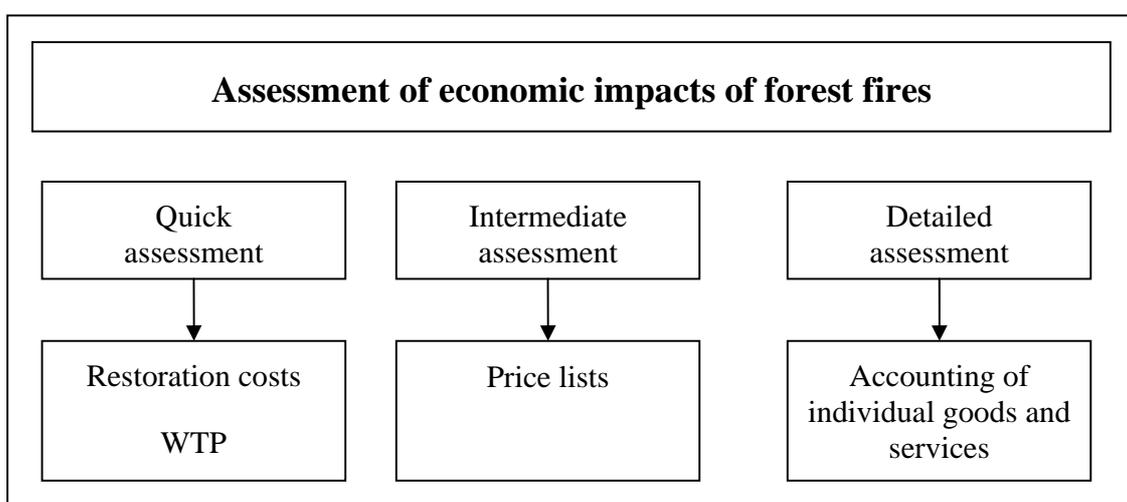
Figure 1.1: Models for assessing economic impacts of forest fires

1.1.1 Quick assessment model

The quick assessment model is the simplest, and its aim is to provide a first estimate of the possible range of economic damages caused by a forest fire. The lower bound of the provided damage estimate is based on forest replacement costs and the upper range on people's willingness to pay to protect an additional hectare of a forest.

Even if this model does not give a very precise estimate and the model is not flexible (e.g. user can not change the model output), it still provides a first estimate requiring very limited data input. The model can be applied immediately after a fire event to obtain a first estimate of potential damages caused by the fire. This information is important in cases where the first emergency measures after the fire is contained depend on the extent and economic value of the damages. Because, immediately after a fire only scarce information about the damage extent of damage exist the model requires very limited information about the fire characteristics, like location (country), fire size (burned area in ha) and predominant tree species. However, it should be taken into account that the

estimates provided by this model are not sufficient for planning of management and other measures after a forest fire, where a more detailed economic damage assessment is needed.

1.1.2   Intermediate assessment model

The intermediate model for forest fire damage assessment provides estimates based on established lists of values for a number of forest goods and services, and fire suppression costs. The goods and services included are timber, non-wood forest products, recreation and carbon sequestration. The estimated values are reported in €per area (hectare) for all EU countries, Croatia, Switzerland and Norway.

To run the model, the user has to specify the fire location (country), fire size (ha), and select the damaged goods and services.

Compared to the quick assessment model this model provides more details about the possible damages and also allows some more flexibility with regards to the specification of damaged goods and services. However, it is still rather limited in the diversity of damages considered, and also the provided marginal values for forest goods and services are fixed. It is recommended that the model is applied for a first detailed estimation of the economic damages caused by a fire. It may be also used as a decision support tool when deciding whether a more detailed estimation of economic damages should be conducted. Nevertheless, its precision is still to low to serve as decision support for planning management measures and other type of investments needed after a fire.

1.1.3   Detailed assessment model

The detailed assessment model is more precise and flexible as the previous models, so it can be better adjusted to the case specific situation. For example, the user can select all the important damages caused by the forest fire. On the other hand, it requires more input data that has to be provided by the user. Nevertheless, the model also provides a number of predefined price lists for different forest goods and services.

The detailed assessment model can be applied for cases where higher precision is required and field data is available. If sufficient data is available this model can be used to support the planning of possible investments (e.g. forest restoration measures) after a forest fire.

1.2 Model for the evaluation of economic efficiency of fire management measures

The model for the evaluation of economic efficiency of fire management measures is a tool to compare two or more fire management alternatives. The model can be used for prediction (*ex ante*) To specify a management alternative the user has to specify which fire management measures are performed (prevention, fire suppression and restoration), when and in what extent, and what would be the potential damages if a fire would occur. The model is based on the Cost-Benefit Analysis[1] and it provides the net present value of a certain management alternative.

The model has three main components (see also figure 1.2):

- assessment of fire management costs,

- fire size specification,

- assessment of potential damages.
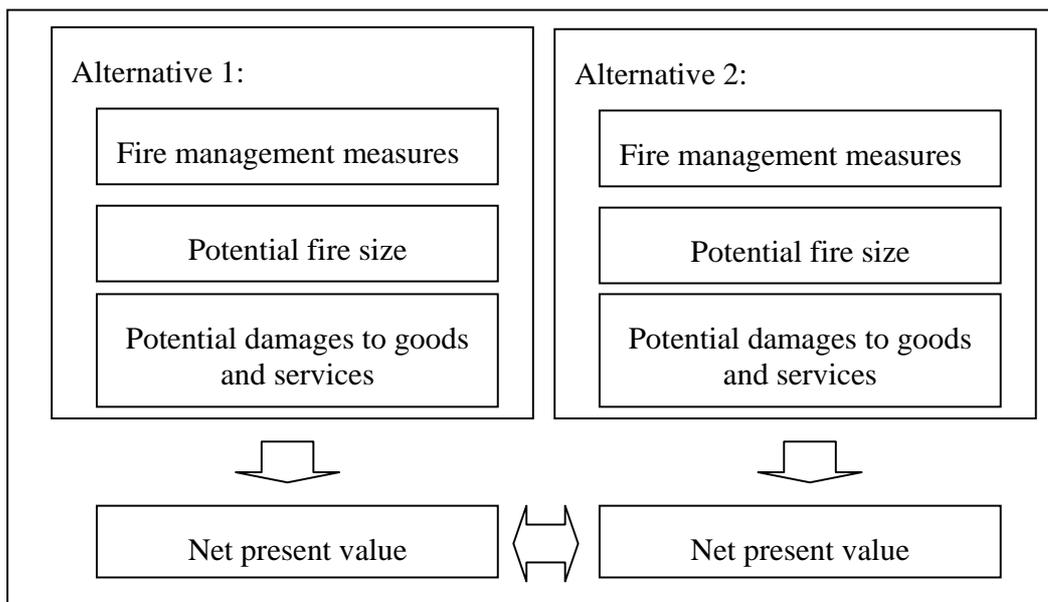
Figure 1.2: Schematic representation of the model for evaluation of the efficiency of fire management measures

Assessment of management costs includes the costs of fire prevention measures, fire suppression and forest restoration. The model only provides pre-established values, while the user has to specify the quantities (e.g. area where a measure is applied, quantity and

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[1] For details see Deliverable 4.5.1.

duration of resources used). The user has also to specify when the management measure is applied (year of application).

2 Software installation

The software and the manual can be downloaded at http://fireintuition.efi.int/firecost.fire. Once the software package is downloaded to your computer, select the **setup.exe** file to begin the installation process.

The software will then automatically check whether all the needed prerequisites are already installed in you computer. The following prerequisites are required:

- Windows Installer 3.1
- .NET Framework 3.5 SP1
- SQL Server Compact 3.5
- Windows Installer 4.5
- SQL Server 2008 Express Edition

If these components are already installed, the installation will start. Otherwise, the prerequisites will be automatically downloaded from the Microsoft website and installed on your computer.

Once the installation is completed you can run the FireCost application from your start menu.

The software is only suitable for MS Windows platforms.

3 Use of FireCost

3.1 Main menu

FireCost offers two main analysis alternatives (see figure 3.1):

- **Assessment of fire damages** – under this option the user can apply different damage assessment models (quick, intermediate and detailed).

- **Efficiency evaluation** – this offers the possibility to compare the economic efficiency of two fire management alternatives.
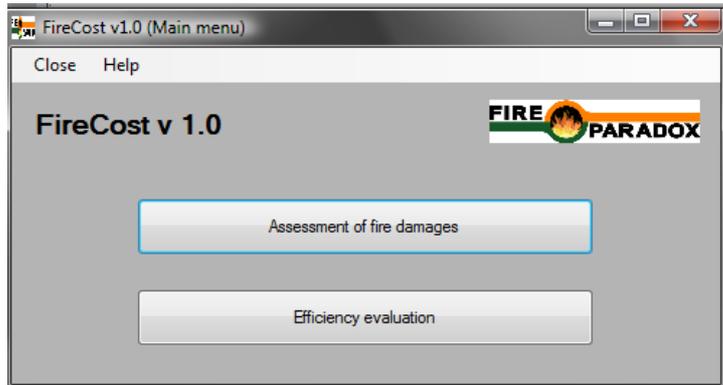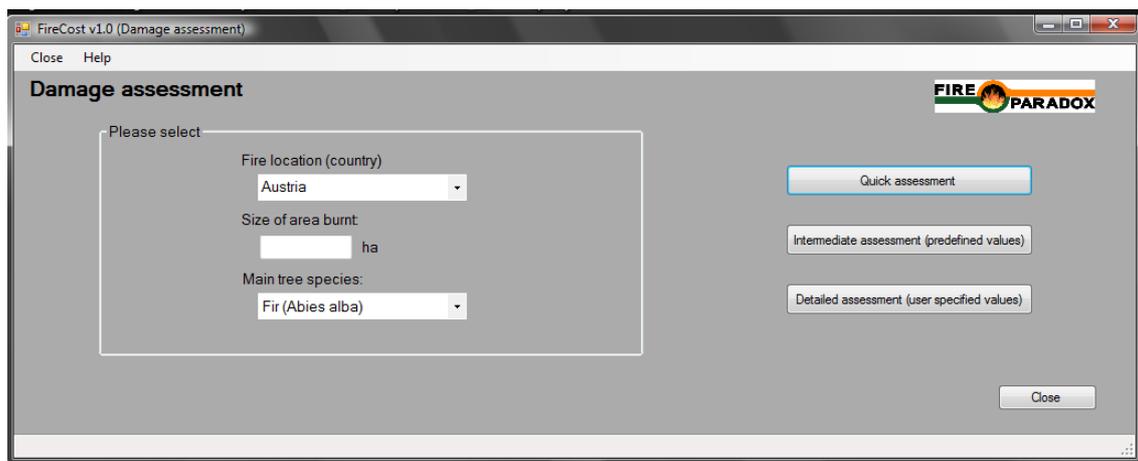
Figure 3.1: FireCost main menu screenshot

3.2   Assessment of fire damages

The main menu screen of the damage assessment offers tree different damage assessment models (see Figure 3.2):

- **Quick assessment -** provides an estimate of the possible range of economic damages caused by a forest fire.

- **Intermediate assessment** (with predefined values) - provides estimates based on established lists of values for a number of forest goods and services, and fire suppression costs.

- **Detailed assessment** (user specified values) – allows the user to estimate economic damages caused by forest fires for a number of different forest goods and services and fire suppression costs.

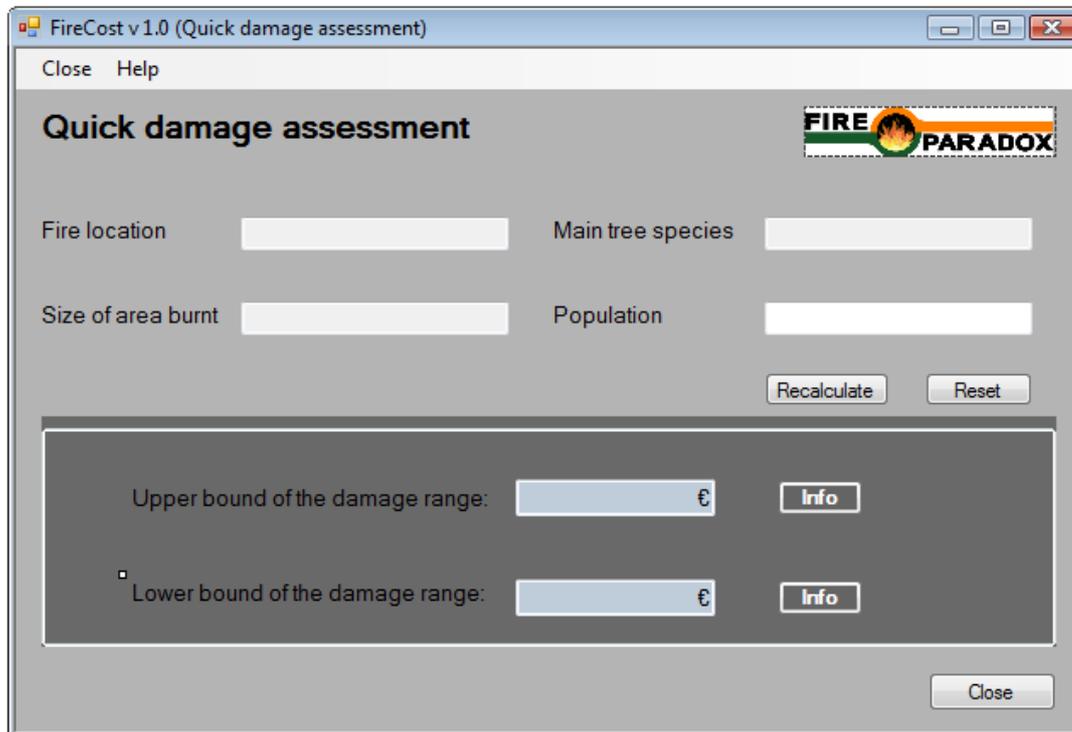**Figure 3.2**: Damage assessment main menu screenshot

Before selecting the model the user has to specify some basic data about the forest fire (see figure 3.2):

- **Fire location (country)** – country where the fire occurred (drop down list of countries).

- **Size of area burnt** –the size of the burned forest area in hectares.

- **Main tree species** – the dominant tree species of the burned forest area. The user can select the following tree species fir (*Abies alba*), beech (*Fagus sylvatica*), Norway spruce (*Picea abies*), Aleppo pine (*Pinus halepensis*), black pine (*Pinus nigra*), maritime pine (*Pinus pinaster*), Scotch pine (*Pinus sylvestris*), holm oak (*Quercus ilex*), penduculate oak (*Quercus robur*), broadleaves, and conifers.

3.2.1   Quick assessment model

The quick assessment model screen provides information about the parameters selected on the main damage assessment page (**fire location**, **size of area burnt** and **main tree species**). Further, the size of the relevant **population** is displayed. The later is applied to calculate the upper bound estimate. As the relevant population we consider the population that would be affected by the loss of the burned forest area. By default in the model as the relevant population of country's habitants older than 18 years are considered. However, the user can introduce a different population size and **recalculate** the upper bound of the damage range estimate. The **reset** button changes back the population size to the default values.

Figure 3.3: Quick damage assessment model screenshot

In the lower part of the screen the estimated upper and lower bound of the potential damage range are displayed.

The damage range is calculated by multiplying the lower and upper bound values by the size of the burned area. Where for the lower bound the tree species and the location of the fire (country) are considered, and for the upper bound the location of the fire (country) and the relevant population (see the following equations).

$$D_{LB} = area * RC_{ij}$$

$$D_{UB} = area * WTP_i * P_i$$

Where D_{LB} = potential damage caused by the forest fire – lower bound (€); D_{UB} = potential damage caused by the forest fire – lower bound (€); *area* = forest area burned (ha); RC_{ij} = restoration costs for tree species j in country i (€/ha); WTP_i = value of willingness to pay to decrease the burned area by 1 ha in country i (€/ha); P_i = population size affected the loss of the burned forest (no. of person older than 18 years). In the model the total country population is considered.

The upper bound value estimate is based on the mean willingness to pay to prevent that a hectare of forest is damaged by forest fire. It could be considered that the total value, presented in the box, considers the total benefits (direct and indirect) that the society would lose if this forest area is destroyed by a forest fire. As such, they could be also seen

as the social value of this forest area. In conventional economics it is generally accepted that measures of economic value should be based on what people want. Using this notion of value, the maximum amount of one thing a person is willing to give up to get more of something else is considered a fair measure of the relative value of the two things to that person. Money is a universally accepted measure of economic value because the amount that people are willing to pay for something reflects how much of all other for-sale goods and services they are willing to give up to get it.

On the contrary, the lower bound estimate is based on the costs of artificial reestablishment of a forest that was destroyed by a forest fire. It is assumed that the costs of restoring ecosystems or their services can be considered as a proxy for the value of these ecosystems or services. This is based on the assumption that, if people incur costs to restore the ecosystem and its services, then that ecosystem services must be worth at least what people paid to restore them.

3.2.2 Intermediate damage assessment

The intermediate assessment model screen provides information about the parameters selected on the main damage assessment page (**fire location**, **size of area burnt** and **main tree species**).

In this part of the screen also the **discount rate** for the calculation of the damages is displayed. However, the user can introduce a different discount rate and **recalculate** the damage estimates. The **reset** button changes back the discount rate and years of decreased good or service provision to the default values.

In the lower part of the screen the losses of forest goods and services and the suppression costs are displayed, as well as the total social and private costs caused by the fire (see figure 3.4).

The loss of timber is estimated according to the following equation:

$$PVC_T = area * (\frac{P}{(1+r)^m})$$

where PVC_T = present value of the lost timber (€); $area_j$ = area burned (ha); P= net revenue of timber per hectare (€/ha); r = annual discount rate (default value in the model 2%); m = years needed to reach optimum economic rotation age. In the model this period is set to 30 years, but can be modified by the user.
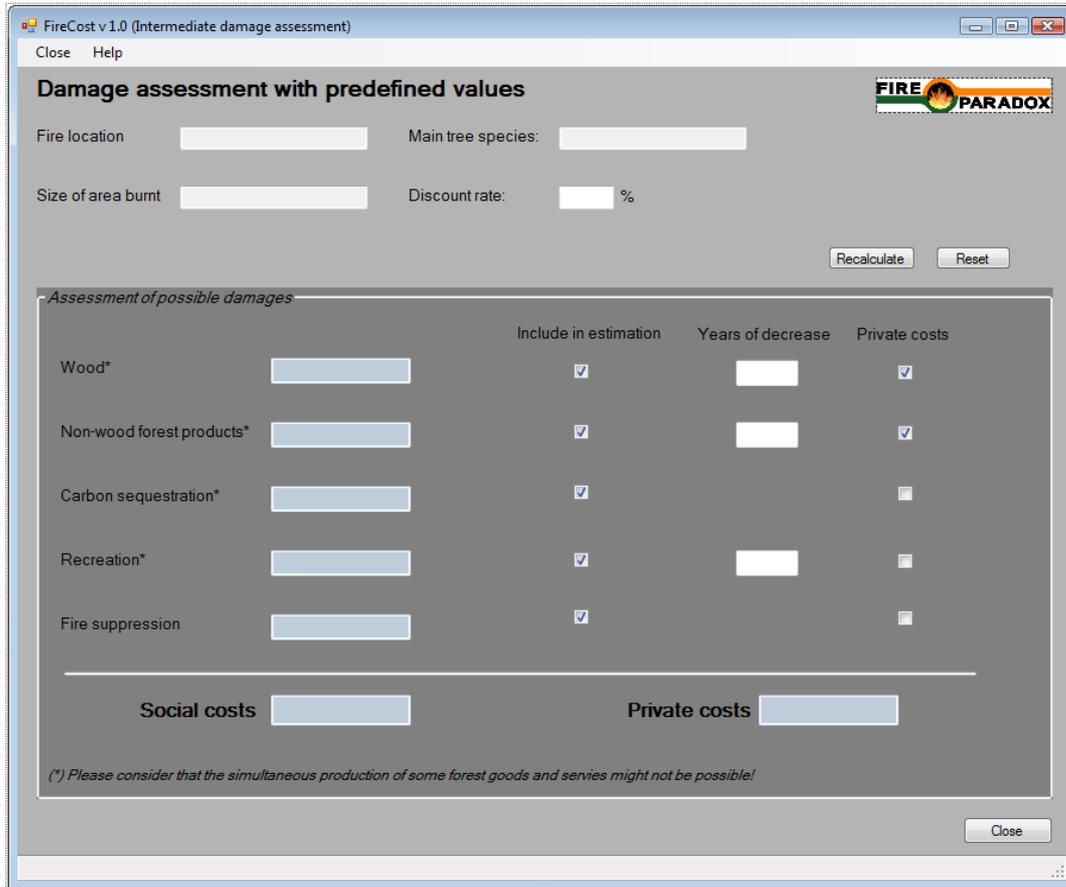
Figure 3.4: Intermediate damage assessment model screenshot

The loss of **non-wood forest products** is estimated as:

$$VPC_{NWFP} = area * P * \left(\frac{(1 + r)^p - 1}{r * (1 + r)^p} \right)$$

where VPC_{NWFP} = present value of lost non-wood forest products (€); *area* = area burned that will temporarily lose its capacity to product non-woods products (ha); *P* = price of the collected/harvested products per unit of area (ha). Remember, that the costs of collecting/harvesting are already included in the price of the product (€/unit); *r* = annual discount rate; *p* = years of decreased quantity of collected/harvested non-wood forest products. It refers to the number of years needed to restore the capacity of the forest to produce a quantity of non-wood forest products similar to the one before the fire. By default this value is set to 5 year, but can be modified by the user and the value of lost NWFP recalculated.

The lost **recreation** benefits are estimated by the equation:

$$PVC_{REC} = V * \frac{(1+r)^p - 1}{r * (1+r)^p}$$

Where PVC_{REC} = present value of the changes in tourism-recreational activities (€); V = average value of recreation per hectare (€/ha); r = annual discount rate; p = number of years of lost recreation activities. By default the number of years of lost recreation activities is set to 5, but can be changed by the user.

For the estimation of the loss of **carbon sequestration** capacities the equation is used:

$$PVC_c = area * PR_C$$

where PVC_C = present value of the carbon emission costs (€); *area* = burned forest area (ha); PR_C = value of carbon sequestration per hectare (€/ha).

The suppression costs are estimated according to the following equation:

$$PVC_{FS} = area * PR_{FS}$$

Where PVC_{FS} = present value of the fire suppression costs (€); *area* = burned forest area (ha); PR_{FS} = fire suppression costs per hectare (€/ha).

Furthermore, the user has also the possibility to select which of the listed goods and services should be **included** into the estimation of the economic damages.

The estimated total damages are expressed as social and private costs, where as private are considered all the costs and damages that have to be bared by a private agent (e.g. forest owner, private or public enterprise) (see also figure 3.5). On the other hand, as social we consider the total costs/damages for a society (including private costs). The user has the possibility to select for each of the displayed goods and services whether they are considered as private or not.
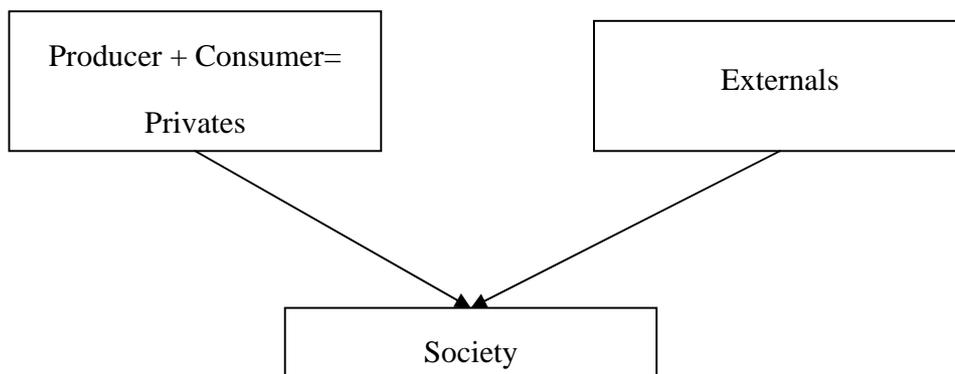
Figure 3.5: Simplified presentation of the concept of private and social costs

The total damages (private and social) are calculated as the sum of all potential damages:

$$SD = \sum_{j=1}^{n} D_j$$

$$PD = \sum_{j=1}^{n} p_j * D_j$$

Where *SD*= total (social) damage (€); *PD*= total private damage; p_j = dummy variable indicating whether the damage is a private or social cost (p is 1 if private and 0 if social); DB^2_j = damage to good j (in €).

To return to the main damage estimation screen the user has to select the **Close button**.

### 3.2.3   Detailed damage assessment

In the detailed assessment model the user specifies what type of losses/benefits or suppression costs were caused by a forest fire.

The affected goods and services, and different fire suppression management inputs can be selected from a dropdown list. By selecting "Other" a new type (not included in the default list) of good or cost type can be added.

Depending on the good or cost type selected "unit", predefined "value" and the number of "years" of decreased level of the good are displayed. The predefined values can be changed by the user. By changing the sign of the value to negative, a benefit can be specified.

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[2] Detailed presentation of the calculation of damages and benefits for different goods is given in continuation.
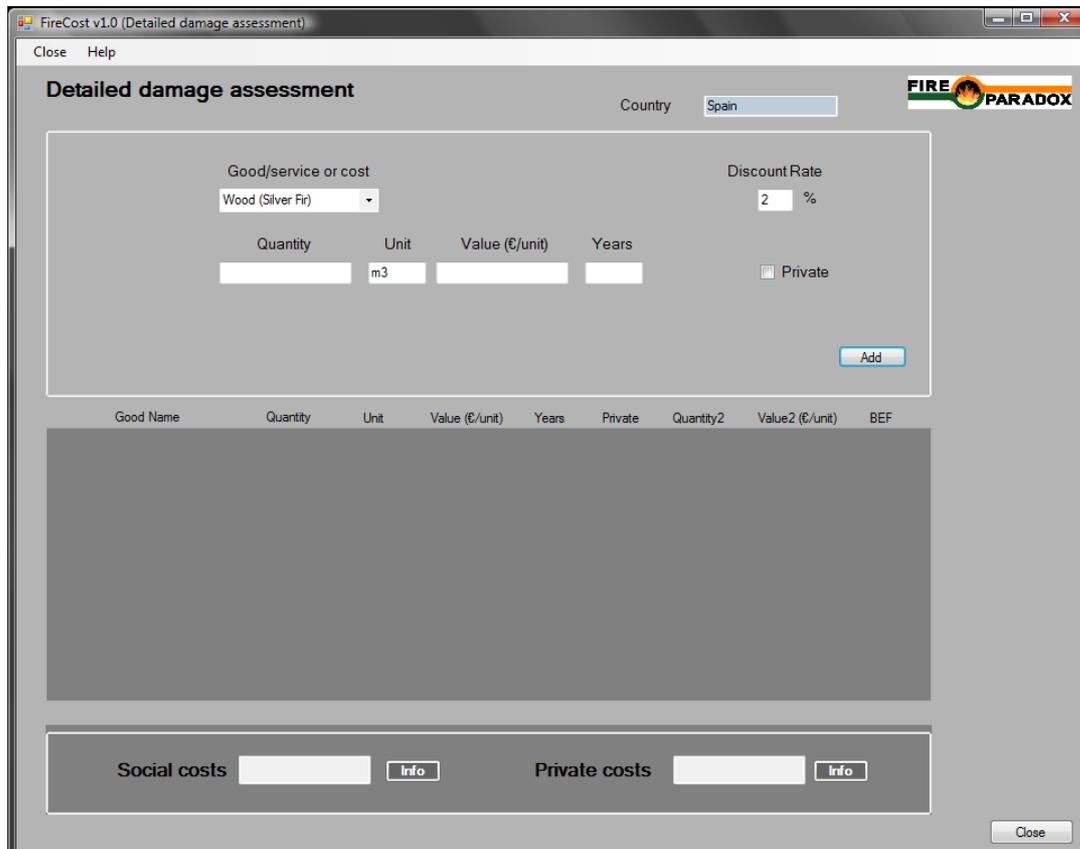
Figure 3.6: Detailed assessment model screenshot

The following main categories of losses/benefits and costs are considered:
- Timber
- Non-wood forest products
- Recreation activities
- Carbon sequestration
- Environmental services
- Suppression costs.

The timber loss for a single tree species is assessed by using the following formula:

$$PVC_T = \left[\left(Vol_1 * \frac{P_1}{(1+r)^m} \right) - Vol_2 * P_2 \right]$$

where PVC_T = present value of the lost timber sale revenues (€); Vol_1 = volume of timber lost (m³); Vol_2 = volume of killed or severely damaged timber (m³); P_1 = roundwood price at forest road for a specific tree species. This price refers to the timber which was already harvested and skidded. Hence, the price includes also the costs of these two operations (€/m³); P_2 = average roundwood price at roadside for salvaged timber (€/m³). As above, this price refers to the timber which was already harvested and skidded. Hence, the price

includes also the costs of these two operations; r = annual discount rate; m = years needed to reach optimum economic rotation age.

The assessment of the economic losses from the reduced availability of non-wood forest products is based on the criteria of the loss of income from the sale of the goods. The following equation is applied to calculate the loss of these goods

$$PVC_{NWFP} = Vol * P * \left(\frac{(1+r)^p - 1}{r * (1+r)^p} \right)$$

where PVC_{NWFP} = present value of lost non-wood forest products (€); Vol = volume of product lost (unit); P = price of the collected/harvested product. Remember, that the costs of collecting/harvesting are already included in the price of the product (€/ton); r = annual discount rate; p = years of decreased quantity of collected/harvested non-wood forest products. It refers to the number of years needed to restore the capacity of the forest to produce a quantity of non-wood forest products similar to the one before the fire.

For the loss of recreation and hunting possibilities the following equation is applied:

$$PVC_{REC} = [(V_1 * N_1) - (V_0 * N_0)] * \left(\frac{(1+r)^p - 1}{r * (1+r)^p} \right)$$

Where PVC_{REC} = present value of the changes in tourism-recreational activities (€); V_0 = average value of one visit before forest fire (€); V_1 = average value of one visit following forest fire (€); N_0 = mean number of visitors per year registered before forest fire; N_1 = mean number of visitors per year registered following forest fire; r = annual discount rate; p = number of years of decreased recreational activities. It refers to the time needed to restore a similar level of recreational activity as before the fire.

However, in most cases where no data about pre- and post-fire number of visitors and values per visit is available; therefore in the model a simplified equation can be applied:

$$PVC_{REC} = V * N * \frac{(1+r)^p - 1}{r * (1+r)^p}$$

Where PVC_{REC} = present value of the changes in tourism-recreational activities (€); V = average value per visit (€); N = mean number of visitors per year; r = annual discount rate; p = number of years of lost recreation activities.

The loss of carbon sequestration for a single tree species can be estimated according to the equation:

$$PVC_C = Vol * BEF * 0.5 * PR_C$$

where PVC_C = present value of the carbon emission costs (€); Vol = volume of burned standing stock (m^3); BEF = biomass expansion factor (coefficient of transformation of the wood volume, expressed in m^3, into above-ground tree biomass, expressed in ton of dry

matter); *0.5* = transformation coefficient (biomass to carbon); PR_C = price per ton of carbon (€/t).

For other environmental goods and services that might be affected by the fire the following equation is applied:

$$PVC_{EG} = P * Ch * V * \left(\frac{(1+r)^p - 1}{r * (1+r)^p}\right)$$

where PVC_{EG} = present value of the loss of environmental forest benefits (€); P = relevant population (person); Ch = changes in output levels of the benefit after the fire (units); V = values for those forest output levels (€/unit); r = annual discount rate; p = years of lost forest environmental benefits following the fire, which refers to the time needed to restore an environmental benefit to before fire level.

The suppression costs are calculated according to equation:

$$PVC_{FS} = \sum_{i=1}^{n} quantity_i * C_{FSi}$$

where i = type of fire management input; PVC_{FS} = total suppression costs €); *quantity* = time of use of fire management input (hours); C_{FSi} = costs of fire management input i (€/hour).

The estimated total damages/benefits are expressed as social and private costs, where as private are considered all the costs and damages that have to be bared by a private agent (e.g. forest owner, private or public enterprise) (see also figure 3.5). On the other hand, as social we consider the total costs/damages for a society (including private costs). The user has the possibility to select for each of the displayed goods and services whether they are considered as private or not.

The total damages/benefits (private and social) are estimated as the sum of all potential damages/benefits:

$$TDB_i = \sum_{j=1}^{n} DB_j$$

$$PDB_i = \sum_{j=1}^{n} p_j * DB_j$$

Where TSC_i = total (social) damage/benefit (€); PSC_i = total private damage/benefit (€); p_j = dummy variable indicating whether the damage/benefit is private or social (p is 1 if private and 0 if social); DB^3_j = damage/benefit to good j (in €).

To return to the main damage estimation screen the user has to select the **Close button**.

3.3 Efficiency evaluation

The main menu screen of the economic efficiency evaluation offers the overview of the costs of two user specified fire management alternatives (see Figure 3.7).
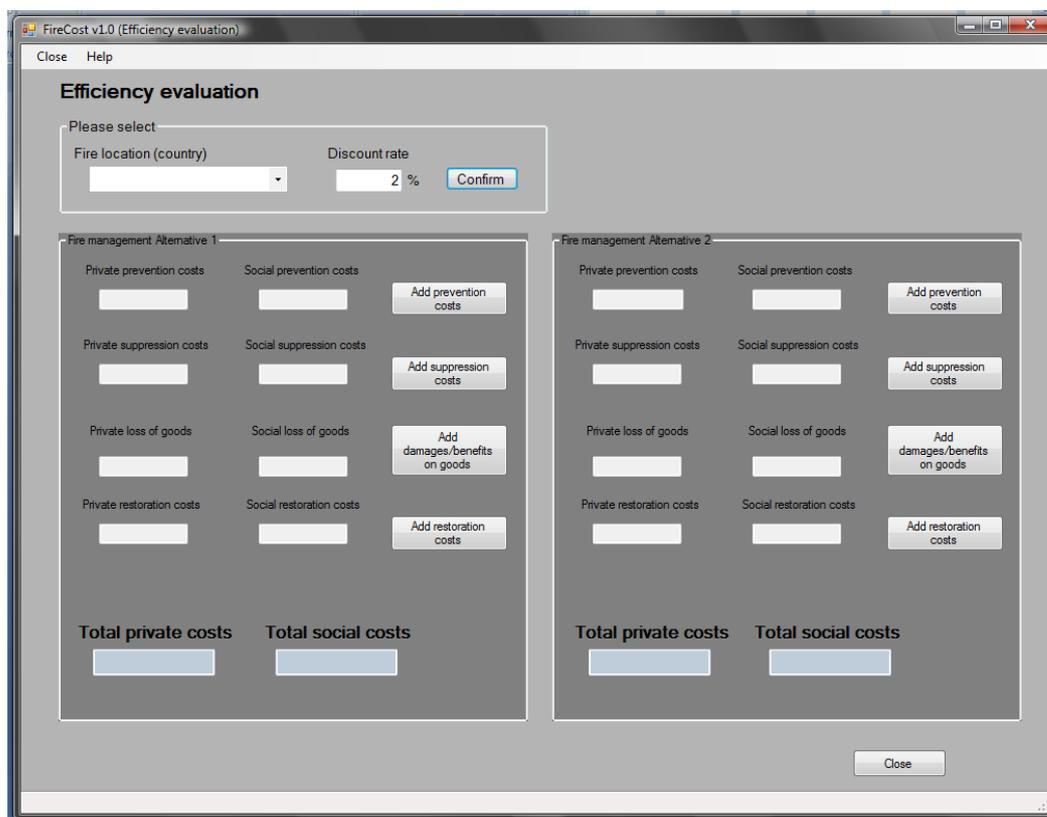
Figure 3.7: Efficiency analysis screenshot

For each of the alternatives the prevention, suppression, damage, restoration and total social and private costs are displayed. The social and private costs are then calculated as the sum of the specified activities and damages:

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[3] Detailed presentation of the calculation of damages and benefits for different goods is given in continuation.

$$TC_i = TPC_i + TSC_i + TDB_i + TRC_i$$

$$PC_i = PPC_i + PSC_i + PDB_i + PRC_i$$

Where TC_i = total (social) costs of alternative i (€);TPC_i = total (social) prevention costs for fire management alternative i (€); SC_i = total (social) suppression costs for fire management alternative i (€); DB_i = total (social) damages/benefits for fire management alternative i (€); RC_i = total (social) restoration costs for fire management alternative i (€);PC_i = total private costs of alternative i (€);PPC_i = total private prevention costs for fire management alternative i (€);PSC_i = total private suppression costs for fire management alternative i (€);PDB_i = total private damages/benefits for fire management alternative i (€); PRC_i = total private restoration costs for fire management alternative i (€).

To calculate the social and private costs for each management alternative the user has to specify the fire location (country), discount rate that should be used (by default the software uses a 2% rate, prevention, suppression and restoration activities and potential damages/benefits to goods and services.

Box 3.1: Discount rate and time in the efficiency evaluation

One of the more important concepts that is applied in all segments of the efficiency evaluation id the time dimension of the management measures. The evaluation is based on the cost-benefit analysis. This method is based on the comparison of all costs and benefits of different management alternatives. However, once all the relevant costs and benefits are expressed in monetary terms, it is necessary to convert them into a common metric, their present value. This process is called discounting and it is based on the fact that the individuals have time preferences between consumption in different periods.

According to this assumption, an individual is not necessarily indifferent between receiving 100€today and receiving the same 100€in ten years time. This is true even if there is no inflation, because 100€today can be used productively in the consequent ten years, producing a value greater than the initial 100€ The rate at which an individual is willing to exchange the present consumption for the future consumption is called the discount rate. The higher is the discount rate, the greater preference is given to the present consumption.

Thus in the evaluation of the efficiency the user has to specify the overall discount rate (the same rate is used for both alternatives and all costs and benefits) and the time of different management measures.

3.3.1 Prevention measures

In this section of the efficiency evaluation the user specifies what type prevention measures would be applied in a management alternative.
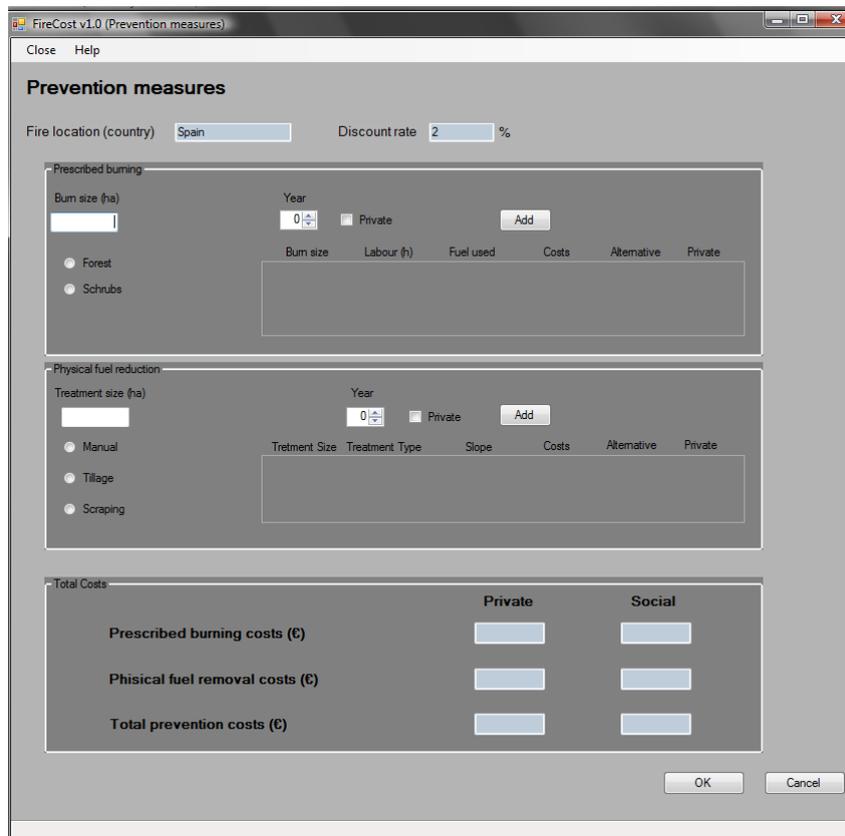
Figure 3.8: Prevention measures screenshot

Two different types of prevention measures can be specified, namely prescribed burning and physical fuel removal (see figure 3.8).

To introduce prescribed burning measures the user has to specify the **burn size** (in ha), the type of vegetation (forest or scrubs), the **year**[4] of the activities and whether the costs are **private** or social. In the case of forest also the **fuel load** has to be selected from a drop-down menu (t/ha) (see figure 3.9). When all the needed information is introduced by pressing the **add button** the costs of the prescribed burning measure are calculated and displayed at the bottom of the page. The prescribed burning costs include personnel and material (€) costs. The user can specify more than one prescribed burning measures (e.g. for different site characteristics or for repeated measures). All included treatments are displayed in the lower right part of the box.

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[4] The year is expressed in relative terms, and is related to the duration of a project or planning period (e.g. if the prevention measure was conducted at the beginning of the planning period then the Year=0).
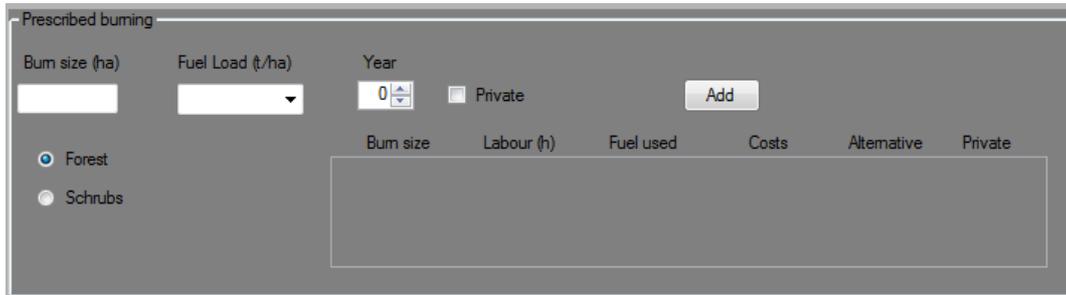
Figure 3.9: Prescribed burning box screenshot

In the case of physical fuel reduction the user introduces information of the **size** of the treatment area (in ha), selects the treatment type (manual, tillage or scraping) the **year**[2] of the activities and whether the costs are **private** or social. If the user selects manual fuel reduction measure also the **vegetation type** (with regard to the height and diameter) and the **slope** have to be selected. All included treatments are displayed in the lower right part of the box (see figure 3.10).

Figure 3.10: Physical removal box screenshot

By pressing the **add button** costs of the specified physical fuel reduction costs are calculated. As in the case of prescribed burning the user can specify various treatments.

The costs (private and social) of prevention measures are estimated as the sum of all prevention measures:

$$TPC_i = \sum_{j=1}^{n} area_j * C_j * \frac{1}{(1+r)^{t_j}}$$

$$PPC_i = \sum_{j=1}^{n} p_j * area_j * C_j * \frac{1}{(1+r)^{t_j}}$$

Where TPC_i= total (social) fire prevention costs for fire management alternative i (€); PPC_i= total private fire prevention costs for fire management alternative i (€); p_j = dummy variable indicating whether the prevention measure is a private or social costs (p

is 1 if private and 0 if social); $area_j$ = treatment area where the prevention measure j is applied (in ha); C_j = cost of prevention measure j (in €/ha); r = discount rate; t = year of the prevention measure application j (year).

To return to the main efficiency evaluation screen and to include the calculated social and private prevention costs into the efficiency evaluation, the user has to select the **OK button**. If the **Cancel button** is pressed the user returns to the main efficiency evaluation screen, without transferring the calculated prevention costs.

3.3.2   Suppression measures

In this section of the efficiency evaluation the user specifies what type of suppression measures would be applied under a management alternative.

For each fire the user can select the **type** and **quantity** (in hours) of different fire management inputs used (see figure 3.11). The following fire management units are already included: (i) machinery (e.g. bulldozer); (ii) group of specialists (7 people); brigade of specialists (12 people); (iii) fire engine; (iv) medium-weight helicopter for transportation and fire extinction (e.g. Bell 412); (v) helicopter for transportation and extinction (e.g. Bell 212); (vi) medium-weight airplane (e.g. AT-802); and (vii) air tanker (e.g. CL215T). The user can also specify other management unit types if needed.

Furthermore the user has to specify the **year** of the suppression activity (also here the year should be expressed in relative terms, with regard to the planning period duration) and whether the costs are considered as **private** (e.g. paid by an individual or enterprise) or social (e.g. paid by the government). By pressing the **add button** the suppression activity is added and displayed on the list (middle of the screen) and the social and private costs are calculated.

The costs (private and social) suppression measures are estimated as the sum of all fire management inputs:

$$TSC_i = \sum_{j=1}^{n} Q_j * C_j * \frac{1}{(1+r)^{t_j}}$$

$$PSC_i = \sum_{j=1}^{n} p_j * Q_j * C_j * \frac{1}{(1+r)^{t_j}}$$

Where TSC_i= total (social) fire suppression costs for fire management alternative i (€); PSC_i= total private fire suppression costs for fire management alternative i (€); p_j = dummy variable indicating whether the fire management input is a private or social cost (p is 1 if private and 0 if social); Q_j = quantity of fire management input j (in hours); C_j = cost of fire management input j (in €/hour); r = discount rate; t = year of the use of fire management input j (year).
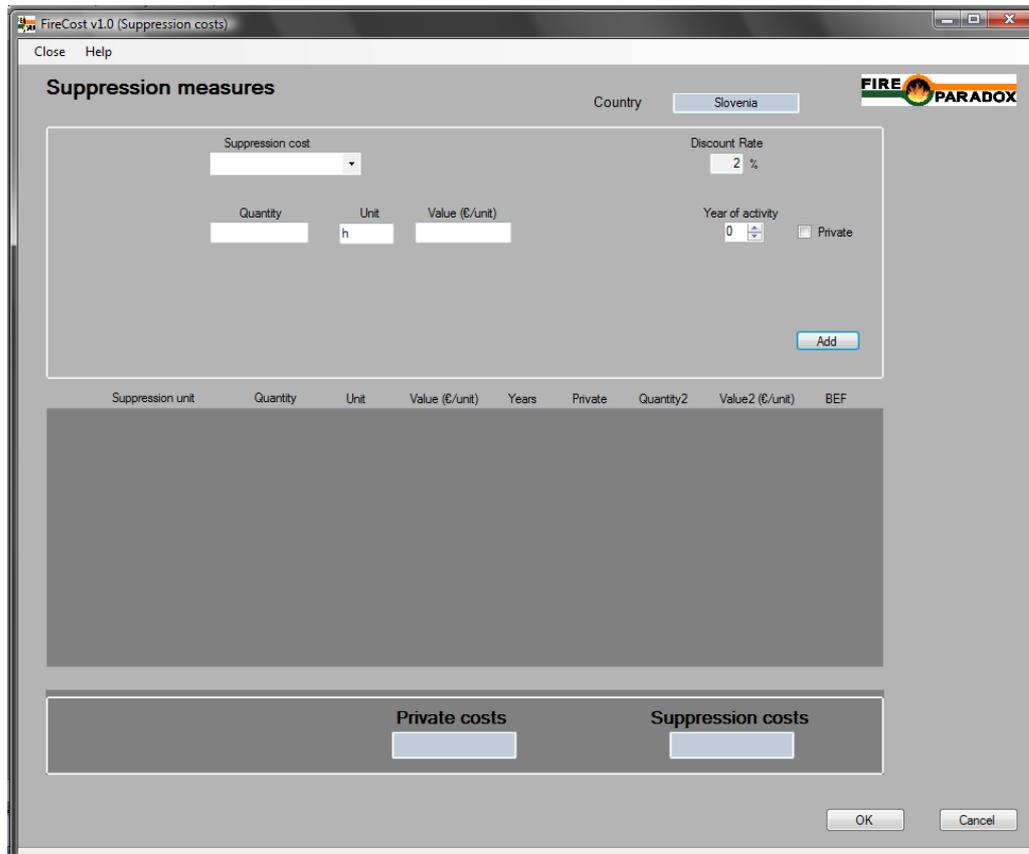
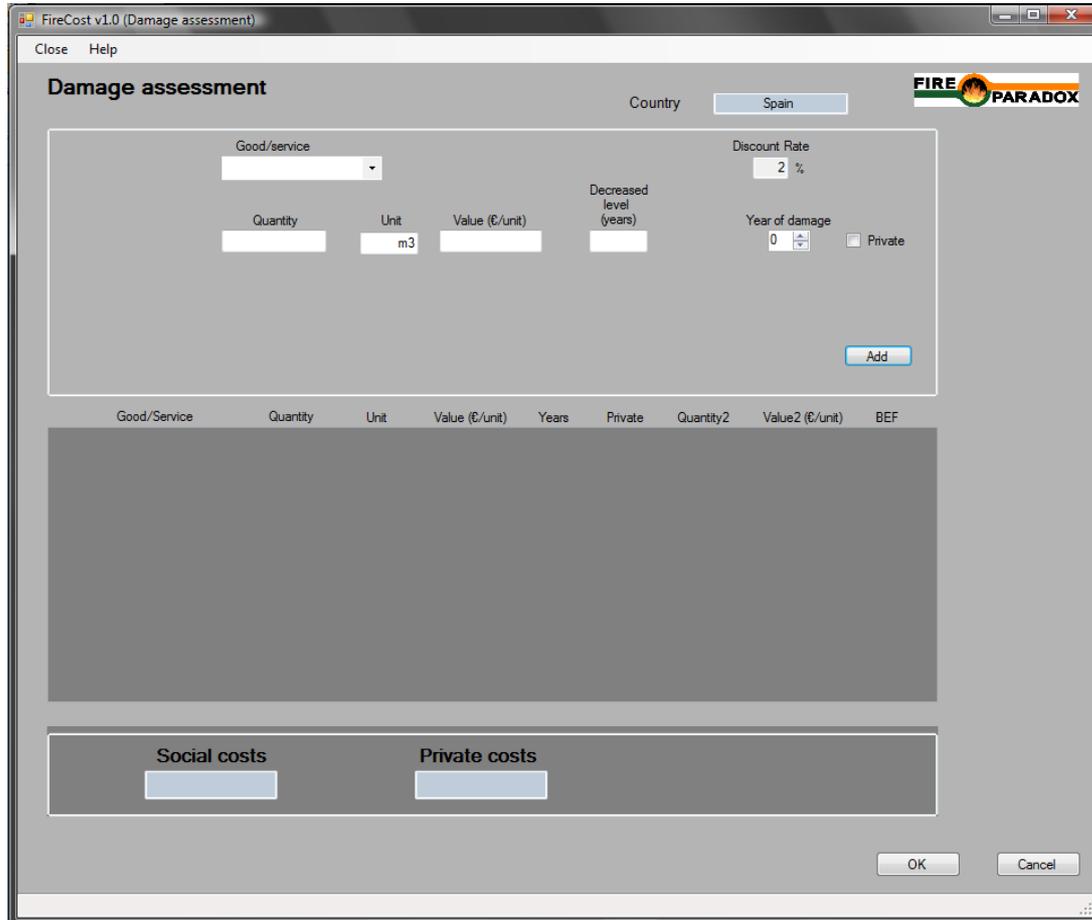**Figure 3.11:** Suppression costs screenshot

To return to the main efficiency evaluation screen and to include the calculated social and private suppression costs into the efficiency evaluation, the user has to select the **OK button**. If the **Cancel button** is pressed the user returns to the main efficiency evaluation screen, without transferring the calculated suppression costs.

3.3.3   Damage/benefit assessment

In this section of the efficiency evaluation the user specifies what type of losses/benefits would be caused by a forest fire under a management alternative.

The affected goods and services can be selected from a dropdown list (see Figure 3.12). By selecting "Other" a new type (not included in the default list) of good or cost type can be added.

Depending on the good or cost type selected "unit", predefined "value" and the number of "years" of decreased level of the good are displayed. The predefined values can be changed by the user. By changing the sign of the value to negative, a benefit can be specified.

Figure 3.12: Damage assessment screenshot

The following main categories of losses/benefits and costs are considered:
- Timber
- Non-wood forest products
- Recreation activities
- Carbon sequestration
- Environmental services
- Suppression costs.

The timber loss for a single tree species is assessed by using the following formula:

$$PVC_T = \left[\left(Vol_1 * \frac{P_1}{(1+r)^m}\right) - Vol_2 * P_2\right]$$

where PVC_T = present value of the lost timber sale revenues (€); Vol_1 = volume of timber lost (m^3); Vol_2 = volume of killed or severely damaged timber (m^3); P_1 = roundwood price at forest road for a specific tree species. This price refers to the timber which was already harvested and skidded. Hence, the price includes also the costs of these two operations (€m^3); P_2 = average roundwood price at roadside for salvaged timber (€m^3). As above,

this price refers to the timber which was already harvested and skidded. Hence, the price includes also the costs of these two operations; r = annual discount rate; m = years needed to reach optimum economic rotation age.

The assessment of the economic losses from the reduced availability of non-wood forest products is based on the criteria of the loss of income from the sale of the goods. The following equation is applied to calculate the loss of these goods

$$PVC_{NWFP} = Vol * P * \left(\frac{(1+r)^p - 1}{r * (1+r)^p} \right)$$

where PVC_{NWFP} = present value of lost non-wood forest products (€); Vol = volume of product lost (unit); P = price of the collected/harvested product. Remember, that the costs of collecting/harvesting are already included in the price of the product (€/ton); r = annual discount rate; p = years of decreased quantity of collected/harvested non-wood forest products. It refers to the number of years needed to restore the capacity of the forest to produce a quantity of non-wood forest products similar to the one before the fire.

For the loss of recreation and hunting possibilities the following equation is applied:

$$PVC_{REC} = [(V_1 * N_1) - (V_0 * N_0)] * \left(\frac{(1+r)^p - 1}{r * (1+r)^p} \right)$$

Where PVC_{REC} = present value of the changes in tourism-recreational activities (€); V_0 = average value of one visit before forest fire (€); V_1 = average value of one visit following forest fire (€); N_0 = mean number of visitors per year registered before forest fire; N_1 = mean number of visitors per year registered following forest fire; r = annual discount rate; p = number of years of decreased recreational activities. It refers to the time needed to restore a similar level of recreational activity as before the fire.

However, in most cases where no data about pre- and post-fire number of visitors and values per visit is available; therefore in the model a simplified equation can be applied:

$$PVC_{REC} = V * N * \frac{(1+r)^p - 1}{r * (1+r)^p}$$

Where PVC_{REC} = present value of the changes in tourism-recreational activities (€); V = average value per visit (€); N = mean number of visitors per year; r = annual discount rate; p = number of years of lost recreation activities.

The loss of carbon sequestration for a single tree species can be estimated according to the equation:

$$PVC_C = Vol * BEF * 0.5 * PR_C$$

where PVC_C = present value of the carbon emission costs (€); Vol = volume of burned standing stock (m^3); BEF = biomass expansion factor (coefficient of transformation of the

wood volume, expressed in m^3, into above-ground tree biomass, expressed in ton of dry matter); *0.5* = transformation coefficient (biomass to carbon); PR_C = price per ton of carbon (€/t).

For other environmental goods and services that might be affected by the fire the following equation is applied:

$$PVC_{EG} = P * Ch * V * \left(\frac{(1+r)^p - 1}{r * (1+r)^p}\right)$$

where PVC_{EG} = present value of the loss of environmental forest benefits (€); P = relevant population (pers); Ch = changes in output levels of the benefit after the fire (units); V = values for those forest output levels (€/unit); r = annual discount rate; p = years of lost forest environmental benefits following the fire, which refers to the time needed to restore an environmental benefit to before fire level.

The suppression costs are calculated according to equation:

$$PVC_{FS} = \sum_{i=1}^{n} quantity_i * C_{FSi}$$

where i = type of fire management input; PVC_{FS} = total suppression costs (€); *quantity* = time of use of fire management input (hours); C_{FSi} = costs of fire management input i (€/hour).

By pressing the **add button** the damage/benefit is added and displayed on the list (middle of the screen) and the social and private costs are calculated.

The estimated total damages/benefits (private and social) are estimated as the sum of all potential damages/benefits:

$$TDB_i = \sum_{j=1}^{n} DB_j * \frac{1}{(1+r)^{t_j}}$$

$$PDB_i = \sum_{j=1}^{n} p_j * DB_j * \frac{1}{(1+r)^{t_j}}$$

Where TDB_i= total (social) damage/benefit for fire management alternative i (€); PDB_i= total private damage/benefit for fire management alternative i (€); p_j = dummy variable indicating whether the damage/benefit is private or social (p is 1 if private and 0 if social); DB^5_j = damage/benefit to good j (in €); r = discount rate; t = year of the damage/benefit to good j (year).

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[5] Detailed presentation of the calculation of damages and benefits for different goods is given in continuation.

To return to the main efficiency evaluation screen and to include the calculated social and private damages/benefits into the efficiency evaluation, the user has to select the **OK button**. If the **Cancel button** is pressed the user returns to the main efficiency evaluation screen, without transferring the calculated damages/benefits.
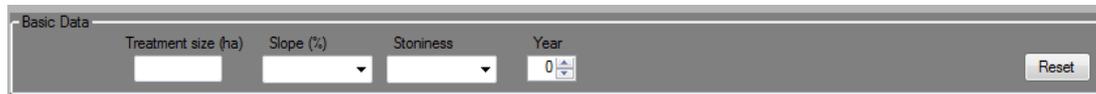
3.3.4   Restoration measures

In this section of the efficiency evaluation the user specifies restoration measures that would be applied in a management alternative.
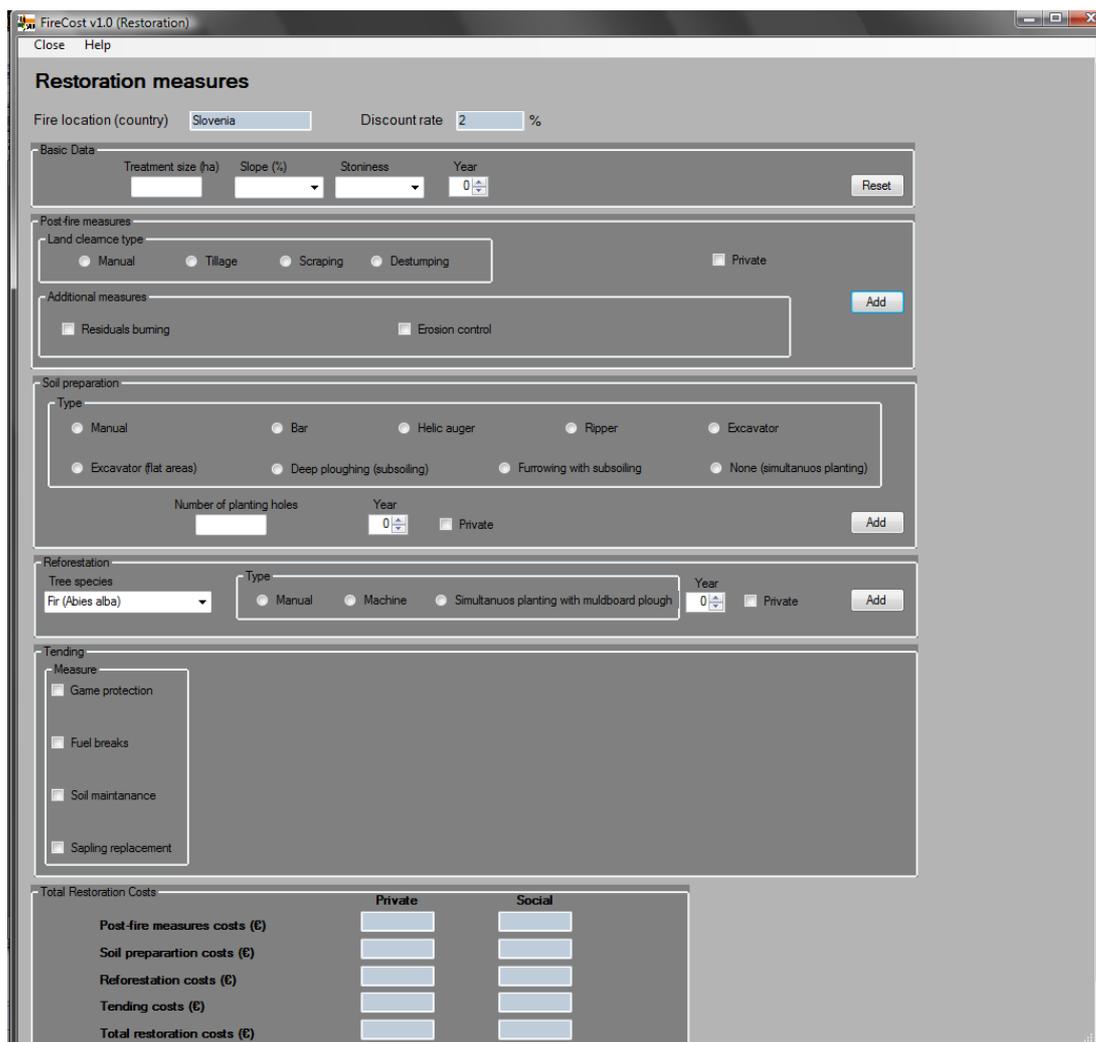
**Figure 3.13:** Restoration assessment screenshot

The following restoration measures can be included: (i) post-fire measures (land clearance, residuals burning and erosion prevention measures); (ii) spoil and plant hole preparation; (iv) reforestation; and (iv) tending measures (game protection, fuel break construction, soil maintenance, sapling replacement) (see Figure 3.13).

To start the introduction of different restoration measures, the user has to state the treatment area **size**, **slope, stoniness** and **year** of the measure application (see Figure 3.14).

Figure 3.14: Basic data box for restoration measures screenshot

In the case of post fire measures four different types of land clearance measures can be included (manual, tillage, scraping and destumping). However, the application of these measures depends on the slope and stoniness of the site (see figure 3.15).
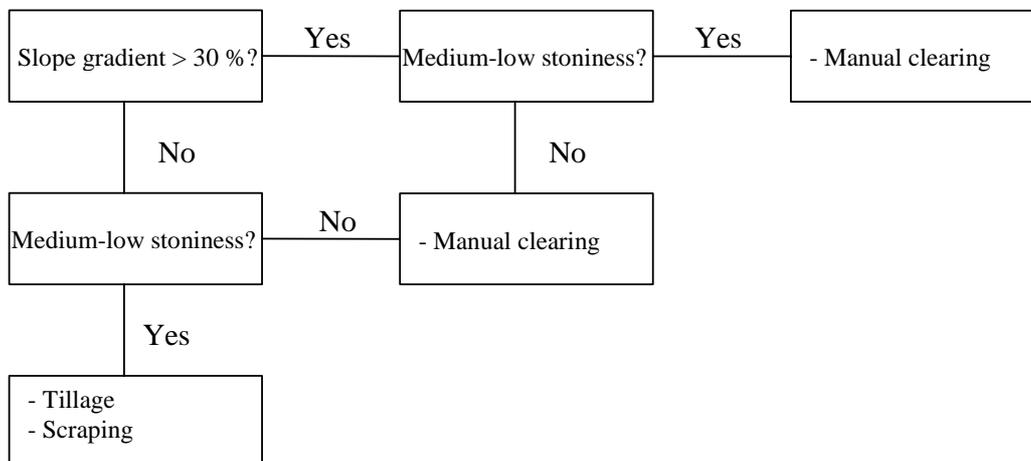

Figure 3.15: Decision diagram for the selection of a land clearing methods

In the case of manual land clearance the user has to select the **vegetation type** (with regard to mean plant height and diameter), while in the case of destumping the **soil type** has to be selected (compact of loose soils) (see figures 3.16 and 3.17). The user has also to specify whether these costs are **private** or not.


Figure 3.16: Manual clearance box screenshot
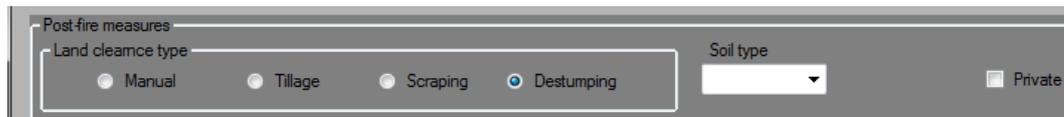
Figure 3.17: Destumping box screenshot

Independently from the land clearance type the user can also select whether residuals burning or erosion protection measures were conducted. In the case of residuals burning the user selects the **vegetation density** (low, medium, high); while for erosion prevention the average **stump diameter** and the **percentage of the area**, where such prevention measuers will be conducted are specified(see figure 3.18).
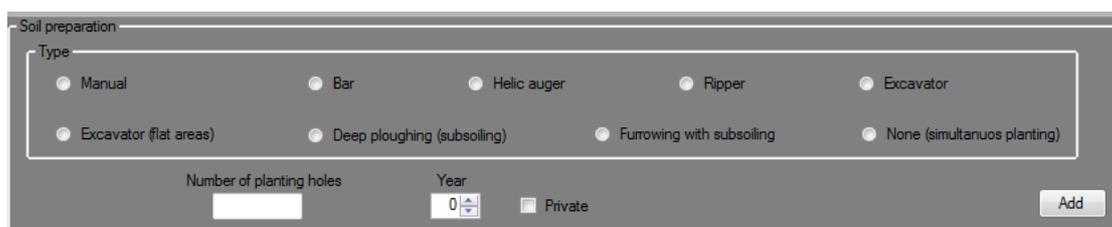
With the add button the post fire measure costs are calculated and summed to the total restoration costs. As in previous cases separately private and social costs are calculated.
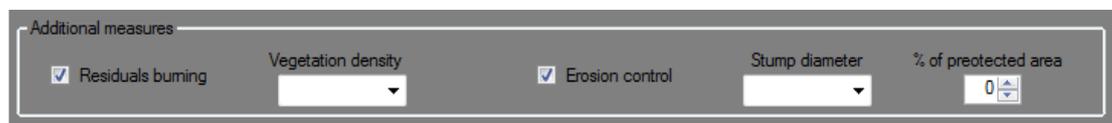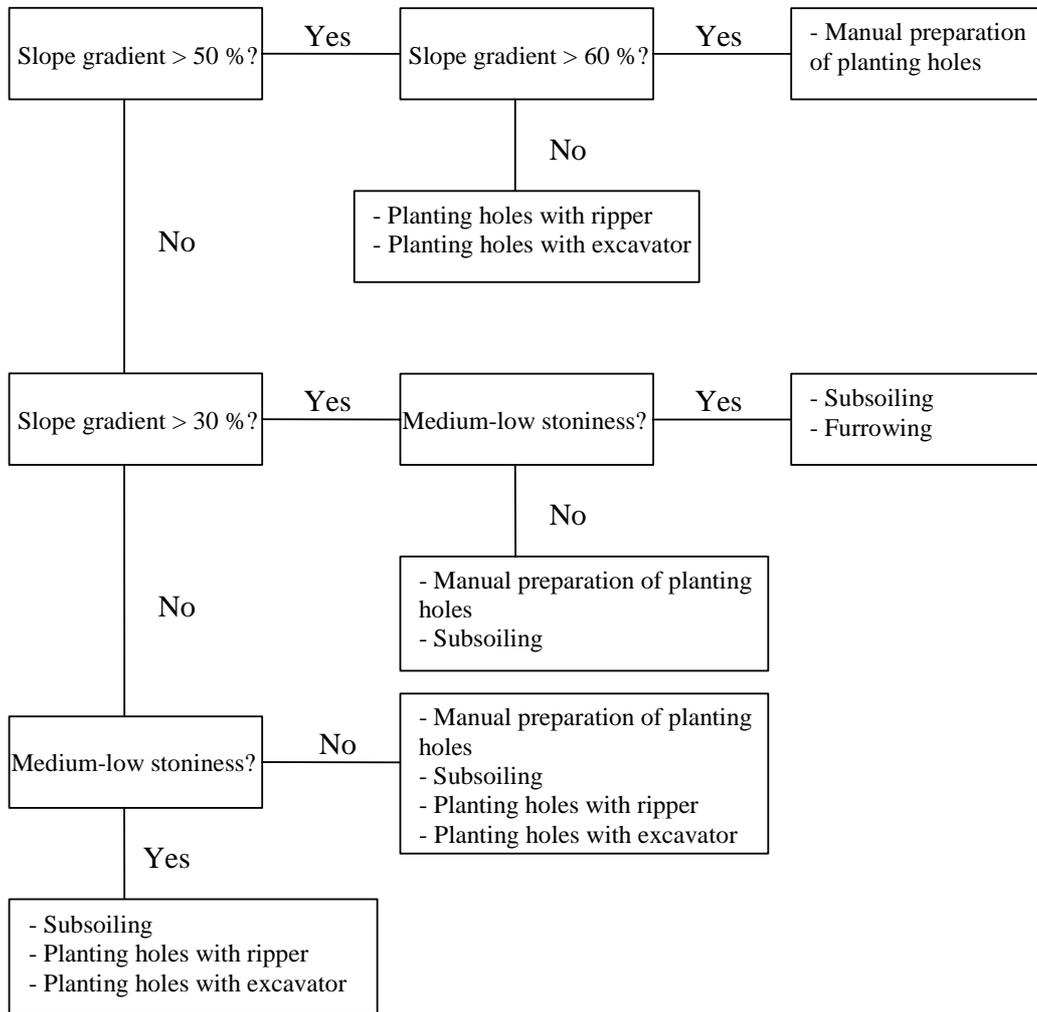

Figure 3.18: Additional post-fire measures box screenshot

With the add button the post fire measure costs are calculated and summed to the total restoration costs. As in previous cases separately private and social costs are calculated.

With regard to soil preparation measures eight different measure types can be selected (Figure 3.19): (i) manual soil preparation; (ii) soil preparation with bar; (iii) soil preparation with helic auger; (iv) soil preparation with ripper; (v) soil preparation with excavator; (vi) preparation of flat areas with an excavator; (vii) subsoiling; and (vii) furrowing with subsoiling. In addition the user can also select that none of the above methods are applied in the case the soil preparation is done by a mouldboard plough with simultaneous planting (in this case he selects this option in the reforestation box). Regardless the selected method the user has to provide information about the number of planting holes or length of soil preparation measures (flat areas with an excavator, subsoiling, and furrowing with subsoiling). The soil preparation type also depends on the site stoniness and slope (see figure 3.20). Further, the year of the soil preparation measures and the cost type (private/social) have to be selected. In the case no year is provided, the year specified in the basic data box is taken.
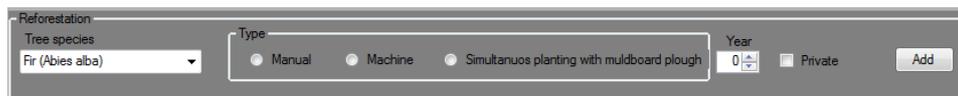

Figure 3.19: Soil preparation measures screenshot

FIRE PARADOX

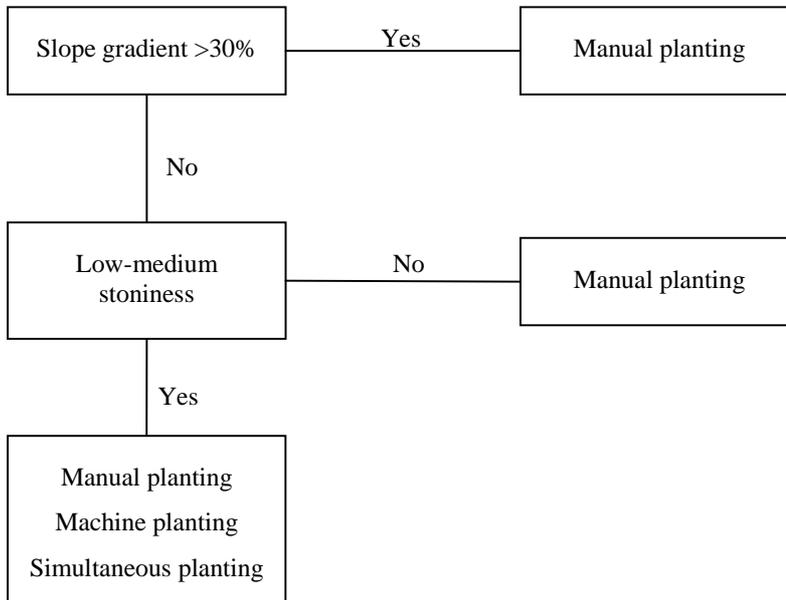**Figure 3.20**: Decision making diagram for soil preparation methods

With the add button the soil preparation costs are calculated and summed to the total restoration costs. Separately private and social costs are calculated.

For the calculation of reforestation measure costs the user has to specify the main **tree species**, reforestation method (manual, machine planting, and simultaneous planting with mouldboard plough), the y**ear** of the reforestation and the cost type (**private**/social). The selection of the planting method depends on the slope and stoniness of the site (see figure 3.22).
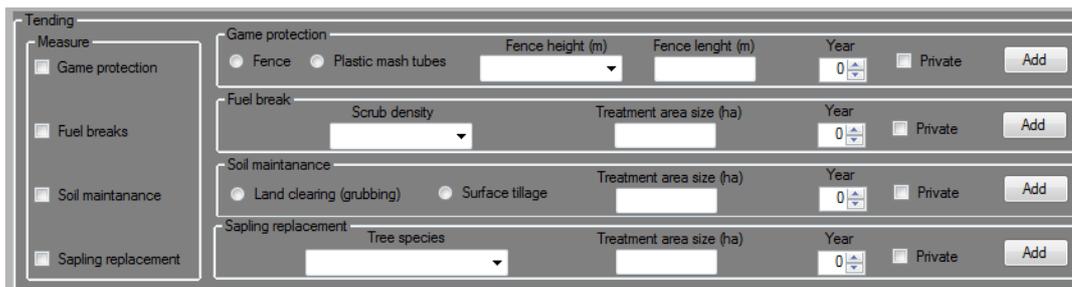

Figure 3.21: Restoration measures screenshot

With the add button the total and private reforestation costs are calculated and summed to the total restoration costs.

Figure 3.22: Decision making diagram of the different planting methods

The last part of the restoration screen compiles four different tending measures (i) protection of plants again game; (ii) fire protection, (iii) soil maintenance; and (iv) sapling replacement (Figure 3.23).

Figure 3.23: Tending measures screenshot

In the case of protection measures against game, the user can select between fence and plastic mash tubes. For fencing the **fence height** and **length**, the **year**, and cost type (**private**/social) have to be specified (figure 3.24); while for plastic mash tubes, the user has to state the **number of tubes**, the **year,** and cost type (**private**/social) (figure 3.25).

Figure 3.24: Basic data box for restoration measures

Figure 3.25: Basic data box for restoration measures

To add fire protection measures (fuel break construction) the **scrub density** and **fuel break length** have to be defined by the user, furthermore, the **year** of the measure and cost type (**private**/social) have to be added (Figure 3.23).

Land clearing (grubbing) and surface tillage are the two types of soil maintenance measures that can be selected. For each of them the **treatment area size**, the **year** of treatment, and type of cost have to be added.

Finally, for the replacement of saplings the user has to select the main **tree species**, the **treatment area size** (ha), **year**, and cost type.

By pressing any of the **add button** the restoration measure is added and the social and private costs are calculated. Whereby, the costs are divided between different tending measures. The estimated total restoration costs (private and social) are estimated as the sum of all restoration operation:

$$TRC_i = \sum_{j=1}^{n} RC_j * \frac{1}{(1+r)^{t_j}}$$

$$PRC_i = \sum_{j=1}^{n} p_j * RC_j * \frac{1}{(1+r)^{t_j}}$$

Where TRC_i= total (social) restoration costs for fire management alternative i (€); PRC_i= total private restoration costs for fire management alternative i (€); p_j = dummy variable indicating whether the restoration cost is private or social (p is 1 if private and 0 if social cost); RC_j = costs of restoration measure j (in €); r = discount rate; t = year of the restoration operation j (year).

To return to the main efficiency evaluation screen and to include the calculated social and private restoration costs into the efficiency evaluation, the user has to select the **OK button**. If the **Cancel button** is pressed the user returns to the main efficiency evaluation screen, without transferring the calculated restoration costs.