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ControlInRoad
Controlling the spread of invasive species with innovative methods in road construction and maintenance

Cost Benefit Calculations
WP 5.2

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1 Executive Summary

The objective of this report is the valuation of methods to control IAPs along roads by the help of cost-benefit observations. This is done for the following three different IAPs: *Heracleum mantegazzianum* (giant hogweed), *Fallopia* spp. (knotweeds) and *Ambrosia artemisiifolia* (common ragweed). This selection is based on whether the different types of plants that are most prevalent in Europe should be treated with different control methods in order to get the highest benefits in terms of the costs related to weed control.

An objective valuation of different control methods enables road operators to select those methods for the respective plants that gain most benefits for the costs of weed control. Due to the fact that costs depend on specific circumstances such as plant density and the treatment width along roads three scenarios are calculated to show the influence of the mentioned parameter on the results.

Different types of evaluation methods exist for this purpose (impact analysis, cost benefit analysis, value benefit analysis, cost-effectiveness analysis). The appropriate selection of a valuation method depends on different circumstances such as type of stakeholders using the valuation results, data situation and valuation targets.

The valuation within this project aims at suggesting those measures for the control/eradication of IAPs along roads that provide the highest cost/benefit ratio for the relevant stakeholders (especially road operators). Existing information on relevant costs allows the monetarisation of costs and therefore the use of all different methods for cost benefit observations. Data situation for benefits of the use of control methods (equal to costs of doing nothing) enables only a qualitative valuation along an ordinal scale based on the description of effects and the effectiveness of different methods to reduce the spread of the plants. Since it is possible to calculate costs accurately the direct connection of benefit values and monetary costs by calculating the cost effectiveness (division of benefit values with monetary cost values) is chosen as the appropriate valuation method. Results of this use of the cost effectiveness analysis are benefit values per costs. These values enable the comparison of control methods and a ranking of control methods.

Due to the fact that costs depend on specific circumstances such as plant density and the treatment width along roads the following three scenarios have been calculated to show the influence of these parameters on the results:

- Minimum scenario: low plant density, 1 m treatment width, upper value of effectiveness range (regarding effectiveness range between 90% and 100%)
- Main scenario: medium plant density, 3 m treatment width, medium value of effectiveness range (regarding effectiveness range between 50% and 90%)
- Maximum scenario: high plant density, 10 m treatment width, lower value of effectiveness range (regarding effectiveness range up to 50%)

The following pictures show an overview on the calculated benefits values per 1.000 EUR for the three scenarios and the three selected IAPs (*H. mantegazzianum, Fallopia* spp.*, A. artemisiifolia)*. The higher the benefit value per costs, the better is the control method compared to the other control methods.

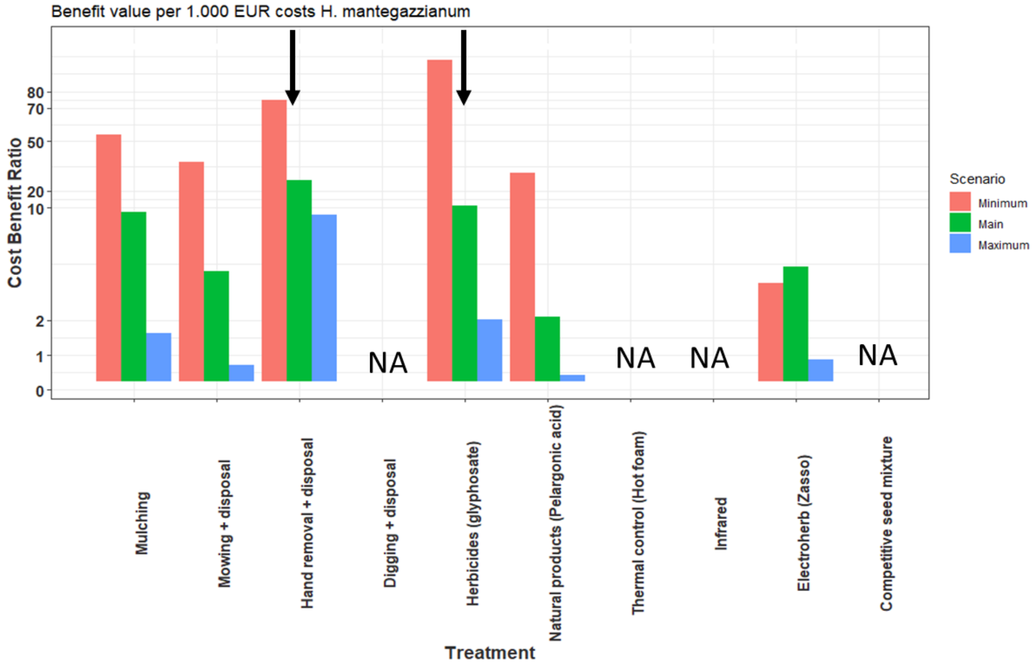

Figure 1: Benefit values per costs, *H. mantegazzianum*

For *H. mantegazzianum* the usage of alternative methods (natural products, Electroherb™) leads to a degradation of the cost-benefit ration compared to the standard methods “herbicide use” and “hand removal (including disposal)”. The hand removal method is the best alternative to the application of herbicides independent of the scenario (described by treatment width, plant density and effectiveness range of methods).

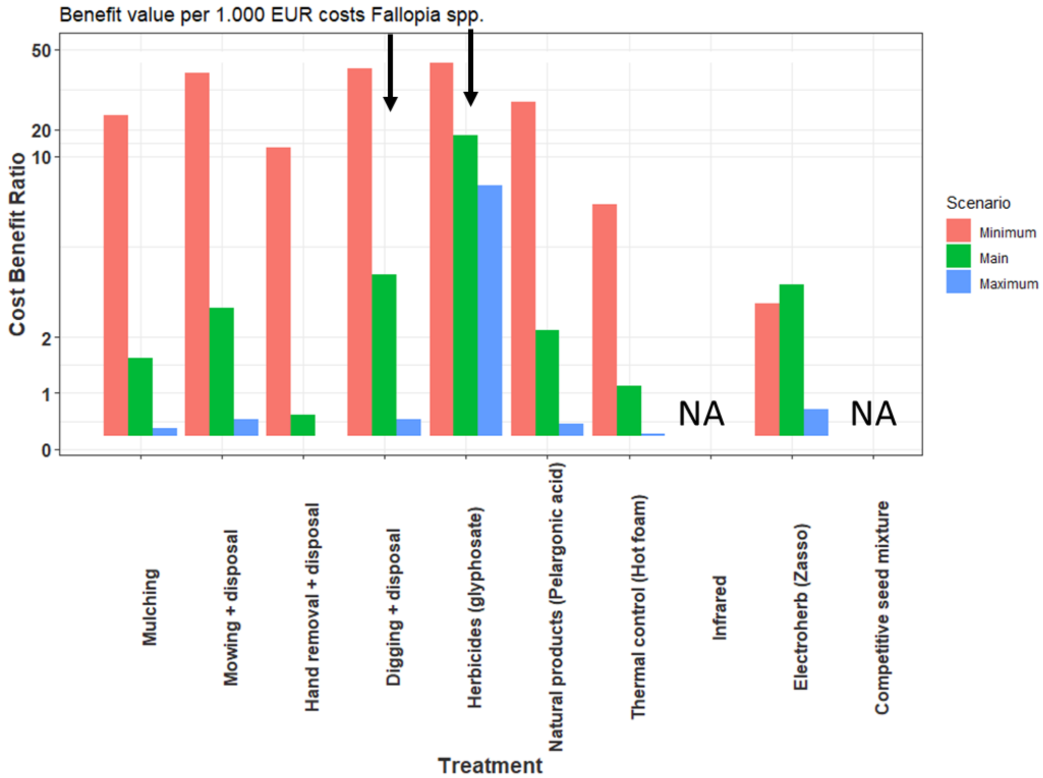

Figure 2: Benefit values per costs, *Fallopia spp.*

For *Fallopia* spp. the control method with the best cost benefit ratio is for all scenarios the use of herbicides. Looking at the best alternative instead of the use of herbicides in case of the minimum and main scenario the control method “digging and disposal” has the best cost benefit ratio. But in the maximum scenario Electroherb^{TM} is identified as the control method with the best cost benefit ratio beside the use of herbicides (although the difference to the benefit values of “Digging+disposal” is not very high).

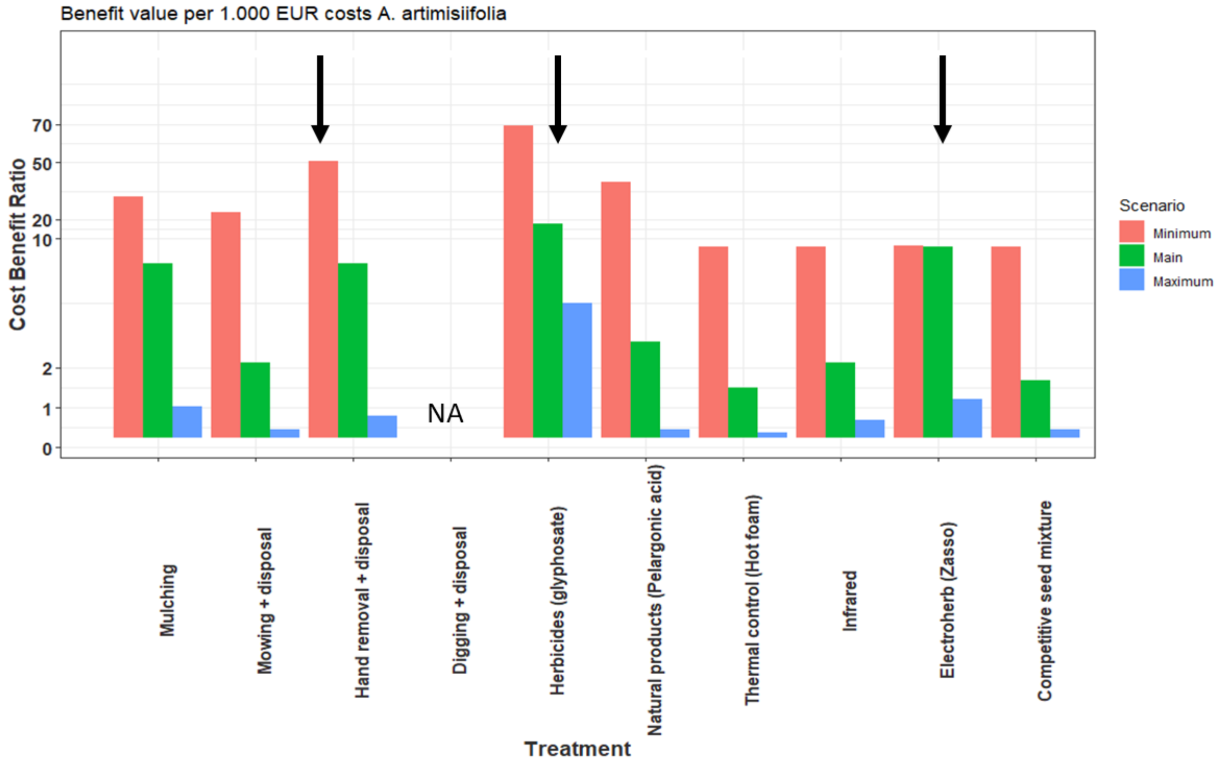

Figure 3: Benefit values per costs, *A. artemisiifolia*

For *A. artemisiifolia* again the standard method of herbicide application has the best cost-benefit ratio for all scenarios. The selection of the second best alternative depends on scenario: For the minimum scenario (low plant density, 1 m treatment area along roads and upper effectiveness (within the selected effectiveness class)) the application of hand removal (+disposal) is best. For the other two scenarios Electroherb^{TM} is the best alternative besides the use of herbicides.

In summary, the following suggestion is made regarding the choice of methods for the control of the selected IAPs instead of applying glyphosate:

Table 1: Recommendation of control method to be used instead of herbicides

<table>
<tr><td colspan="4">Recommendation of control method to be used instead of herbicides (glyphosate)
Based on the calulation of a cost benefit ratio (by using a cost effectiviness analysis)</td></tr>
<tr><td rowspan="3"></td><td colspan="3">Scenario</td></tr>
<tr><td>Minimum</td><td>Main</td><td>Maximum</td></tr>
<tr><td>Low plant density, 1m treatment width, upper value of effectiveness range (regarding effectiveness range between 90% and 100%)</td><td>Medium plant density, 3m treatment width, medium value of effectiveness range (regarding effectiveness range between 50% and 90%)</td><td>High plant density, 10m treatment width, lower value of effectiveness range (regarding effectiveness range up to 50%)</td></tr>
<tr><td rowspan="2">H. mante-gazzianum</td><td>1. Hand removal (+disposal)</td><td>1. Hand removal (+disposal)</td><td>1. Hand removal (+disposal)</td></tr>
<tr><td>2. Mulching</td><td>2. Mulching</td><td>2. Mulching</td></tr>
<tr><td rowspan="2">Fallopia spp.</td><td>1. Digging (+disposal)</td><td>1. Digging (+disposal)</td><td>1. Electroherb</td></tr>
<tr><td>2. Mowing + dispoal</td><td>2. Electroherb</td><td>2. Digging (+disposal)</td></tr>
<tr><td rowspan="2">A. arte-misiifolia</td><td>1. Hand removal (+disposal)</td><td>1. Electroherb</td><td>1. Electroherb</td></tr>
<tr><td>2. Natural products</td><td>2. Mulching</td><td>2. Mulching</td></tr>
</table>

When working with the results of the cost-benefit assessment carried out, it should be noted that long-term field trials regarding the effects of different control methods on different IAPs are required under certain circumstances in order to increase the assessment results and the informative value of the cost-benefit assessment. Nevertheless, the results presented provide a good first indication of which control methods are better than others under certain circumstances (scenarios). They can serve as a starting point for detailed location-specific assessments (using location-specific input data).

2 Introduction

The main objective of this report (D5.2) is to evaluate control methods of IAPs along roads using cost benefit observations. The report presents the methods used to evaluate costs and benefits of different standard and alternative methods to control IAPs. The results of this evaluation are presented and the control methods in terms of a cost benefit ratio are ranked.

This is done for the following three IAPs: *Heracleum mantegazzianum* (giant hogweed), *Fallopia* spp. (knotweeds) and *Ambrosia artemisiifolia* (common ragweed). These species have been selected to evaluate whether different types of plants found in Europe should be treated with different control methods in order to get the highest benefits for the costs of the use of the control methods.

An objective evaluation of different control methods enables road operators to select those methods for the respective plants that gain most benefits for the costs of the use of methods. Due to the fact that costs depend on specific circumstances such as plant density and the treatment width along roads the following three scenarios have been calculated to show the influence of these parameters on the results:

- Minimum scenario: low plant density, 1 m treatment width, upper value of effectiveness range (regarding effectiveness range between 90% and 100%) – see: chapter 0)
- Main scenario: medium plant density, 3 m treatment width, medium value of effectiveness range (regarding effectiveness range between 50% and 90%) – see: chapter 0)
- Maximum scenario: high plant density, 10 m treatment width, lower value of effectiveness range (regarding effectiveness range up to 50%) – see: chapter 0)

It is the aim of this report to reduce uncertainties regarding the different existing control methods and their effects and costs for road operators. The focus is on the maintenance of roads not on the construction of roads since control methods for construction cannot really be compared to control methods for maintenance.

The report is divided in to five main chapters:

- Chapter 3 presents potential valuation methods, the pros and cons and the necessary data framework to be able to conduct the methods. This is the basis for the decision on one valuation method.
- Chapter 4 describes the three selected IAPs (based on deliverable 2.2). Potential standard and alternative control methods (out of those described in deliverable 3.1) are identified for each of the selected IAPs. Control treatment frameworks per IAPs and control methods are identified and described. These frameworks are one main basis of the assessment of costs and benefits.
- Chapter 5 identifies and values the costs per control method and IAP based on the outcomes of chapter 4 and research on cost components and their standard cost values.
- Chapter 6 identifies and values the benefits of the successful control of the three selected IAPs for road operators. This is based on a literature review, a two-step stakeholder consultation and necessary expert judgments.
- Chapter 0 finally links the results of costs and benefits to generate an overall judgment of control methods for each of the three selected IAPs.

3 Valuation of measures for IAP control on roadsides – overview of valuation methods

The choice of the most appropriate valuation method depends on different circumstances such as:

- Type of stakeholders relevant for the valuation of measures:
    - The public sector – the general public as well as specific groups (e.g. residents, specific age groups, lobby groups)
    - Companies
- Data availability
    - Possibility to monetize costs of measures (implementation and operation) in an adequate and comparable way
    - Possibility to monetize benefits (impacts) of the measures in an adequate and comparable way
- Valuation target
    - Priority ranking of different measures
    - Final selection of measures
    - Ecological impact of measures

To select an appropriate method for the valuation of standard and alternative measures for controlling/eradicating invasive alien plants along roads it is therefore necessary to

- present and describe existing methods for the valuation
- describe the data requirements and the applicability of methods with respect to different valuation targets
- fix the target of valuation
- describe the relevant stakeholders for whom the valuation is done
- clarify what kind of data is available for costs and benefits

Guidelines for the analysis of constructional, operational and organisational measures in the transport sector exist in many countries. Examples for such guidelines are:

- In Austria: FSV: RVS 02.01.22 - Decision Making Support | Cost-Benefit-Trials in Traffic and Transport (2010)
- In Germany: FGSV: Evidence on usage of methods for decision making in transport planning (2010)
- In Switzerland: Schweizerischer Verband der Strassen- und Verkehrsfachleute: Swiss Norm SN 641 820 – Cost Benefit-Trials in the road sector (2013) (2013)
- Strukturfonds-ERDF, Kohäsionsfonds und ISPA: Guidance to Cost Benefit Trails for investment projects (2003)

The aim of these guidelines is to give advice in the valuation of costs and benefits to be able to present economic viability of the applied measure and to justify the use of public money.

These guidelines distinguish different methods of cost-benefits-trials. The Austria RVS 02.01.22 presents the following methods:

- Impact analysis (or Effect analysis) (IA)

  The impact analysis describes all ascertainable qualitative and quantitative impacts systematically but without a formal value synthesis. A formal value synthesis aggregates the different impact dimensions. With this step an absolute (dimensionless) measure, the decision calculus is derived. This is done in an intuitive pragmatic way.

- Cost benefit analysis (CBA)

  Based on the impact analysis the CBA describes all impacts in money values und adds all monetized impacts (costs and benefits) of a measure to one value. Benefits are usually described as cost reductions due to the impact of the measure. The decision calculus is a measure value with the dimension monetary units per monetary unit (generalised ratio test).

- Value benefit analysis (VBA)

  The value benefit analysis brings all different impact characteristics (with their different dimensions) to a comparable dimensionless measure value via transformation (using a benefit function). This measure value is the standardised target achievement rate. Such a rate has to be weighted along their relative relevance of the impact and has to be added to the dimensionless benefit value. The costs of a project/treatment are measured as every other impact category and added to the benefit value in the same way. The decision calculus is a measure value without dimension and is called benefit value.

- Cost-effectiveness analysis (CEA)

  The cost-effectiveness analysis derives the benefit value for all impacts except the costs of the measure in the same way as for the value benefit analysis. This benefit value has to be connected with the costs of the measure (that are calculated in the same way as for the CBA and exist therefore as monetised values). The decision calculus is a measure value with the dimension “benefit points per money unit”. For this case at least two comparable measures have to be calculated to be able to compare them. It is not possible to compare a single measure with a scenario that does not apply a measure.

The cited Austrian guideline has been developed especially for different types of valuation of the transport infrastructure. The methods are therefore linked to different targets that a valuation of such an infrastructure project can have. The valuation of methods to control IAPs can also have different targets, but partly not directly the same as for transport infrastructure valuation. The target-method-matrix of the Austrian guideline is transferred from the transport infrastructure situation to the IAP-control situation of the objective report:

Table 2: Relevance of benefit-cost observations for different targets of infrastructure evaluation

Target of transport infrastructure evaluation	Target of IAP-control evaluation	IA	CBA	VBA	CEA
Priority ranking	Priority ranking		X		
Check of alternatives across modes	-		X		
Pre-selection of infrastructure variants within one mode	Pre-selection of methods for one specific IAP		X	X	
Selection of infrastructure variants	Selection of methods for one specific IAP		X	X	X
Ecological impacts	Ecological impacts	X			

The assessment within this project aims to propose those measures to control IAPs along roads that provide the highest cost/benefit ratio for the relevant stakeholders. Cost-benefit observations should help decision-makers to select or preselect those IAP control measures that achieve the highest cost/benefit ratio. From this point of view, all assessment methods with the exception of the single impact analysis are usable methods. The impact analysis is not recommended because it is only be used for the evaluation of ecological impacts.

Therefore, a final selection of one of the three potential methods depends on the data situation regarding costs and benefits. The following table shows the potential use of the three remaining valuation methods depending on the data situation.

Table 3: Relevance of benefit-cost observation by quality of valuation data

Monetary values for	Qualitative values (ordinal ranking) for	CBA	VBA	CEA
Costs and benefits	-	X		
Costs	Benefits			X
-	Costs and benefits		X	

Based on the data availability regarding costs (presented in chapter 5) and benefits (presented in chapter 6) the cost-effectiveness analysis (CEA) has been selected , because costs are available in terms of monetary values and benefits are available in terms of ordinal ranked qualitative values.

4 Overview on control measures and IAPs to be analysed

4.1 IAPs to be analysed

For the cost-effectiveness analysis (CEA), the following three IAPs have been selected: *H. mantegazzianum* (giant hogweed), *Fallopia.* spp. (knotweeds) and *A. artemisiifolia* (common ragweed) (Figure 1). All three species occur regularly along roadsides and were identified as important IAPs that require attention and control (Follak et al. 2018, Deliverable 2.1). Control options (manual, mechanical, chemical) for these species are available, however, their control is still challenging due to their biological and ecological characteristics (Deliverable 2.2., Deliverable 3.1).

H. mantegazzianum is a large, perennial, seed-propagated monocarpic (= flowers only once in a lifetime) herb, usually growing 2 to 3 m high. Since 2017, *H. mantegazzianum* is on the List of Invasive Alien Species of Union Concern (http://data.europa.eu/eli/reg_impl/2017/1263/oj). *H. mantegazzianum* has impacts on biodiversity through competitive displacement of native plant species. The species is hazardous to humans, because it exudes a sap, containing several chemical agents (e.g. furocoumarins) which sensitize human skin and lead to severe burning when exposed to sunlight. The plant sap can be toxic to some animals feeding on them.

Fallopia species are herbaceous, rhizomatous perennial species. *Fallopia* spp. include *F. japonica* (Japanese knotweed: heart-shaped but flattened at the base), *F. sachalinensis* (giant knotweed: leaf rounded acuminate forming a heart shape) and *F. x bohemica* (Bohemian knotweed: intermediate leaf base shape). Bohemian knotweed is a hybrid of giant and Japanese knotweed. *Fallopia* spp. belong to the most problematic IAPs as they cause significant disruption to natural and managed habitats. They form dense, monospecific stands outcompeting and displacing native species in particular in riparian zones. *Fallopia* spp. occur regularly along road verges and embankments. Their spread is vegetative and evolves through the dissemination of rhizome or cane fragments (mainly through the transport of contaminated soil). In the United Kingdom, the cost associated with the presence of *F. japonica* is calculated at £150 million at development sites plus £5 million for river sites, £5 million for road networks and £2 million for rail networks (Williams et al. 2010). Taking all other cost for local authorities, research, householders the total cost is estimated with £165 million in the UK.

A. artemisiifolia is a monoecious, wind-pollinated, annual herb, and its height varies from 10 cm to 2.5 m, according to the environmental conditions. It causes substantial crop-yield losses and its copious, highly allergenic pollen creates considerable public health problems.
The total costs of the impact of *A. artemisiifolia* on health and agriculture for the European Union and neighboring countries have been estimated to €4.5 billion per year (Bullock et al. 2012) . *A. artemisiifolia* is able to disperse quickly and efficiently along roadsides (Essl et al. 2015).

Figure 4: Invasive alien plants used in the cost-benefit analysis (from left to right): *H. mantegazzianum* (giant hogweed), *Fallopia* spp. (knotweeds) and *A. artemisiifolia* (common ragweed) (© S. Follak)

4.2 Usual vegetation management versus specific IAP-control

IAP control should be applied according to the management process described in Deliverable 5.1 (Figure 5).

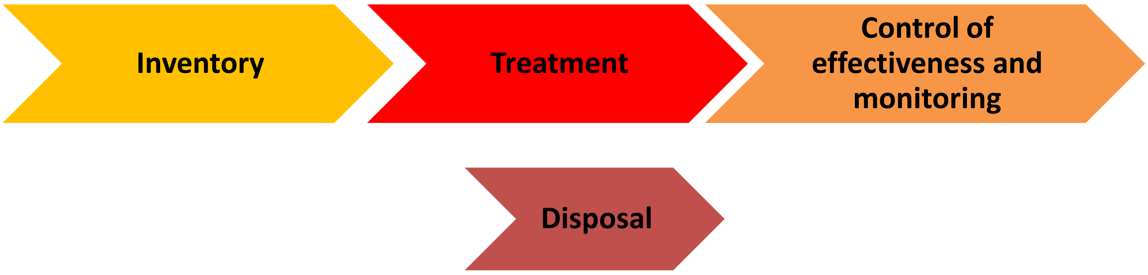

Figure 5: Process steps for IAP control (extract)

The first step includes the recording of the IAPs along the roadsides. Then, IAPs should be managed specifically with standard or alternative control methods described in chapter 4.4 and 4.6. The measures will be carried out instead of the common vegetation management. Mowing is the most common method for vegetation control along roadsides and is usually applied two times a year. Hence, this common vegetation management is replaced e.g. by mowing the IAP population three times or by the application of glyphosate two times over a certain number of years. Some strategies include the disposal of plant material.
A post-control monitoring is necessary to avoid re-growth of the IAP and includes an observation of the treated area and the application of measures to control emerging or missed individuals (if necessary).

The assessment of effectiveness of control methods is based on the correct application of treatments regarding time, frequency and further measures (cleaning etc.).

4.3 Quality of information and data

The selection and description of control strategies for the selected IAPs is based on the results of a literature search (Deliverable 3.1), the field trial (Deliverable 3.3) and expert judgement (stakeholder consultation, Deliverable 4.1). Each control strategy includes the following parameters:

- number of treatments per year
- duration of control
- duration of the monitoring period and
- the overall effectiveness.

The number of treatments per year, the duration of the treatment and of the monitoring period and the effectiveness may differ in practice due to the characteristics of the population (i.e. small vs. large infestation, established population with large seedbank/rhizome network vs. outbreak) and locations of the populations in the countries (difference in climatic conditions).
In some cases, average values for the number of treatments are used for the calculation, as there was not enough empirical evidence for the respective control strategies to distinguish between different values. For other methods, a proposed control strategy from the literature (e.g. control with glyphosate for *Fallopia* spp. according to Jones et al. 2018) or from the field trial (Deliverable 3.3) is applied. For *Fallopia* spp. a range of treatments per year and of the duration is used based on the literature (Bollens 2005) and expert judgement.

In general, most studies had a limited control implementation time and/or monitoring response period, i.e. they did not evaluate control outcomes beyond two or three years (e.g. Jones et al. 2018, Milakovic et al. 2014 a, b). Thus, information to estimate the necessary duration of each control strategy is limited. Some authors recommend that a control method should be applied over four years or more (e.g. Kettenring & Adam 2011).

Based on this, the duration for most control strategies is set to five years. In some cases, the duration of the control is shorter due to the method used. It is also difficult to assess the effectiveness of a control strategy, as even long-term conclusions can differ from original findings (Ketting & Adams 2011). Thus, for the assessment of the effectiveness a simplified scale has been used (‘low’, ‘medium’, ‘high’, see for further details chapter 4.4 and 4.6).

4.4 Standard methods

Current standard methods of IAP control principally involve mulching, mowing, hand removal and herbicide use. Proper disposal of the plant material is critical to the control process (see for further details Deliverable 3.1 and Deliverable 4.2, Figure 2). The standard methods included in the CEA were the following:

<u>Mowing / mulching</u>
It is defined as the mechanical trimming of grass, weeds and other light vegetation. Both are the most widespread methods for vegetation management and the control of IAPs along roadsides. Plants should be cut at the ground level. In the mulching method, the plant is cut and broken up and ripped plant material remains on the soil where it decomposes over time. In the mowing method, the plant is cut and the plant material is removed. In general, control should be done before flowering to avoid the dispersal of seeds, however timing and frequency of cutting is crucial for some species as they are able to re-sprout fast. Therefore, plants should be cut either in a specific growing period like for *A. artemisiifolia* or cut as deep as possible below the growing point like for *Lupinus polyphyllus*.

Hand removal
Many herbaceous plants can be pulled out. It is important to remove as much of the root system as possible, because even a small portion can restart the infestation. Plants can be pulled out by hand or with a digging fork or shovel. It is easiest to undertake this type of control in the spring or early summer when the top soil is damp, and the plants are young. Hand removal is an effective and highly targeted method for the management of IAPs in particular in areas with a low infestation level. For annual plants, hand removal should be done before seeds are set to avoid the spread of the seeds. This method is very successful for plants with small, shallow roots like *Impatiens glandulifera*.

Digging
Digging involves the removal of infested soil and ground material and is usually performed by heavy equipment, like a backhoe loader. Excavation of infested soil and its disposal off site is probably the most effective, once-off method for eradication. However, root fragments of rhizomes may remain in the soil of the managed area. In particular, this method is applied to rhizomatic IAPs like *Fallopia* spp. or *Asclepias syriaca*.

Herbicide application
The application of herbicides is a widely used method to control weeds and IAPs along roadsides. It provides much flexibility and low costs, considering the equipment for application and the spectrum of active substances that are available. In Europe, the most important active substance is glyphosate. It is not selective and can be applied to control a wide variety of annuals, perennials, trees and shrubs. Other selective herbicides can be used for a targeted control of broadleaf weeds (e.g. triclopyr). Herbicides can be applied in two different ways: foliar application (treatment of individual plants, small and/or large infestations) and spot treatment (e.g. stem application). As a rule, foliar herbicides should be applied to young, tender, actively growing plants prior to flowering. Foliar application is fast and large infestations can be treated. However, in many European countries, national laws restrict the use of herbicides along roadsides or their use is waived on a voluntary basis. In general, herbicide use is viewed critically due to environmental concerns.

Disposal
Proper disposal of plant material and soil containing IAP seeds or rootstock (rhizomes) is essential for the control success. Plant material can be treated on-site or removed to authorized landfill sites with the appropriate biosecurity measures in place. Reasonable treatments include composting, (deep) burial or controlled burning. For the selected species, it is recommended that plant material without seeds from *H. mantegazzianum* and *A. artemisiifolia* can be composted in industrial/commercial facilities. *Fallopia* spp. should not be composted at all because they have vegetative parts (rhizomes, corms) that may survive in compost. The plant material should be disposed of by deep burial or controlled burning.

4.5 Standard methods for the control of selected IAPs

Each control method is briefly described for the respective plant species based on the results of a literature search (Deliverable 3.1), the field trial (Deliverable 3.3) and expert judgement (stakeholder consultation, Deliverable 4.1). Information is given about the number of required treatments per year, duration of the control strategy, of the monitoring period required and the overall effectiveness.
The following simplified scale has been used for the selected IAPs:

- ’high’ – population is eradicated (population is eliminated from an area by application of measures)
- ‘medium’ – population is suppressed (population is reduced in an area by application of measures, i.e. reduction in e.g. infested area, coverage, abundance, height)
- ‘low’ – population is not suppressed (population is not reduced or even increases/spreads in an area despite the application of measures, i.e. no reduction in e.g. infested area, coverage, abundance, height)

In the following Table 3, an overview about methods and their effectiveness on the selected IAPs is given.

Table 4: Overview about the effectiveness of the standard methods for the control of *Heracleum mantegazzianum*, *Fallopia* spp. and *Ambrosia artemisiifolia*

Species	**Method**	**Effectiveness**		
		Low = no suppression of population	Medium = suppression of population	High = eradication of population
Heracleum mantegazzianum				
	Mulching		X	
	Mowing + disposal		X	
	Hand removal + disposal			X
	Glyphosate			X
Fallopia spp.				
	Mulching	X		
	Mowing + disposal		X	
	Hand removal + disposal		X	
	Digging + disposal			X
	Glyphosate		X	
Ambrosia artemisiifolia				
	Mulching		X	
	Mowing + disposal		X	
	Hand removal + disposal			X
	Glyphosate			X

4.5.1 Heracleum mantegazzianum

A range of control options (manual, mechanical, chemical) for *H. mantegazzianum* along roadsides are available (e.g. Nielsen et al. 2005, Rajmis et al. 2016, see Deliverable 2.2). The main goal is to kill the plants without any seed returning into the seed bank.

Information on the duration of a control period for *H. mantegazzianum* is limited but should be extended to five years (Klima & Synowiec 2016). It is also recommended by some authors that a control method should be applied over 4 years or more (Wilson et al. 2004, Kettenring & Adam 2011). For the CEA, it is concluded that the area should be managed for five years independent of the method employed except the method “hand removal + disposal”.

Continuous monitoring of the treated sites is important for preventing re-establishment. Monitoring includes the removal of emerging or missed individuals. *H. mantegazzianum* forms a short-term persistent seed bank (Moravcová et al. 2006). Recent studies have suggested that following presumed control of the population, the managed area should be monitored well beyond the reported period of seed bank persistence (i.e. 7 years, Moravcová et al. 2018). Consequently, it is important to monitor the managed area for at least eight years after treatment. Full personal protective equipment must be worn when handling *H. mantegazzianum* to protect against the hazards of the sap, particularly when stems are cut which release the sap.

The following standard methods have been selected:

<u>Mulching</u>
H. mantegazzianum populations should be cut (with a mulcher) at least three times during the growing season (e.g. late April, mid-June, mid-August; cut before flowering or the beginning of seed set) for five consecutive years (EPPO 2009, Klima & Synowiec 2016, Grguric 2018). This method allows the plant population to be contained and it prevents most individuals from developing inflorescence and seed production during the growing season. Nevertheless, under mulching conditions, there may be re-growth from below-ground after treatment and individual plants may develop (small) flowers. Thus, a return of seeds to the soil seed bank cannot be completely ruled out. The effectiveness of this approach is classified as ‘medium’.

<u>Mowing + disposal</u>
H. mantegazzianum populations should be cut (with a mowing machine) at least three times during the growing season (e.g. late April, mid-June, mid-August; cut before flowering or the beginning of seed set) for five consecutive years (EPPO 2009, Klima & Synowiec 2016, Grguric 2018). Using this strategy resulted in a *Heracleum sosnowskyi* (congener of *H. mantegazzianum*) control outcome of 42–97% according to Klima & Synowiec (2016). The plant material should be disposed of in an authorized landfill site and treated by industrial/commercial composting facilities. This method allows the plant population to be contained and prevents most individuals from developing inflorescence and seed production during the growing season. Nevertheless, a return of seeds to the soil seed bank cannot be ruled out as even mowed plants may re-grow and produce small flowers, which may not be cut completely by consecutive mowing. Thus, the effectiveness is classified as ‘medium’

<u>Hand removal + disposal</u>
Hand removal including the root system (= root cutting, i.e. plant is cut at least 15 cm below the stem, the central growth cone of the plant is removed) is very effective and may provide 100% control of plants during one growing season (EPPO 2009, Klima & Synowiec 2016). It needs to be applied only once and the effectiveness of this method is classified as ‘high’. The plant material should be disposed on an authorized landfill site and treated by industrial/commercial composting facilities.

Glyphosate

The most commonly referenced herbicide for *H. mantegazzianum* control is glyphosate due to efficient control results (Grguric 2018). However, total control of this species may be achieved only by continuous herbicide application over several years (Caffrey 2001, EPPO 2009, Klima & Synowiec 2016, Grguric 2018). *Heracleum sosnowskyi* (congener of *H. mantegazzianum*) populations were effectively controlled by glyphosate applied three times a year for five consecutive years according to Klima & Synowiec (2016). If this suggested measure (+ monitoring period) is implemented successfully, it can be assumed that the population is effectively controlled (effectiveness = 'high').

Table 5: Overview on standard methods for the control of *Heracleum mantegazzianum*, the required number of applications, recommended duration of the treatment and monitoring, and the effectiveness of the method

Method	Number of treatments per year	Duration of management [year]	Duration of monitoring [years]	Effectiveness
Mulching	3	5	8	medium
Mowing + disposal	3	5	8	medium
Hand removal + disposal	1	1	8	high
Glyphosate	2	5	8	high

4.5.2 *Fallopia* spp.

A range of control options (manual, mechanical, chemical) for *Fallopia* spp. along roadsides is available (e.g. Jones et al. 2018, see Deliverable 2.2). Containment and eradication of *Fallopia* spp. is considered to be very difficult or even impossible (Bollens 2005, Kabat et al. 2006, Jones et al. 2018). Jones et al. (2018) stated that no treatment completely eradicated *Fallopia* spp. in their study within three years; thus, treatment of re-growth is required for subsequent years. Monitoring of *Fallopia* spp. should be carried out for as long as possible (until no further re-growth is observed). In this study, the monitoring period after treatment is set to eight years according to the other two species.

The following standard methods have been selected (Table 4):

Mulching

Information on the number of cutting treatments required to control *Fallopia* spp. is variable (Bollens 2005, Kabat et al. 2006, Jones et al. 2018). It may range from 2 times a year to biweekly. Mulching is generally believed not be effective according to the questionnaire (Deliverable 4.1). Likewise, the literature data (e.g. Bollens 2005) and expert judgement (stakeholder consultation) reveal that *Fallopia* spp. cannot be suppressed by this method as populations will likely recover and even may increase fostered by the fact that very small stem fragments resulting from mulching can re-grow. Mulching has to be applied continuously over many years. To address these issues, the proposed strategy includes mulching in a range from 4 to 8 times over a period of > 10 years. The effectiveness is 'low'.

Mowing + disposal

Information on the number of cutting treatments required to control *Fallopia* spp. is variable (Bollens 2005, Kabat et al. 2006, Jones et al. 2018). It may range from 2 times a year to biweekly. In general, high frequent mowing per year over many years is recommended in order to reduce plant vigor of the population (e.g., 3 to 5 times up 4 to 7 years as proposed by Bollens 2005). Plant material must be professionally disposed on authorized landfill sites for deep burial (e.g. Environment Agency 2019). This minimizes the risk of vital stem fragments remaining on the surface after mowing. In accordance with Bollens (2005) and high frequency mowing between 4 and 8 times over 7 years together with a professional disposal can in the long-run exhaust and suppress a *Fallopia* spp. population. Mowing + disposal is generally believed to be more effective than mulching according to the questionnaire (Deliverable 4.1). The effectiveness is considered to be 'medium'.

Hand removal + disposal

Fallopia spp. (following an initial cutting using brush saw and clipper) stems and rhizomes should be removed (hand, spade) eight times during the summer season (July, August; Perlmutter 2017) for at least 7 consecutive years (Bollens 2005) to achieve an effect (exhaustion). It is recommended to dispose plant material professionally on authorized landfill sites for deep burial (e.g. Environment Agency 2019). The main goal is to reduce plant vigor and to contain the plant. Overall, it cannot be ruled out that the plants still may recover after treatment as *Fallopia* spp. has an impressive ability of regeneration (= effectiveness is 'medium').

Digging + disposal

Excavation (usually performed by heavy equipment, like a backhoe loader + disposal) should be done in spring to a depth of 2.5 m (Jones et al. 2018). It is recommended to dispose plant material professionally on authorized landfill sites for deep burial (e.g. Environment Agency 2019). Excavation of infested soil is probably the most effective, once-off method for eradication. The effectiveness is classified as 'high'.

Glyphosate

Fallopia spp. can be most efficiently controlled by glyphosate (Bollens 2005, Jones et al. 2018). A good efficacy on *Fallopia* spp. (reduction of stem density) was observed after three years of treatment applied twice a year by foliar application (Jones et al. 2018). Applying this strategy, the effectiveness is classified as 'medium.

Information on the length of monitoring period after treatment is not available. The period is set to 8 years in accordance withthe two other species.

Table 6: Overview on standard methods for the control of *Fallopia* spp., their required number of applications, recommended duration of the treatment and monitoring and the effectiveness of the method

Method	**Number of treatments per year**	**Duration of management [year]**	**Duration of monitoring [year]**	**Effectiveness**
Mulching	4-8*	>10	8	low
Mowing + disposal	4-8*	7	8	medium
Hand removal + disposal	8	7	8	medium
Digging + disposal	1	1	8	high
Glyphosate	2	3	8	medium

* a range between 4 and 8 treatments per year is used according to the literature and information from the stakeholder consultation

4.5.3 *Ambrosia artemisiifolia*

A range of control options (manual, mechanical, chemical) for *A. artemisiifolia* along roadsides are available (Deliverable 2.2). *A. artemisiifolia* is an annual plant that completes its life cycle, from germination to the production of seeds, within one year. It forms a persistent soil seed bank (i.e., seeds can remain alive in the soil for many years, Essl et al. 2015). Thus, the main aim is to prevent pollen and seed production.

No exact information is available from the literature for how long the treatments should be performed. Most control studies on *A. artemisiifolia* do not evaluate control beyond 2 years (e.g. Milakovic et al. 2014a). In general, it is recommended that a control method should be applied for 4 years or more (Wilson et al. 2004, Kettenring & Adam 2011). For the CEA, it is concluded that the area should be managed for five years independent of the method employed.

The survival of seeds depends on their burial depth. Unburied seeds lose their viability over 4 years (Essl et al. 2015). It can be assumed that high proportions of seeds along roadsides accumulate on the soil surface and remain largely unburied. Thus, it is recommended that the managed area should be monitored at least for eight years. It is granted that viable seeds present on the soil surface are (almost) not present anymore after this period. It has to be taken into account that seeds remaining deeper in the soil maintain their viability for a long time. Therefore, even after the treatment individuals may germinate, in particular when soil movement takes place.
The following standard methods have been selected (Table 5):

<u>Mulching</u>
Mulching should be done as close to the ground as possible. The timing of the treatment is crucial as it greatly influences the plant's possibility for re-growth and flowering. Successive treatments within a year are necessary. It has been recommended to mulch roadsides three times a year (under experimental conditions: beginning of July, middle of August and September; according to Milakovic et al. 2014a, b). Machines could strongly facilitate the spread of *A. artemisiifolia* in particular when applied during autumn when ripening seeds are available (Vitalos & Karrer 2009). However, by applying this method (i.e. three cutting times before flowering), the risk of spreading seeds of *A. artemisiifolia* is minimized. Under practical conditions (suboptimal timing, cutting depth), it cannot be ruled out that there may be still re-growth from belowground parts and thus, individual plants may develop (small) flowers and seeds. As the plant material is not disposed, stems with viable seeds may remain on the ground (seeds ripen even after cutting). Thus, the effectiveness is classified as 'medium'.

<u>Mowing + disposal</u>
Mowing should be done as close to the ground as possible before flowering. The timing of the treatment is crucial as it greatly influences the plant's possibility for re-growth and flowering. Successive treatments within a year are necessary. It has been recommended to mow roadsides three times a year (under experimental conditions: before flowering/seed ripening, at beginning of July, in middle of August and September; according to Milakovic et al. 2014a, b). The plant material should be disposed on an authorized landfill site and treated by industrial/commercial composting facilities (Starfinger & Sölter 2016). Machines could strongly facilitate the spread of *A. artemisiifolia* in particular when applied during autumn when ripening seeds are available (Vitalos & Karrer 2009). However, by applying this method (i.e. three cutting times before flowering), the risk of spreading seeds of *A. artemisiifolia* is minimized.

Under practical conditions (suboptimal timing of cutting, cutting depth), it cannot be ruled out that, there may be still re-growth from belowground parts and thus, individual plants may develop (small) flowers and seeds. In the field trial 2019, mowing performed poorly compared to the other measures tested (Deliverable 3.3.) Thus, the effectiveness is classified as 'medium'.

Hand removal + disposal
All plants are uprooted systematically and it is recommended to remove the plants once a year before flowering and seed set (June/July). The plant material should be disposed on an authorized landfill site and treated by industrial/commercial composting facilities (Starfinger & Sölter 2016). The field trial 2019 underlined the efficacy of this method (Deliverable 3.3). Thus, the effectiveness is classified as 'high', because *A. artemisiifolia* is prevented from pollen production and seed ripening.

Glyphosate
A. artemisiifolia can be controlled effectively by glyphosate (100% efficacy, application at different developmental stages) (Gauvrit and Chauvel 2010, Verschwele et al. 2012). It is recommended to apply the herbicide once a year. The effectiveness is classified as 'high' because *A. artemisiifolia* is prevented from pollen production and seed ripening.

Table 7: Overview on standard methods for the control of *Ambrosia artemisiifolia*, their required number of applications, recommended duration of the treatment and monitoring and the effectiveness of the method

Method	Number of treatments per year	Duration of management [year]	Duration of monitoring [year]	Effectiveness
Mulching	3	5	8	medium
Mowing + disposal	3	5	8	medium
Hand removal + disposal	1	5	8	high
Glyphosate	1	5	8	high

4.6 Alternative methods

Alternative methods of IAPs control along roadsides principally involve mechanical, thermal and biological control methods as well as the application of natural products (see for further details Deliverable 3.1 and Deliverable 4.2, Figure 2). The alternative methods considered in the CEA are the following:

Competitive seed mixture
It involves the removal of the IAPs by tillage operations and the subsequent sowing of mixtures of plant species, which are deemed suitable for road verges (roadside). This helps to outcompete the IAPs and to establish a native plant community (Gentili et al. 2015, Schuster et al. 2018). For example, Gentili et al. (2015) demonstrated a reduction of coverage of *A. artemisiifolia* by 95 % (commercial seed mixture, one-year experiment). In the seed mixture, specific plant species can be used that produce exudates, which are phytotoxic to neighbouring plants (i.e., to the IAPs). For example, *Festuca rubra commutata* produces the potent phytotoxin meta-tyrosine that strongly suppresses the growth of broadleaved weeds (Tworkoski & Glenn 2012). Moreover, the use of specific plant growth-promoting bacteria (PGPB) in seed coatings (or other appropriate forms of application) can be very valuable.

PGPB strengthen the emerging seed and young seedlings by accelerating their germination and growth (O'Callaghan 2016, Deliverable 3.2).

Natural products

There are a number of natural products (= natural phytotoxic substances, also called 'bioherbicides') available for weed control (e.g. organic acids and essential oils) (Dayan & Duke 2010). Organic acids include acetic acid and fatty acids like caprylic acid, capric acid and pelargonic acid. These active ingredients are marketed commercially as non-selective, post-emergent contact herbicides ("burndown effect"). They are most effective against (young) annual broadleaf plants (e.g. Crmaric et al. 2018). Despite some limitations (high costs, not very effective against grass species and perennials, repeated application may be necessary), it is assumed that organic acids are a valuable option for IAP control along roadsides in certain situations (e.g. direct spot spraying of specific IAPs, band application along the central reservation).

Hot foam

Hot foam has been considered as the most efficient thermal weed control method as compared to e.g. direct flame or hot water. It is a non-toxic method and is applicable for numerous weed species. Currently, hot foam is basically used to manage weeds in public areas and on hard surfaces, but it can also be used as a control method along roads and railway sites (Wei et al. 2010). The method uses hot water in combination with foam made from natural, non-toxic ingredients including plant oils and sugars from maize, oil rape, wheat and potato. When the solution is applied to a weed, the hot solution acts as a thermal blanket, keeping the heat on the weed long enough to kill it. Temperatures above 60°C destroy the plant cells (protein denaturation). Due to its anti-sag property, hot foam is also valuable for controlling high-stalked weeds (Wei et al. 2010). In comparison to hot water, the temperature stays five times longer on the plant. In general, the effective temperature should not fall below 57°C. With hot water, the temperature drops down already after a few seconds.

Infrared

The infrared weeder uses propane gas to heat up a ceramic burner to a temperature over 950°C (Figure 2). The plants are killed immediately. Compared to other methods, the infrared weeder needs more energy compared to hot water and direct flames (Astatkie et al. 2007). However, the infrared weeder was shown to be most effective in controlling weeds compared to hot water and direct flame (Astatkie et al. 2007). Equipment is available, from small hand-held models to models with an integrated drive motor. The equipment is easy to use, does not produce an open flame and is noiseless.

Electroherb™

Electric current can be used to control IAPs. The company Zasso offers such a device for electrical weed control (referred to as Electroherb™ throughout the text) and this technique was used for the calculations in the CBA as well as in the field trial (Deliverable 3.3). For the Electroherb™ treatment, a direct current of high-voltage electricity is passed systemically through a metal applicator into the leaves of the weed plants down into stem and the roots of the plant (Figure 2). The main mode of action is a physical destruction of water-filled cells. The treatment is possible even on areas with a low conducting surface like gravel, sand or e.g. gaps between stone pavement or cracks in hard surfaces. Different power sources can be used (e.g., tractors with a power generator). The electric power is transformed in a special process into high-frequency (3 to 30 kHz) high voltage (4.000 to 7.000 V). Depending on their size, the large machines (3 m width, 20 modules) may require up to 100 kW in very plant-dense areas. The running speed largely depends on the density and the type of the treated plant material, the operating width and the electrical power of the available devices. To date, many Electroherb™ systems used for cleaning curbsides in Brazil are operated at a speed of

3 km/h. Plants with deep and wide rhizomes may need higher energy per plant resulting in lower speed.

Figure 6: Examples of standard and alternative methods for the control of IAPs along roadsides used in the Cost-Benefit-Analysis: (A) hot foam, (B) hand removal, (C) Electroherb^{TM} and (D) infrared (© S. Follak, F. Trognitz)

4.7 Alternative methods for the control of selected IAPs

Each control method is briefly described for the respective plant species based on the results of a literature search (Deliverable 3.1), the field trial (Deliverable 3.3) and expert judgement (stakeholder consultation, Deliverable 4.1). Information is given about the number of required treatments per year, duration of the control strategy, of the monitoring period required and the overall effectiveness.

Effectiveness was assessed as described for the standard methods (chapter 4.5).

Table 8: Overview about the effectiveness of the alternative methods for the control of *Heracleum mantegazzianum*, *Fallopia* spp. and *Ambrosia artemisiifolia*

Species	**Method**	**Effectiveness**		
		Low = increase/spread of population	Medium = suppression of population	High = eradication of population
Heracleum mantegazzianum				
	Pelargonic acid		X	
	Electroherb™		X	
Fallopia spp.				
	Pelargonic acid		X	
	Hot foam		X	
	Electroherb™		X	
Ambrosia artemisiifolia				
	Competitive seed mixture	X		
	Pelargonic acid			X
	Hot foam			X
	Infrared			X
	Electroherb™			X

4.7.1 *Heracleum mantegazzianum*

It is recommended that the control methods are applied for five years and the managed area should be monitored for at least eight years after treatment as pointed out in chapter 4.5.1. The following two alternative methods have been selected:

Pelargonic acid
The active ingredient pelargonic acid has been chosen, because it is proposed as an alternative to glyphosate due to its non-selectivity and it is commercially widely available. Unfortunately, studies on the effect of pelargonic acid on *H. mantegazzianum* are limited (e.g. Cheng 2014). Pelargonic acid is - in contrast to glyphosate - not a systemic herbicide and only the aboveground parts of the weed are destroyed ("burndown effect"). Regrowth in particular of mature plants and perennial plant species (like *H. mantegazzianum*) will most likely occur (Webber III et al. 2014). In general, multiple applications of pelargonic acid are needed to attain a high efficacy and should be applied to small individuals (Barker & Postrak 2014). Moreover, a good spray coverage of *H. mantegazzianum* populations is essential for the control effort (plants continue growing from unsprayed parts of the plant). Thus, for the CEA, it is suggested to apply pelargonic acid at least three times per year over five consecutive years. However, due to the mentioned limitations (perennial character, sufficient spray coverage) it is presumed that *H. mantegazzianum* populations can only be controlled moderately (effectiveness = 'medium').

Electroherb™

H. mantegazzianum can be suppressed by this method (M. Eberius, pers. comm. 2019). Emerging seedlings and young plants (i.e. in the 1st year of development) can be killed effectively with one treatment as the growth cone is sufficiently near to the soil surface. Plants should be treated in June when younger plants and plants from seeds have emerged and are already larger than the surrounding vegetation. Large and older plants (2nd year and older) are more difficult to handle, thus a second treatment may be necessary (M. Eberius, pers. comm. 2019). Thus, the effectiveness of this method is considered to be ‘medium’.

Table 9: Overview on alternative methods for the control of *Heracleum mantegazzianum*, the required number of applications, recommended duration of the treatment and monitoring and the effectiveness of the method

Method	**Number of treatments per year**	**Duration of management [year]**	**Duration of monitoring [year]**	**Effectiveness [%]**
Pelargonic acid	3	5	8	medium
Electroherb™	2	5	8	medium

4.7.2 *Fallopia* spp.

It is recommended that the control methods are be applied for five years and the managed area should be monitored for at least eight years after treatment as pointed out in chapter 4.3.2. The following three alternative methods have been selected:

Pelargonic acid

Studies on the effect of pelargonic acid on *Fallopia* spp. are rather limited (e.g. Nowak 2015). Perennial species will regrow within several weeks after application of pelargonic acid (e.g. Webber III et al. 2014). Thus, regrowth of *Fallopia* spp. will occur. Nowak (2015) showed that *Fallopia* spp. populations were not sufficiently controlled under field conditions along roadsides (New York/USA) when applied one time in a year (July). Thus, multiple applications of pelargonic acid are needed to attain a high efficacy (height: 10 to 15 cm, adequate spray coverage is essential). For the CEA, it is suggested to apply pelargonic acid at least four times per year over five consecutive years. However, it is expected that the pelargonic acid treatment would only result in a containment, but not in a significant reduction or a complete control of *Fallopia* spp. (effectiveness = ‘medium’).

Hot foam

In the field trial 2019, hot foam (Foamstream, http://www.weedingtech.com) was tested and the results indicated that *Fallopia* spp. was considerably affected by two applications (Deliverable 3.3). Certainly, the results of the field trial do not allow any assertion about long-term effects on *Fallopia* spp. However, for the CEA, it is assumed that three applications of hot foam during the growing period can prevent *Fallopia* spp and thus, the effectiveness is classified as medium.

Electroherb™

Based on the field trials in 2018 and 2019 (Deliverable 3.3), the following strategy is recommended: *Fallopia* spp. population should be mulched the first two years before the first treatment with Electroherb™ (height 10 to 30 cm). *Fallopia* spp. populations show noticeable damage immediately after the Electroherb™ application and aboveground shoots die within a few days. However, regrowth from the belowground rhizomes occurs and a second treatment is necessary to attain a high efficacy. Certainly, the results of the field trial do not allow any assertion about long-term effects on *Fallopia* spp. However, it is assumed, if this control strategy is applied for five years, the population of *Fallopia* spp. can be supressed (effectiveness = 'medium').

Table 10: Overview on alternative methods for the control of *Fallopia* spp., their required number of applications, recommended duration of the treatment and monitoring and the effectiveness of the method

Method	Number of treatments per year	Duration of management [year]	Duration of monitoring [year]	Effectiveness [%]
Pelargonic acid	4	5	8	medium
Hot foam	3	5	8	medium
Electroherb™	3*	5	8	medium

*includes mulching before the first treatment with Electroherb™ the first two years

4.7.3 *Ambrosia artemisiifolia*

It is recommended that the control methods are applied for five years (except the method "competitive seed mixture") and the managed area should be monitored for at least eight years after treatment as pointed out in chapter 4.3.3. The following five alternative methods have been selected:

<u>Competitive seed mixture</u>
In this treatment, a seed mixture is seeded in order to suppress emergence and development of *A. artemisiifolia*. The seed mixture is sown only once in the first year. Before sowing, a seedbed preparation is carried out to ensure efficient germination of the seed mixture.

In the field trial 2019, the effect of a competitive seed mixture on *A. artemisiifolia* has been tested (Deliverable 3.3). However, germination of the seed mixture was very poor most likely due to the unfavourable weather conditions (drought) and thus, the effect on *A. artemisiifolia* was negligible. The magnitude of impact on IAPs by competing seed mixtures is highly variable (e.g. Schuster et al. 2018) and due to the results of the field trial, the effectiveness of this method is considered to be 'low'.

<u>Pelargonic acid</u>
A. artemisiifolia populations can be effectively controlled by pelargonic acid. Highest efficacy is achieved when pelargonic acid is applied at an early growth stage (i.e. 4-leaf stage) as demonstrated by Waßmuth & Verschwele (2009). However, *A. artemisiifolia* typically occurs in different developmental stages along roadsides under practical conditions. Older individuals will most likely re-sprout and a second treatment is necessary. Results of the field trial showed a high efficacy on *A. artemisiifolia* when applied two times (spot treatment) (Deliverable 3.3). Thus, it is recommended to apply the herbicide at least twice a year for five consecutive years. The effectiveness is classified as 'high' because *A. artemisiifolia* is prevented from seed ripening.

<u>Hot foam</u>
The principle of thermal control is that temperatures above 60°C destroy the plant cells (protein denaturation). This impact causes an irreversible damage of the plant leaves and leads to necrosis. Hot foam keeps the heat and allows a better penetration (e.g. compared to hot water). In the field trial 2019, hot foam (Foamstream, http://www.weedingtech.com) was tested and the results indicated that *A. artemisiifolia* was destroyed after one application (Deliverable

3.3). The effectiveness is classified as 'high' because *A. artemisiifolia* is prevented from seed ripening.

<u>Infrared</u>

A. artemisiifolia populations can be controlled by infrared (InfraWeeder http://www.infraweeder.ch/) as demonstrated in the field trial even at different developmental stages of *A. artemisiifolia* (Deliverable 3.3.). However, the field trial showed that individual plants regenerated after one application (in particular when applied at a late developmental stage), thus, it is recommended to apply this method twice during the growing period. The effectiveness can be classified as 'high', because *A. artemisiifolia* is prevented from seed ripening.

<u>Electroherb™</u>

Preliminary results from the field trial in 2018 showed an effective control of *A. artemisiifolia* as individuals were completely destroyed and no re-sprouting was observed. The results of the field trial in 2019 underlined the high efficacy of this method (Deliverable 3.3). The effectiveness is classified as 'high', because *A. artemisiifolia* is prevented from seed ripening.

Table 11: Overview on alternative methods for the control of *Ambrosia artemisiifolia*, their required number of applications, recommended duration of the treatment and monitoring and the effectiveness of the method

Method	**Number of treatments per year**	**Duration of management [year]**	**Duration of monitoring [year]**	**Effectiveness [%]**
Competitive seed mixture	1	1	8	low
Pelargonic acid	2	5	8	high
Hot foam	1	5	8	high
Infrared	2	5	8	high
Electroherb™	1	5	8	high

5 Costs

5.1 General framework

For the calculation of the costs to control/eradicate invasive alien plants along road infrastructure some general information and assumptions are needed to define a general cost framework that is relevant for all different control/eradication methods. This enables a costs comparison under equal circumstances.

Relevant cost components for all methods are:

- Investment costs for material that is needed for carrying out the different control measures.

  As described in chapter 3 CEA uses yearly cost values (for a certain period to be defined). Investment costs are not used directly but have to be depreciated depending on their economic life span.

- Running costs for the use of required machines (energy, machine maintenance and similar)
- Additional costs depending on the method (transport, disposal, chemicals, seeds and similar)
- Personnel costs for operating the method
- Personnel costs for monitoring

As described in chapter 3 a CEA calculates costs as an actual cash value for a certain time period. Rajmis et al (2016) suggest a time period of 10 years to validate different methods for controlling *H. mantegazzianum* and a social discount rate [1] between 1 and 3% (based on Florio and Sirtori 2013, Drupp et al. 2015). Based on this the actual cash values in this study are calculated for ten years with an average social discount rate of 2%. Calculations with 1% and 3% have been made but are not presented in this report since the relevant cost comparison between methods does not differ with discount rates.

Costs do not only depend on cost values but also on the size of the treatment area and plants per area:

- It is assumed that road operators are responsible for an area of 3 metres beside the road. This value can differ between road types and countries, and it is used here to compare the different methods. Changing this value also changes the comparison results of the method because some methods are more cost intensive per area unit than others. Therefore, a variation of the treatment width (1 metre and 10 metres) is included in the scenario calculations.
- For plant density an upper and a lower value per selected IAP is used to compare the different methods. Connecting these plant densities with the workload (plants per hour), the type of control method and type of IAP results in a minimum and a maximum duration of effort per road km (see chapter 5.3 and 5.4), depending on the control method and type of IAP.

In addition to this the number/frequency of applications per year is very important. Discussion in the literature, different information on this from stakeholder discussion and within the

[1] is the discount rate used in computing the value of money spent on public projects.

stakeholder workshop show, that this treatment frequency differs especially regarding mulching and mowing of *Fallopia* spp. Therefore, additional calculations have been done for mulching and mowing of *Fallopia* spp. to check if the variation of the treatment frequency of these control methods leads to other results and suggestions.

To use a duration value per road km (in hours) it is necessary to define the different cost values per cost components in costs per hour. Compiled prices have to be recalculated to EUR/hour, if literature and other sources for prices (stakeholder consultation, price lists of companies offering products on the market, price calculation estimates of different agricultural institutions) present prices per different units (EUR/area, EUR/volume). This is done using the above mentioned information on area definition plus information on treatment depth (differentiated per method; see chapter 5.3 and 5.4).

5.2 Data and information sources

Cost benefit observations are based on a broad set of information and data from different sources. Some information and data are well documented. Some are based on the expert judgement of the project team due to a lack of existing literature or other available resources.

Expert judgement includes the results of the field trials conducted within the project as well as the two rounds of stakeholder integration (a first round via an online survey and a second round via expert interviews by phone) to include a broader expert judgment regarding the information that is not based on literature and other external data sources.

The following table presents sources used for the different input values for calculating the costs of the application of different control methods.

Table 12: Data and information sources

Data	Source
Unit cost values for machines	Kuratorium für Technik und Bauwesen in der Landwirtschaft , KTBL (https://www.ktbl.de/home/) Zasso GmbH Weedingtech Ltd. Brühwiler Baterswil
Unit values for labour costs	Austrian collective contract for road workers https://www.kollektivvertrag.at/kv/strassengesellschaften-ang/strassengesellschaften-rahmen/279124?term=strassengesellschaften
Unit costs for additional products (e.g. herbicides) and services (e.g. transport, disposal)	Homepages of different providers: https://www.my-hammer.de/preisradar/was-kostet-gruenschnitt-entsorgen/ https://www.unkrautvernichter-shop.de Zasso GmbH Weedingtech Ltd.

Number of necessary treatments (depending on kind of IAP and control method)	Expert judgment of the project team (AGES, AIT, ZASSO) also based on field trials, information gathered via stakeholder consultations
Duration of one treatment per road-km	Expert judgment of the project team (AGES, AIT, ZASSO), Information of different providers (weedingtech, Brühwiler Baterswil), information gathered via stakeholder consultations
Treatment width along road	Information gathered via stakeholder consultations, talks with road operators (especially in Burgenland during field trials)
Qualitative assessment of damages caused by IAPs differentiated by user categories and relevance of damage for the road operator	Expert judgment of the project team (Herry Consult) based on literature and information gathered via stakeholder consultations Reinhardt F, Herle M, Bastiansen F and Streit B (2003): Economic Impact of the Spread of Alien Species in Germany, Frankfurt/Main, 2003 Rajmis S., Thiele J., Marggraf R. (2016): A cost-benefit analysis of controlling giant hogweed (*Heracleum mantegazzianum*) in Germany using a choice experiment approach. NeoBiota 31, 19–41. Säumel I, Weber F, Kowarik I (2016): Toward livable and healthy urban streets: Roadside vegetation provides ecosystem services where people live and move, Berlin 2016.
Effectiveness of methods (effectiveness of eradication, if the particular strategy is used under "optimal" conditions)	Expert judgement of the project team (AGES, AIT, ZASSO) based on field trials (within the project), expert knowledge and literature
Number of years of necessary treatments to reach the this (above) effectiveness	Expert judgement of the project team (AGES, AIT, ZASSO) based on field trials (within the project), expert knowledge and literature
Number of years of monitoring (after end of treatment to ensure the long-term effect)	Expert judgement of the project team (AGES, AIT, ZASSO) based on field trials (within the project), expert knowledge and literature

5.3 Standard methods

For the relevant standard methods (see chapter 4.2) the following cost information (costs per hour) are relevant (for machine costs the values represent the total depreciation and operation costs):

Table 13: Cost components of standard methods

Standard methods Cost components and their costs/hour (EUR/h)											
Method		Labor	Tractor	Mower	Medium for mower	Spade	Excavator shovel	Disposal+ transport	Herbi-cides	Machines for spraying	Carrier for spraying machine
source		1)	KTBL 2)	KTBL, own calculations	KTBL	Several price lists, own caclulations	KTBL, own calculations	Several price lists, own caclulations	Several price lists, own caclulations	KTBL, own calculations	KTBL, own calculations
Mulching	H+F+A*)	21,42	24,66	4,07	16,26	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Mowing + disposal	H+F+A*)	21,42	24,66	4,07	16,26	n.a.	n.a.	76,77	n.a.	n.a.	n.a.
Hand removal + disposal	H+F*)	21,42	n.a.	n.a.	n.a.	2,52	n.a.	5,37	n.a.	n.a.	n.a.
	A*)	21,42	n.a.	n.a.	n.a.	2,80	n.a.	5,97	n.a.	n.a.	n.a.
Digging + disposal	F*)	21,42	24,66	n.a.	n.a.	n.a.	419,34	291,21	n.a.	n.a.	n.a.
Herbicides (glyphosate)	H+F+A*)	21,42	24,66	n.a.	n.a.	n.a.	n.a.	n.a.	10,58	0,015	6,15
*) H: *H. mantegazzianum* F: *Fallopia* spp. A: *A. artemisiifolia*								n.a. not applicable			
1) https://www.kollektivvertrag.at/kv/: Ø wage for road workers (collective agreement in Austria for road operators, Group C, 3-4 years work expirience)											
2) Kuratorium für Technik und Bauwesen in der Landwirtschaft (German institue for technique and constructure in agriculure)											

The presented values will differ from country to country. This is especially true for wages. With the excel-based cost calculation model developed for this project it is possible to calculate country-specific costs per method. This can be done upon request and by provision of country specific cost values per hour.

The presented costs have to be linked with the yearly treatments required and the duration of one treatment for one kilometre of roadside. Both the number of treatments and duration depend on the kind of IAP, the width of the roadside being treated and the plant density. As described above calculations have been done with different widths of treatment and plant density to show the range of possible results.

In addition to the direct costs of control/eradication it is necessary to monitor the controlled areas after control/eradication activities. This has to be done several years after the "final" control/eradication activity. As long as these monitoring activities are within the ten years of the CEA-time horizon, the costs of these activities have to be considered and planned for.

The following tables show the relevant input data regarding number of treatments per year, duration of the treatment, number of controls after the "final" control/eradication activity and duration of this monitoring (detailed information: see chapter 4.5).

Table 14: Cost calculation - Input data for *Heracleum mantegazzianum* for the different scenarios minimal (MIN), main (MAIN) and maximal (MAX)

H. mantegazzianum													
Method	Number of treat-ments per year	Duration per treatment in hours (per street kilometre, one side of the street)			Treatment width (m)			Treat-ment depth (m)	Controll efforts (prevention of reestablishment)				Proba-bility of 100% eradi-cation
		MIN	**MAIN**	MAX	MIN	**MAIN**	MAX		Number of years with full efforts	Number of years for monitoring after treatment	Number of monitoring per year	Efforts per monitoring (hours per year per street-km and side of the street)	
Mulching	3	0,2	0,6	2,0	1	3	10	n.a	5	8	1	0,5	me-dium
Mowing + disposal	3	0,2	0,6	2,0	1	3	10	n.a	5	8	1	0,5	me-dium
Hand removal (uprooting) +	1	2,0	5,9	19,8	1	3	10	0,2	1	8	1	0,5	high
Digging + disposal	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Herbicides (glyphosate)	3	0,2	0,6	2,0	1	3	10	n.a	5	8	1	0,5	high

n.a. not applicable

Table 15: Cost calculation - Input data for *Fallopia* spp. for the different scenarios minimal (MIN), main (MAIN) and maximal (MAX)

Fallopia spp.													
Method	Number of treat-ments per year	Duration per treatment in hours (per street kilometre, one side of the street)			Treatment width (m)			Treat-ment depth (m)	Controll efforts (prevention of reestablishment)				Proba-bility of 100% eradi-cation
		MIN	**MAIN**	MAX	MIN	**MAIN**	MAX		Number of years with full efforts	Number of years for monitoring after treatment	Number of monitoring per year	Efforts per monitoring (hours per year per street-km and side of the street)	
Mulching	4	0,3	0,8	2,6	1	3	10	n.a	10	8	1	0,75	low
Mowing + disposal	4	0,3	0,8	2,6	1	3	10	n.a	7	8	1	0,75	me-dium
Hand removal (uprooting) +	8	2,6	7,7	25,8	1	3	10	0,2	7	8	1	0,75	me-dium
Digging + disposal	1	1,3	3,9	12,9	1	3	10	2,0	1	8	1	0,75	high
Herbicides (glyphosate)	2	0,3	0,8	2,6	1	3	10	n.a	3	8	1	0,75	me-dium

n.a. not applicable

In addition to the presented scenarios additional calculations with eight treatments per year for mulching and mowing have been done in case of *Fallopia* spp.

Table 16: Cost calculation - Input data for *Ambrosia artemisiifolia* for the different scenarios minimal (MIN), main (MAIN) and maximal (MAX)

Ambrosia artemisiifolia													
Method	Number of treat-ments per year	Duration per treatment in hours (per street kilometre, one side of the street)			Treatment width (m)			Treat-ment depth (m)	Controll efforts (prevention of reestablishment)				Proba-bility of 100% eradi-cation
									Number of years with full efforts	Number of years for monitoring after treatment	Number of monitoring per year	Efforts per monitoring (hours per year per street-km and side of the street)	
		MIN	**MAIN**	MAX	MIN	**MAIN**	MAX						
Mulching	3	0,2	0,5	1,8	1	3	10	n.a	10	8	1	0,75	me-dium
Mowing + disposal	3	0,2	0,5	1,8	1	3	10	n.a	7	8	1	0,75	me-dium
Hand removal (uprooting) +	1	1,8	5,3	17,8	1	3	10	0,1	7	8	1	0,75	high
Digging + disposal	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Herbicides (glyphosate)	1	0,2	0,5	1,8	1	3	10	n.a	3	8	1	0,75	high
n.a. not applicable													

The yearly costs are calculated by linking the unit costs with the information on treatment efforts. The number of years requiring treatment, the number of monitoring years, the social discount rate and the time horizon of ten years are the basis for calculating the bar value of the costs over ten years per method and selected IAP. The following tables show the costs calculated for the three scenarios:

- Minimum scenario: low plant density, 1 m treatment width
- Main scenario: medium plant density, 3 m treatment width
- Maximum scenario: high plant density, 10 m treatment width

Table 17: Costs and net present value of costs – standard methods, *Heracleum mantegazzianum* for the different scenarios minimal (Min), main (Main) and maximal (Max)

Control/eradication of ***H. mantegazzianum*** **Costs and net present value of costs** for 10 years Main **Results Standard Methods** (3m treatment width, medium plant density) Results of Sensitivity Analysis Standard methods (1m and 10m treatment width, minimum and maximum plant density)																
EUR pro road-km of one road side		Mulching			Mowing + disposal			Hand removal (uprooting) + disposal			Digging + disposal			Herbicides (glyphosate)		
		Min	Main	Max	Min	Main	Max	Min	Main	Max	Min	Main	Max	Min	Main	Max
Operation	Labor	6	191	1.212	6	191	1.212	4	127	808	n.a	n.a	n.a	6	191	1.212
	Tractor	7	220	1.396	7	220	1.396	0	0	0	n.a	n.a	n.a	7	220	1.396
	Mower	1	36	230	1	36	230	0	0	0	n.a	n.a	n.a	0	0	0
	Carrier for mower	5	145	920	5	145	920	0	0	0	n.a	n.a	n.a	0	0	0
	Spade	0	0	0	0	0	0	0	15	95	n.a	n.a	n.a	0	0	0
	Excavator shovel	0	0	0	0	0	0	0	0	0	n.a	n.a	n.a	0	0	0
	Disposal+ transport	0	0	0	22	684	4.346	1	32	203	n.a	n.a	n.a	0	0	0
	Herbicides	0	0	0	0	0	0	0	0	0	n.a	n.a	n.a	3	94	599
	Machines for spraying	0	0	0	0	0	0	0	0	0	n.a	n.a	n.a	0	0	1
	Carrier für spraying machine	0	0	0	0	0	0	0	0	0	n.a	n.a	n.a	2	55	348
Moni-toring	Labor	54	54	54	54	54	54	86	86	86	n.a	n.a	n.a	54	54	54
Total costs (10 years)		72	646	3.812	94	1.330	8.158	91	260	1.192	n.a	n.a	n.a	71	614	3.610
Net present value (2% discount rate)		65	616	3.661	94	1.330	8.158	84	253	1.185	n.a	n.a	n.a	64	585	3.466
n.a. not applicable																

Looking at the main calculation scenario the lowest cost within the CEA time horizon of ten years to treat *H. mantegazzianum* can be achieved by applying the hand removal method. This is mainly due to the fact, that this method has to be applied only in the first year (monitoring activities (included in the costs) after treatment ensure the control of emerging plants). Only in case of the minimum scenario (low plant density, only 1 m of treatment area along roads) the use of herbicides causes the lowest costs. In this case the costs for machines (tractor, carrier and spraying machine) are very low due to the short necessary working time.

Table 18: Costs and net present value of costs – standard methods, *Fallopia* spp. for the different scenarios minimal (min), main (main) and maximal (max)

Control/eradication of ***Fallopia* spp.** **Costs and net present value of costs** for 10 years Main **Results Standard Methods** (3m treatment width, medium plant density) Results of Sensitivity Analysis Standard methods (1m and 10m treatment width, minimum and maximum plant density																
EUR pro road-km of one road side		Mulching			Mowing + disposal			Hand removal (uprooting) + disposal			Digging + disposal			Herbicides (glyphosate)		
		min	main	max	min	main	max	min	main	max	min	main	max	min	main	max
Operation	Labor	21	662	4.203	15	463	2.942	294	9.267	58.840	3	83	525	3	99	630
	Tractor	24	762	4.839	17	533	3.387	0	0	0	3	95	605	4	114	726
	Mower	3	97	614	2	68	430	0	0	0	0	0	0	0	0	0
	Carrier for mower	16	503	3.191	11	352	2.233	0	0	0	0	0	0	0	0	0
	Spade	0	0	0	0	0	0	3	105	667	0	0	0	0	0	0
	Excavator shovel	0	0	0	0	0	0	0	0	0	51	1.620	10.286	0	0	0
	Disposal+ transport	0	0	0	41	1.278	8.112	57	1.789	11.356	36	1.125	7.143	0	0	0
	Herbicides	0	0	0	0	0	0	0	0	0	0	0	0	1	38	240
	Machines for spraying	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Carrier für spraying machine	0	0	0	0	0	0	0	0	0	0	0	0	1	22	139
Moni-toring	Labor	0	0	0	48	48	48	48	48	48	129	129	129	112	112	112
Total costs (10 years)		64	2.023	12.846	134	2.742	17.152	403	11.209	70.911	221	3.052	18.687	121	386	1.848
Net present value (2% discount rate)		59	1.854	11.770	122	2.582	16.171	375	10.567	66.869	210	3.041	18.676	108	368	1.802

Looking at the main calculation scenario the lowest cost within the CEA time horizon of ten years to treat *Fallopia* spp. can be achieved by applying herbicides. This is mainly due to the fact that this method only needs to be used twice a year and only for three years (compared to the other standard methods which take 7 to 10 years except digging + disposal). The cost advantage of herbicides increases with the plant density and the treatment width. Only in the areas of very low plant density and 1 m treatment width along roads is the mulching method somewhat cheaper than the use of herbicides.

When applying 8 instead of 4 treatments per year for mulching and mowing, the costs (net present value) for these two control methods are also doubled. If this higher number of treatments per year is applied, mulching has no longer the lowest costs in the minimum scenario.

Table 19: Costs and net present value of costs – standard methods, *Ambrosia artemisiifolia* for the different scenarios minimal (min), main (main) and maximal (max)

Control/eradication of ***A. artemisiifolia*** **Costs and net present value** of costs for 10 years Main **Results Standard Methods** (3m treatment width, medium plant density) Results of Sensitivity Analysis Standard methods (1m and 10m treatment width, minimum and maximum plant density																
EUR pro road-km of one road side		Mulching			Mowing + disposal			Hand removal (uprooting) + disposal			Digging + disposal			Herbicides (glyphosate)		
		min	main	max	min	main	max	min	main	max	min	main	max	min	main	max
Operation	Labor	5	172	1.091	5	172	1.091	18	573	3.637	n.a	n.a	n.a	2	57	364
	Tractor	6	198	1.256	6	198	1.256	0	0	0	n.a	n.a	n.a	2	66	419
	Mower	1	36	230	1	36	230	0	0	0	n.a	n.a	n.a	0	0	0
	Carrier for mower	4	130	828	4	130	828	0	0	0	n.a	n.a	n.a	0	0	0
	Spade	0	0	0	0	0	0	2	75	476	n.a	n.a	n.a	0	0	0
	Excavator shovel	0	0	0	0	0	0	0	0	0	n.a	n.a	n.a	0	0	0
	Disposal+ transport	0	0	0	22	684	4.346	5	160	1.014	n.a	n.a	n.a	0	0	0
	Herbicides	0	0	0	0	0	0	0	0	0	n.a	n.a	n.a	1	31	200
	Machines for spraying	0	0	0	0	0	0	0	0	0	n.a	n.a	n.a	0	0	0
	Carrier für spraying machine	0	0	0	0	0	0	0	0	0	n.a	n.a	n.a	1	18	116
Moni-toring	Labor	54	54	54	54	54	54	54	54	54	n.a	n.a	n.a	54	54	54
Total costs (10 years)		71	590	3.460	92	1.274	7.805	79	861	5.181	n.a	n.a	n.a	59	227	1.152
Net present value (2% discount rate)		63	562	3.322	84	1.221	7.500	71	823	4.977	n.a	n.a	n.a	52	213	1.103
n.a. not applicable																

For *A. artemisiifolia* in all cases the use of herbicides is the cheapest method. It has to be applied only one time a year for 5 years. All other relevant methods need a treatment for the full-time horizon of the CEA (10 years).

5.4 Alternative methods

For the relevant alternative methods (see chapter 4.6) the following cost information (costs per hour) are relevant (for machine costs the values represent the total of depreciation and operation costs):

Table 20: Cost components of alternative methods

Alternative methods Cost components and their costs/hour (EUR/h)									
		Labor	Tractor	Spade	Disposal+ transport	Machines for spraying	Carrier for spraying machine	Pelargonic acid	Foam-stream fixed costs
Source		1)	KTBL 2)	Several price lists, own caclulations	Several price lists, own caclulations	KTBL, own calculations	KTBL, own calculations	Several price lists, own caclulations	Wedding-tech, own caclulations
Natural products (Pelargonic acid)	H*)	21,42	24,66	n.a.	n.a.	0,015	6,15	195,47	n.a.
	F*)	21,42	24,66	n.a.	n.a.	0,012	4,73	150,36	n.a.
	A*)	21,42	24,66	n.a.	n.a.	0,017	6,83	217,19	n.a.
Thermal control (Hot foam)	A*)	21,42	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	24,97
Infrared	A*)	21,42	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Electroherb (Zasso)	A,H*)	21,42	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	F*)	21,42	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Competitive seed mixture	A*)	21,42	n.a.	2,80	5,97	n.a.	n.a.	n.a.	n.a.

		Foam+ Diesel	Pick-Up (small truck) (f+v)	Infra weeder fixed costs	Propan-gas	Mulching bevor electro-herb	Zasso-unit + tractor (f+v)	Seed mixture
source		Wedding-tech, own caclulations	KTBL 2)	Infraweeder, own caclulations	Several price lists, own caclulations	Zasso KTBL, own calculations	Zasso, own caclulations	Several price lists, own caclulations
Natural products (Pelargonic acid)	H*)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	F*)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	A*)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Thermal control (Hot foam)	A*)	27,47	16,86	n.a.	n.a.	n.a.	n.a.	n.a.
Infrared	A*)	n.a.	n.a.	6,27	2,45	n.a.	n.a.	n.a.
Electroherb (Zasso)	A,H*)	n.a.	n.a.	n.a.	n.a.	0,00	315,00	n.a.
	F*)	n.a.	n.a.	n.a.	n.a.	66,41	360,00	n.a.
Competitive seed mixture	A*)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	79,92

*) H: *H. mantegazzianum* F: *Fallopia* spp. A: *A. artemisiifolia*

n.a. not applicable

1) https://www.kollektivvertrag.at/kv/: Ø wage for road workers (collective agreement in Austria for road operators, Group C, 3-4 years work expirience)

2) Kuratorium für Technik und Bauwesen in der Landwirtschaft (German institue for technique and constructure in agriculure)

Table 21: Cost calculation, alternative methods - Input data for *Heracleum mantegazzianum* for the different scenarios minimal (MIN), main (MAIN) and maximal (MAX)

H. mantegazzianum													
Method	Number of treat-ments per year	Duration per treatment in hours (per street kilometre, one side of the street)			Treatment width (m)			Treat-ment depth (m)	Controll efforts (prevention of reestablishment)				Proba-bility of 100% eradi-cation
		MIN	**MAIN**	MAX	MIN	**MAIN**	MAX		Number of years with full efforts	Number of years for monitoring after treatment	Number of monitoring per year	Efforts per monitoring (hours per year per street-km and side of the street)	
Natural products	3	0,2	0,6	2,0	1	3	10	n.a	5	8	1	0,5	me-dium
Thermal control (Hot foam)	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Infrared	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Electroherb (Zasso)	2	0,3	0,3	1,3	1	3	10	n.a	5	8	1	0,5	me-dium
Competitive seed mixture	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	-
n.a. not applicable													

Table 22: Cost calculation, alternative methods - Input data for *Fallopia* spp. for the different scenarios minimal (MIN), main (MAIN) and maximal (MAX)

***Fallopia* spp.**													
Method	Number of treat-ments per year	Duration per treatment in hours (per street kilometre, one side of the street)			Treatment width (m)			Treat-ment depth (m)	Controll efforts (prevention of reestablishment)				Proba-bility of 100% eradi-cation
		MIN	**MAIN**	MAX	MIN	**MAIN**	MAX		Number of years with full efforts	Number of years for monitoring after treatment	Number of monitoring per year	Efforts per monitoring (hours per year per street-km and side of the street)	
Natural products	4	0,3	0,8	2,6	1	3	10	n.a	5	8	1	0,75	me-dium
Thermal control (Hot foam)	3	1,9	5,7	19,0	1	3	10	n.a	5	8	1	0,75	me-dium
Infrared	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Electroherb (Zasso)	3	0,3	0,3	1,3	1	3	10	n.a	5	8	1	0,75	me-dium
Competitive seed mixture	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
n.a. not applicable													

Table 23: Cost calculation, alternative methods - Input data for *Ambrosia artemisiifolia* for the different scenarios minimal (MIN), main (MAIN) and maximal (MAX)

A. artemisiifolia													
Method	Number of treat-ments per year	Duration per treatment in hours (per street kilometre, one side of the street)			Treatment width (m)			Treat-ment depth (m)	Controll efforts (prevention of reestablishment)				Proba-bility of 100% eradi-cation
		MIN	**MAIN**	MAX	MIN	**MAIN**	MAX		Number of years with full efforts	Number of years for monitoring after treatment	Number of monitoring per year	Efforts per monitoring (hours per year per street-km and side of the street)	
Natural products	2	0,2	0,5	1,8	1	3	10	n.a	5	8	1	0,5	high
Thermal control (Hot foam)	1	1,9	5,7	19,0	1	3	10	n.a	5	8	1	0,5	high
Infrared	2	2,0	6,0	20,0	1	3	10	n.a	5	8	1	0,5	high
Electroherb (Zasso)	1	0,3	0,3	1,3	1	3	10	n.a	5	8	1	0,5	high
Competitive seed mixture	1	1,9	5,6	18,8	1	3	10	n.a	1	8	1	0,5	low

n.a. not applicable

Table 24: Costs and net present value of costs – alternative methods, *Heracleum mantegazzianum* for the different scenarios minimal (Min), main (Main) and maximal (Max)

Control/eradication of ***H. mantegazzianum*** **Costs and net present value of costs** for 10 years Main **Results Alternative Methods** (3m treatment width, medium plant density) Results of Sensitivity Analysis Standard methods (1m and 10m treatment width, minimum and maximum plant density																
EUR pro road-km of one road side		Natural products (Pelargonic acid)			Thermal control (Hot foam)			Infrared			Electroherb (Zasso)			Competitive seed mixture		
		Min	Main	Max	Min	Main	Max	Min	Main	Max	Min	Main	Max	Min	Main	Max
Operation	Labor	6	191	1.212	n.a	n.a	n.a	n.a	n.a	n.a	71	71	286	n.a	n.a	n.a
	Tractor (f+v)	7	220	1.396	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
	Spade (f+v)	0	0	0	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
	Disposal+ transport	0	0	0	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
	Machines for spraying (f+v)	0	0	1	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
	Carrier für spraying machine (f+v)	2	55	348	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
	Pelargonic acid	55	1.743	11.064	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
	Foam-stream fixed costs	0	0	0	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
	Foam+ Diesel	0	0	0	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
	Pick-Up (small truck) (f+v)	0	0	0	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
	Infrared weeder fixed costs	0	0	0	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
	Propan-gas	0	0	0	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
	Mulching before	0	0	0	n.a	n.a	n.a	n.a	n.a	n.a	13	158	2.506	n.a	n.a	n.a
	Zasso unit + tractor	0	0	0	n.a	n.a	n.a	n.a	n.a	n.a	1.050	1.050	4.200	n.a	n.a	n.a
	Seed mixture	0	0	0	n.a	n.a	n.a	n.a	n.a	n.a	0	0	0	n.a	n.a	n.a
Moni-toring	Labor	54	54	54	n.a	n.a	n.a	n.a	n.a	n.a	54	54	54	n.a	n.a	n.a
Total costs (10 years)		124	2.262	14.075	n.a	n.a	n.a	n.a	n.a	n.a	1.187	1.333	7.045	n.a	n.a	n.a
Net present value (2% discount rate)		114	2.170	13.529	n.a	n.a	n.a	n.a	n.a	n.a	1.137	1.281	6.769	n.a	n.a	n.a
n.a. not applicable																

The use of natural products for the treatment of *H. mantegazzianum* is only cheaper if the minimum scenario (1 m treatment width, low plant density) is relevant. If the plant density or the treatment width is increasing the use of the alternative Electroherb^{TM} method is cheaper than the use of natural products. This caused by the rather high costs of the pelargonic acid per area. An increase of the area leads therefore to high costs for pelargonic acid.

Table 25: Costs and net present value of costs – alternative methods, *Fallopia* spp. for the different scenarios minimal (min), main (main) and maximal (max)

Control/eradication of ***Fallopia* spp.**
Costs and net present value of costs for 10 years
Main **Results Alternative Methods** (3m treatment width, medium plant density)
Results of Sensitivity Analysis Standard methods (1m and 10m treatment width, minimum and maximum plant density

EUR pro road-km of one road side		Natural products (Pelargonic acid)			Thermal control (Hot foam)			Infrared			Electroherb (Zasso)			Competitive seed mixture		
		min	main	max	min	main	max	min	main	max	min	main	max	min	main	max
Operation	Labor	11	331	2.101	459	1.836	7.649	n.a.	n.a.	n.a.	107	107	428	n.a.	n.a.	n.a.
	Tractor (f+v)	12	381	2.419	0	0	0	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
	Spade (f+v)	0	0	0	0	0	0	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
	Disposal+ transport	0	0	0	0	0	0	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
	Machines for spreading (f+v)	0	0	1	0	0	0	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
	Carrier für spreading machine (f+v)	2	73	464	0	0	0	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
	Pelargonic acid	74	2.324	14.753	0	0	0	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
	Foam-stream fixed costs	0	0	0	535	2.140	8.917	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
	Foam+ Diesel	0	0	0	589	2.354	9.810	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
	Pick-Up (small truck) (f+v)	0	0	0	361	1.445	6.021	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
	Infrared weeder fixed costs	0	0	0	0	0	0	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
	Propan-gas	0	0	0	0	0	0	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
	Mulching before	0	0	0	0	0	0	n.a.	n.a.	n.a.	24	303	4.817	n.a.	n.a.	n.a.
	Zasso unit + tractor	0	0	0	0	0	0	n.a.	n.a.	n.a.	1.800	1.800	7.200	n.a.	n.a.	n.a.
	Seed mixture	0	0	0	0	0	0	n.a.	n.a.	n.a.	0	0	0	n.a.	n.a.	n.a.
Moni-toring	Labor	80	80	80	80	80	80	n.a.	n.a.	n.a.	80	80	80	n.a.	n.a.	n.a.
Total costs (10 years)		179	3.189	19.819	2.024	7.856	32.478	n.a.	n.a.	n.a.	2.011	2.291	12.526	n.a.	n.a.	n.a.
Net present value (2% discount rate)		165	3.059	19.050	1.939	7.547	31.222	n.a.	n.a.	n.a.	1.927	2.204	12.037	n.a.	n.a.	n.a.

n.a. not applicable

The use of natural products for the treatment of *Fallopia* spp. is only cheaper if the minimum scenario (1 m treatment width, low plant density) is applicable. If the plant density or the treatment width is increasing the use of the alternative Electroherb^{TM} method is cheaper than the use of natural products. This is caused by the rather high costs of the pelargonic acid per area. An increase of the area leads therefore to high costs for pelargonic acid.

Table 26: Costs and net present value of costs – alternative methods, *Ambrosia artemisiifolia* for the different scenarios minimal (min), main (main) and maximal (max)

Control/eradication of ***A. artemisiifolia*** **Costs and net present value** of costs for 10 years Main **Results Alternative Methods** (3m treatment width, medium plant density) Results of Sensitivity Analysis Standard methods (1m and 10m treatment width, minimum and maximum plant density																
EUR pro road-km of one road side		Natural products (Pelargonic acid)			Thermal control (Hot foam)			Infrared			Electroherb (Zasso)			Competitive seed mixture		
		min	main	max	min	main	max	min	main	max	min	main	max	min	main	max
Operation	Labor	4	115	727	153	612	2.550	428	1.285	4.284	36	36	143	4	121	766
	Tractor (f+v)	4	132	838	0	0	0	0	0	0	0	0	0	0	0	0
	Spade (f+v)	0	0	0	0	0	0	0	0	0	0	0	0	1	16	100
	Disposal+ transport	0	0	0	0	0	0	0	0	0	0	0	0	1	34	213
	Machines for spreading (f+v)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
	Carrier für spreading machine (f+v)	1	37	232	0	0	0	0	0	0	0	0	0	0	0	0
	Pelargonic acid	37	1.162	7.376	0	0	0	0	0	0	0	0	0	0	0	0
	Foam-stream fixed costs	0	0	0	178	713	2.972	0	0	0	0	0	0	0	0	0
	Foam+ Diesel	0	0	0	196	785	3.270	0	0	0	0	0	0	0	0	0
	Pick-Up (small truck) (f+v)	0	0	0	120	482	2.007	0	0	0	0	0	0	0	0	0
	Infrared weeder fixed costs	0	0	0	0	0	0	125	376	1.255	0	0	0	0	0	0
	Propan-gas	0	0	0	0	0	0	49	147	490	0	0	0	0	0	0
	Mulching before	0	0	0	0	0	0	0	0	0	6	72	1.135	0	0	0
	Zasso unit + tractor	0	0	0	0	0	0	0	0	0	525	525	2.100	0	0	0
	Seed mixture	0	0	0	0	0	0	0	0	0	0	0	0	14	450	2.857
Moni-toring	Labor	54	54	54	54	54	54	54	54	54	54	54	54	96	96	96
Total costs (10 years)		99	1.498	9.227	702	2.645	10.853	656	1.862	6.082	620	686	3.432	116	716	4.033
Net present value (2% discount rate)		91	1.436	8.868	670	2.539	10.431	641	1.823	5.960	591	657	3.295	109	709	4.026
n.a. not applicable																

Also, for *A. artemisiifolia* the same statements as for the two other analysed plants is true although a broader number of alternative methods are applicable for this IAP.

6 Benefits

6.1 General framework

The benefits of controlling / eradicating IAPs can be defined as benefits for the relevant stakeholder compared to the situation without controlling / eliminating IAPs (doing nothing). This means that potential damage that can be avoided by using control methods and therefore does not occur must be assessed. This assessed non-occurring damage represents the advantage of using these control methods for the relevant stakeholders. This advantage is taken into account in the CEA and compared to the costs of using the control methods (in order to avoid / reduce the occurrence of damage).

Therefore, it is first necessary to identify different categories of damages that occur due to the appearance and spread of IAPs.

The main stakeholders / parties / persons who are potentially affected by IAPs can be broken down into the following categories:

- Road operators (main focus of this project)
- Agricultural sector
- Humans
- Environment

When IAPs are controlled/eradicated along roadsides direct effects appear only along roads, because anywhere else plants are not directly treated. Therefore, mainly road operators profit directly from such control measures. All other parties may only be indirectly affected due to the reduction of spread.

In addition, it is necessary to estimate the effectiveness of the different control methods (standard and alternative methods) within the chosen CEA time frame of ten years. The effectiveness influences the reduction of damage due to IAPs. The more effective a control method is, the better the damage can be reduced and the greater the benefits of the control method.

This measure of effectiveness is presented in terms of qualitative description for standard methods in Table 5, Table 6 and Table 7 and for alternative methods in Table 9, Table 10 and Table 11.

6.2 Benefit categories and benefits

Based on a literature review and discussions with road operators (along with the output of the guided interviews conducted within the project) the main categories for the affected parties (see chapter 6.1) have been identified:

- Road operators (main focus of this project) (results of discussion with road operators)
    - Damage to road surface / pavements
    - Damage to road signs (incl. reduction of sight due to overgrowing)
    - Damage to road embankments and curbs
    - Allergic diseases and skin irritation for road workers
- Agriculture (Reinhardt et al 2003)

    - Reduction of crops
    - Reduction of livestock
- Humans (Reinhardt et al 2003, Rajmis et al 2016)
    - Allergic disease
    - Skin irritations, burns by direct contact
- Environment (Säumel et al. 2016)
    - Reduction of biodiversity and native plants
    - Reduction of ecosystem services (noise protection, air quality, temperature regulation, shielding function etc.)

An additional benefit of the reduction of IAPs along roads for the road operators is the resulting reduction of efforts for the general plant management. At the stage of applying one of the various control methods, this application replaces the standard operating procedure. This is true for all methods and therefore no difference occurs between the applications of different control methods. Costs for plant management are in general treated as part of the cost comparison of different methods and therefore included in the cost part and not in the benefit part. This avoids double counting on both sides of the cost benefit valuation.

Benefits (respective damages) can be presented in monetary values (quantitative, cardinal ranking) or in qualitative values (ordinal ranking). For pure CEA (see chapter 3) it is necessary to have monetary values for all benefit categories. This enables a direct comparison with costs and the derivation of a cost benefit ratio.

However, it is not possible to monetize all damages caused by IAPs along roads because of the following reasons:

- Direct effects of controlling/eradicating IAPs appear only along roads (but not overall in a certain region, because control measures are not implemented in the whole region) and the indirect effects are therefore not quantifiable.
- Direct damage on road infrastructure (see first three damage categories in Table 27) and its costs depend on the road type and its structure as well as the IAP density along road sides. Literature analysis could not identify average costs per road kilometre due to such damage types.

Therefore, benefits are presented in an ordinal scale differentiated by damage type and the three selected IAPs. An additional attribute to be considered for the specific focus of this project is the relevance of the different damage types for road issues (and therefore for road operators).

The ordinal valuation is based on a literature review on damages due to IAPs in general and for the three selected IAPs specifically (see chapter 10 for information on used literature). A two-step stakeholder consultation (online questionnaire and personal interviews by phone done in WP 5.1) complemented the literature analysis.

The following table shows the ordinal ranking of the damage categories per selected IAP based on a three-stage scale.

The table presents three different assessment scores per damage type:

- Damage range: Values the damage of this damage type by a three-step ordinal scale independent of the affected parties and therefore not necessary relevant for the road operators

- Relevance for road issues: relevance of the damage type for the road operator measured with a three-step ordinal scale. Not all damage types are of interest for road operators.
- Overall relevance for road: this is the overall damage assessment for road operators per damage type. It is derived by multiplying the damage range with the range for "relevance for road issues".

The total damage score relevant for road operators per IAP (last row of the following table) is derived by adding up the values of the "overall relevance for road" per damage type. Following the first paragraph of this subchapter these values present damages of IAPs for road operators if no control/eradication measures are implemented along roads. This damage value is equal to the benefit of using a control method that allows 100% eradication of the IPAs (having no damages any more).

Table 27: Damage types and damage ranges

Assignment of damage types to IAP including estimation of damage range (qualitative 0 to 2) and relevance of damage type for road issues (0 to 2)				
Type of damage due to IAP		*H. mantegazzianum*	*Fallopia* spp.	*A. artemisiifolia*
Damage to road surface / pavements	damage range (qualitative)	0	1	0
	relevance for road issues	2	2	2
	Overall relevance for road	**0**	**2**	**0**
Damage to road signs (incl. reduction of sight due to overgrowing)	damage range (qualitative)	1	1	0
	relevance for road issues	2	2	2
	Overall relevance for road	**2**	**2**	**0**
Damage to road embankments	damage range (qualitative)	1	2	1
	relevance for road issues	2	2	2
	Overall relevance for road	**2**	**4**	**2**
Reduction of crops (agriculture)	damage range (qualitative)	0	1	2
	relevance for road issues	0	0	0
	Overall relevance for road	**0**	**0**	**0**
Reduction of livestock (agriculture)	damage range (qualitative)	0	0	0
	relevance for road issues	0	0	0
	Overall relevance for road	**0**	**0**	**0**
Allergic disease	damage range (qualitative)	0	0	2
	relevance for road issues	1	1	1
	Overall relevance for road	**0**	**0**	**2**
Skin irritations, burns by direct contact	damage range (qualitative)	2	0	0
	relevance for road issues	1	1	1
	Overall relevance for road	**2**	**0**	**0**
Reduction of biodiversity and native plants	damage range (qualitative)	1	2	0
	relevance for road issues	1	1	1
	Overall relevance for road	**1**	**2**	**0**
Reduction of ecosystem services	damage range (qualitative)	1	2	1
	relevance for road issues	0	0	0
	Overall relevance for road	**0**	**0**	**0**
Total benefit value (regarding road issues) assuming 100% effectiviness of method		**7**	**10**	**4**

6.3 *Side effects of standard and alternative methods*

Herbicides have raised public concern because of their impacts on human health and the environment. Side effects can occur on non-target organisms, especially on those that live in the aquatic or in the soil environment. Herbicide control programs are most likely to negatively impact native species (Kettenring & Adams 2011). **Mowing/mulching** and **digging/hand pulling** are believed to cause fewer side effects. However, large-scale excavations (e.g. for *Fallopia* spp. control) are a major impact on the environment as they leave an area of exposed soil. High frequent mowing/mulching may have an impact on plant species richness along roadsides and invertebrates (Jakobsson et al. 2018).

The proposed alternative methods have also side effects on the environment and non-target organism. **Pelargonic acid** is a compound of low toxicity and low environmental impact (Dayan et al. 2009) as it decomposes rapidly in both land and water environments. However, it is marketed as a herbicide and products containing pelargonic acid must be used following the instructions on the label and in line with the relevant plant protection product regulations. Pelargonic acid is a non-selective herbicide and could harm non-target plants if spray drifts beyond the intended target area.

Thermal heating methods provide rapid weed control without leaving chemical residues in the soil and water. Some of the methods have been evaluated for side effects. For example, Rahkonen et al. (1999) showed that flame weeding led to 19 % reduction in soil microbial biomass at 0–5 mm depth. In a study from Dierauer & Pfiffner (1993), there was no effect of flame weeding on carabid beetles. In the case of flame weeding, Ascard et al. (2007) concluded that a significant damage to the soil microflora or fauna is not likely under practical conditions.

Unfortunately, studies on the effects of **infrared and hot foam** on non-target organisms are not available (Ascard et al. 2007). Hot foam is considered to be a technique with limited risks to the environment (Wei et al. 2010). Nevertheless, both hot foam and infrared could be detrimental to some soil-surface-inhabiting organisms (e.g. carabid beetles, spiders). Because the thermal treatment of the hot foam and infrared is short-term, only the topmost few millimeters of the soil may be heated. Thus, significant damage to the soil microflora may not to be expected.

Unfortunately, there are no studies available about possible side effects on non-target organisms of the Electroherb™ method. However, preliminary results suggest that insects are presumably less affected by the Electroherb™ method compared to hot water (Deliverable 3.3).

7 Cost benefit comparison

Costs for the implementation of different methods to control/eradicate IAPs are presented in monetary values in chapter 5. Damages of IAPs if no control/eradication measures are implemented along roads are presented in terms of an ordinal scale in Table 27. The linkage of costs and benefits is necessary for an overall validation of the different methods. To be able to link monetary values with a qualitative assessment (ordinal ranking) two possibilities exist (see chapter 3):

- Transforming the costs (monetary values) into normative utility values comparable with the values of the ordinal scale of the benefits (see description of the value benefit analysis in chapter 3) or
- Direct connection of benefit values and monetary costs by calculating the cost effectiveness (division of benefit values with monetary cost values) (see description of the cost effectiveness analysis in chapter 3). Results of this step are benefit values per costs.

For the evaluation of the control methods the second valuation method was chosen since costs have been calculated accurately and the second valuation method enables the direct use of these calculated costs without reducing the information quality.

To evaluate the benefits of the different control methods the damage score has to be linked to the effectiveness of the different methods. Again a four-level ordinal scale is used to value the effectiveness of the different methods (after 10 years of method implementation) for the three selected IAPs (see Table 5 until Table 11).

The valuation of effectiveness per method and IAP is based on a literature review (for standard methods and partly also for alternative methods) and on results of the greenhouse and field trials of the project (for alternative methods). Due to the fact that the greenhouse trials as well as the field trials performed in this project are not long-term studies, results of these trials give only a rough estimate on the effectiveness. Improved and solid estimates of the effectiveness of the different methods need further field trials with a longer time span for statistical observations as well as a broader test setting at more locations (with different conditions regarding the main variables like weather, soil etc.).

The following scale is used for classifying the effectiveness of control methods (based on information of chapter 4:

- “High”: 90%-100% effectiveness of eradication, if the particular strategy is used under "optimal" conditions: The particular strategy is highly effective and leads to a nearly or even complete eradication of the respective IAP within the managed area.
- “Medium”: 50-89% effectiveness of eradication, if the particular strategy is used under "optimal" conditions: The particular strategy is moderately effective and leads to a containment (i.e., population does not further spread) of the respective IAP within the managed area.
- “Low”: Below 50% effectiveness of eradication, if the particular strategy is used under "optimal" conditions: The particular strategy is poorly effective and it is likely that the respective IAP is not sufficiently controlled and spreads further after treatment within the managed area.

The following table presents the derivation of benefit values (relevant for road operators) per costs for the reviewed standard control methods including the expected range of the benefits due to the sensitivity analysis. This sensitivity analysis has been worked out regarding

- the costs (depending on the treatment width and plant density) and
- the effectiveness of control methods (after ten years of method implementation)

Table 28: Benefit values per costs, standard methods for the different scenarios minimal (min), main (main) and maximal (max)

Benefit values (relevant for road operators) per costs Measures for control of invasiv alian plants along roads Costs: netpresent value (discount rate: 2%) in EUR for a time of 10 years per road-km for one side of the road																
		Standard methods														
		Mulching			Mowing + disposal			Hand removal + disposal			Digging + disposal			Herbicides (glyphosate)		
		min	main	max	min	main	max	min	main	max	min	main	max	min	main	max
H. mantegazzianum	Benfit value (reduction of damage relevant for road operators)	7	7	7	7	7	7	7	7	7	n.a	n.a	n.a	7	7	7
	Effectiviness of method (after 10 years, optimal conditions)	me-dium	me-dium	me-dium	me-dium	me-dium	me-dium	high	high	high	n.a	n.a	n.a	high	high	high
	Average achievable benefit value	3,5	4,6	6,0	3,5	4,6	6,0	6,3	6,7	7,0	n.a	n.a	n.a	6,3	6,7	7,0
	Costs of measure (EUR)	65	616	3.661	94	1.330	8.158	84	253	1.185	n.a	n.a	n.a	64	585	3.466
	Benfit value per 1.000 EUR costs	**54,1**	**7,4**	**1,6**	**37,2**	**3,4**	**0,7**	**75,0**	**26,3**	**5,9**	n.a	n.a	n.a	**98,9**	**11,4**	**2,0**
Fallopia spp.	Benfit value (reduction of damage relevant for road operators)	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
	Effectiviness of method (after 10 years, optimal conditions)	low	low	low	me-dium	me-dium	me-dium	me-dium	me-dium	me-dium	high	high	high	me-dium	me-dium	me-dium
	Average achievable benefit value	1,5	3,0	4,5	5,0	6,5	8,5	5,0	6,5	8,5	9,0	9,5	10,0	5,0	6,5	8,5
	Costs of measure (EUR)	59	1.854	11.770	122	2.582	16.171	375	10.567	66.869	210	3.041	18.676	108	368	1.802
	Benfit value per 1.000 EUR costs	**25,5**	**1,6**	**0,4**	**41,1**	**2,5**	**0,5**	**13,3**	**0,6**	**0,1**	**42,8**	**3,1**	**0,5**	**46,1**	**17,7**	**4,7**
A. artemisiifolia	Benfit value (reduction of damage relevant for road operators)	4	4	4	4	4	4	4	4	4	n.a	n.a	n.a	4	4	4
	Effectiviness of method (after 10 years, optimal conditions)	me-dium	me-dium	me-dium	me-dium	me-dium	me-dium	high	high	high	n.a	n.a	n.a	high	high	high
	Average achievable benefit value	2,0	2,6	3,4	2,0	2,6	3,4	3,6	3,8	4,0	n.a	n.a	n.a	3,6	3,8	4,0
	Costs of measure (EUR)	63	562	3.322	84	1.221	7.500	71	823	4.977	n.a	n.a	n.a	52	213	1.103
	Benfit value per 1.000 EUR costs	**31,7**	**4,6**	**1,0**	**23,8**	**2,1**	**0,5**	**50,5**	**4,6**	**0,8**	n.a	n.a	n.a	**69,3**	**17,8**	**3,6**
n.a. not applicable																

When applying eight instead of four treatments per year for mulching and mowing, the costs (net present value) for these two control methods are also doubled. This cost increase halves the cost benefit ratio (benefit value per 1.000 EUR) for these two control methods.

Table 29: Benefit values per costs, alternative methods for the different scenarios minimal (min), main (main) and maximal (max)

Benefit values (relevant for road operators) per costs Measures for control of invasiv alian plants along roads Costs: netpresent value (discount rate: 2%) in EUR for a time of 10 years per road-km for one side of the road																
		Alternative methods														
		Natural products (Pelargonic acid)			Thermal control (Hot foam)			Infrared			Electroherb (Zasso)			Competitive seed mixture		
		min	main	max	min	main	max	min	main	max	min	main	max	min	main	max
H. mantegazzianum	Benfit value (reduction of damage relevant for road operators)	7	7	7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	7	7	7	n.a.	n.a.	n.a.
	Effectiveness of method (after 10 years, optimal conditions)	me-dium	me-dium	me-dium	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	me-dium	me-dium	me-dium	n.a.	n.a.	n.a.
	Average achievable benefit value	3,5	4,6	6,0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	3,5	4,6	6,0	n.a.	n.a.	n.a.
	Costs of measure (EUR)	114	2.170	13.529	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	1.137	1.281	6.769	n.a.	n.a.	n.a.
	Benfit value per 1.000 EUR costs	**30,7**	**2,1**	**0,4**	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	**3,1**	**3,6**	**0,9**	n.a.	n.a.	n.a.
Fallopia spp.	Benfit value (reduction of damage relevant for road operators)	10	10	10	10	10	10	n.a.	n.a.	n.a.	10	10	10	n.a.	n.a.	n.a.
	Eeffectiveness of method (after 10 years, optimal conditions)	me-dium	me-dium	me-dium	me-dium	me-dium	me-dium	n.a.	n.a.	n.a.	me-dium	me-dium	me-dium	n.a.	n.a.	n.a.
	Average achievable benefit value	5,0	6,5	8,5	8,5	8,5	8,5	n.a.	n.a.	n.a.	5,0	6,5	8,5	n.a.	n.a.	n.a.
	Costs of measure (EUR)	165	3.059	19.050	1.939	7.547	31.222	n.a.	n.a.	n.a.	1.927	2.204	12.037	n.a.	n.a.	n.a.
	Benfit value per 1.000 EUR costs	**30,3**	**2,1**	**0,4**	**4,4**	**1,1**	**0,3**	n.a.	n.a.	n.a.	**2,6**	**2,9**	**0,7**	n.a.	n.a.	n.a.
A. artemisiifolia	Benfit value (reduction of damage relevant for road operators)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	Effectiveness of method (after 10 years, optimal conditions)	high	high	high	high	high	high	high	high	high	high	high	high	low	low	low
	Average achievable benefit value	3,6	3,8	4,0	3,6	3,8	4,0	3,6	3,8	4,0	3,6	3,8	4,0	0,6	1,2	1,8
	Costs of measure (EUR)	91	1.436	8.868	670	2.539	10.431	626	1.786	5.843	591	657	3.295	109	709	4.026
	Benfit value per 1.000 EUR costs	**39,7**	**2,6**	**0,5**	**5,4**	**1,5**	**0,4**	**5,7**	**2,1**	**0,7**	**6,1**	**5,8**	**1,2**	**5,5**	**1,7**	**0,4**
n.a. not applicable																

To give a better comparison and better decision-making regarding the use of different methods for the selected IAPs the following tables show the main results of the cost benefits trials per IAP including all analysed methods.

Table 30: Benefit values per costs, *Heracleum mantegazzianum*

Control/eradiction of ***H. mantegazzianum*** Benefit values (relevant for road operators) per costs Measures for control of invasive alien plants along roads Costs: netpresent value (discount rate: 2%) in EUR for a time of 10 years per road-km for one side of the road										
		Low plant density 1m treatment width upper efficiency level			Medium plant density 3m treatment width medium efficiency level			High plant density 10m treatment width low efficiency level		
		Average achievable benefit value (for road operators)	Costs (EUR)	**Benfit value per 1.000 EUR costs**	Average achievable benefit value (for road operators)	Costs (EUR)	**Benfit value per 1.000 EUR costs**	Average achievable benefit value (for road operators)	Costs (EUR)	**Benfit value per 1.000 EUR costs**
Standard methods	Mulching	3,5	65	**54,1**	4,6	616	**7,4**	6,0	3.661	**1,6**
	Mowing + disposal	3,5	94	**37,2**	4,6	1.330	**3,4**	6,0	8.158	**0,7**
	Hand removal + disposal	6,3	84	**75,0**	6,7	253	**26,3**	7,0	1.185	**5,9**
	Digging + disposal	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Herbicides (glyphosate)	6,3	64	**98,9**	6,7	585	**11,4**	7,0	3.466	**2,0**
Alternative Methods	Natural pro-ducts (Pelargo-nic acid)	3,5	114	**30,7**	4,6	2.170	**2,1**	6,0	13.529	**0,4**
	Thermal control (Hot foam)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Infrared	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Electroherb (Zasso)	3,5	1.137	**3,1**	4,6	1.281	**3,6**	6,0	6.769	**0,9**
	Competitive seed mixture	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
n.a. not applicable										

The above results give the following ranking for the relevant benefit values per costs for the different methods:

Table 31: Ranking of methods, *Heracleum mantegazzianum*

Control/eradiction of ***H. mantegazzianum*** **Ranking of benfits, costs and benefits per costs** Benefit values (relevant for road operators) per costs Measures for control of invasive alien plants along roads Costs: netpresent value (discount rate: 2%) in EUR for a time of 10 years per road-km for one side of the road				
		Low plant density 1m treatment width upper efficiency level	Medium plant density 3m treatment width medium efficiency level	High plant density 10m treatment width low efficiency level
		Benfit value per 1.000 EUR costs	**Benfit value per 1.000 EUR costs**	**Benfit value per 1.000 EUR costs**
Standard methods	Mulching	**3**	**3**	**3**
	Mowing + disposal	**4**	**5**	**5**
	Hand removal + disposal	**2**	**1**	**1**
	Digging + disposal	n.a.	n.a.	n.a.
	Herbicides (glyphosate)	**1**	**2**	**2**
Alternative Methods	Natural pro-ducts (Pelargo-nic acid)	**5**	**6**	**6**
	Thermal control (Hot foam)	n.a.	n.a.	n.a.
	Infrared	n.a.	n.a.	n.a.
	Electroherb (Zasso)	**6**	**4**	**4**
	Competitive seed mixture	n.a.	n.a.	n.a.

n.a. not applicable

For *H. mantegazzianum* the use of alternative methods leads to a degradation of the cost-benefit ratio compared to the standard methods herbicides and hand removal (including disposal). The hand removal method is the best alternative to the application of herbicides for scenario 1 and even the best method for scenario 2 and 3.

Table 32: Benefit values per costs, *Fallopia* spp.

Control/eradiction of ***Fallopia* spp.** Benefit values (relevant for road operators) per costs Measures for control of invasive alien plants along roads Costs: netpresent value (discount rate: 2%) in EUR for a time of 10 years per road-km for one side of the road										
		Low plant density 1m treatment width upper efficiency level			Medium plant density 3m treatment width medium efficiency level			High plant density 10m treatment width low efficiency level		
		Average achievable benefit value (for road operators)	Costs (EUR)	**Benfit value per 1.000 EUR costs**	Average achievable benefit value (for road operators)	Costs (EUR)	**Benfit value per 1.000 EUR costs**	Average achievable benefit value (for road operators)	Costs (EUR)	**Benfit value per 1.000 EUR costs**
Standard methods	Mulching	1,5	59	**25,5**	3,0	1.854	**1,6**	4,5	11.770	**0,4**
	Mowing + disposal	5,0	122	**41,1**	6,5	2.582	**2,5**	8,5	16.171	**0,5**
	Hand removal + disposal	5,0	375	**13,3**	6,5	10.567	**0,6**	8,5	66.869	**0,1**
	Digging + disposal	9,0	210	**42,8**	9,5	3.041	**3,1**	10,0	18.676	**0,5**
	Herbicides (glyphosate)	5,0	108	**46,1**	6,5	368	**17,7**	8,5	1.802	**4,7**
Alternative Methods	Natural pro-ducts (Pelargo-nic acid)	5,0	165	**30,3**	6,5	3.059	**2,1**	8,5	19.050	**0,4**
	Thermal control (Hot foam)	8,5	1.939	**4,4**	8,5	7.547	**1,1**	8,5	31.222	**0,3**
	Infrared	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Electroherb (Zasso)	5,0	1.927	**2,6**	6,5	2.204	**2,9**	8,5	12.037	**0,7**
	Competitive seed mixture	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
n.a. not applicable										

The above results give the following ranking for the relevant benefit value per costs per method:

Table 33: Ranking of methods, *Fallopia* spp.

<table>
<tr><td colspan="5">Control/eradiction of Fallopia spp.
Ranking of benfits, costs and benefits per costs
Benefit values (relevant for road operators) per costs
Measures for control of invasive alien plants along roads
Costs: netpresent value (discount rate: 2%) in EUR for a time of 10 years per road-km for one side of the road</td></tr>
<tr><td colspan="2" rowspan="2"></td><td>Low plant density
1m treatment width
upper efficiency level</td><td>Medium plant density
3m treatment width
medium efficiency level</td><td>High plant density
10m treatment width
low efficiency level</td></tr>
<tr><td>Benfit value per 1.000 EUR costs</td><td>Benfit value per 1.000 EUR costs</td><td>Benfit value per 1.000 EUR costs</td></tr>
<tr><td rowspan="5">Standard methods</td><td>Mulching</td><td>5</td><td>6</td><td>6</td></tr>
<tr><td>Mowing + disposal</td><td>3</td><td>4</td><td>4</td></tr>
<tr><td>Hand removal + disposal</td><td>6</td><td>8</td><td>8</td></tr>
<tr><td>Digging + disposal</td><td>2</td><td>2</td><td>3</td></tr>
<tr><td>Herbicides (glyphosate)</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td rowspan="5">Alternative Methods</td><td>Natural pro-ducts (Pelargo-nic acid)</td><td>4</td><td>5</td><td>5</td></tr>
<tr><td>Thermal control (Hot foam)</td><td>7</td><td>7</td><td>7</td></tr>
<tr><td>Infrared</td><td>n.a.</td><td>n.a.</td><td>n.a.</td></tr>
<tr><td>Electroherb (Zasso)</td><td>8</td><td>3</td><td>2</td></tr>
<tr><td>Competitive seed mixture</td><td>n.a.</td><td>n.a.</td><td>n.a.</td></tr>
<tr><td colspan="5">n.a. not applicable</td></tr>
</table>

For *Fallopia* spp. the best cost benefit ratio can be reached with the use of herbicides in all scenarios. The best control method (instead of the use of herbicides) differs between scenarios. For the minimum and the main scenario, the application of digging (+disposal) leads to the best cost benefit ration beside the use of herbicides. For the maximum scenario the application of the Electroherb™ method leads to the best cost benefit ration beside the use of herbicides.

When applying eight instead of four treatments per year for mulching and mowing, these two methods lose at least one ranking position in all scenarios (due to the fact that the cost benefit ratio is halved).

Table 34: Benefit values per costs, *Ambrosia artemisiifolia*

Control/eradiction of ***A. artemisiifolia***
Benefit values (relevant for road operators) per costs
Measures for control of invasive alien plants along roads
Costs: netpresent value (discount rate: 2%) in EUR for a time of 10 years per road-km for one side of the road

		Low plant density 1m treatment width upper efficiency level			Medium plant density 3m treatment width medium efficiency level			High plant density 10m treatment width low efficiency level		
		Average achievable benefit value (for road operators)	Costs (EUR)	**Benfit value per 1.000 EUR costs**	Average achievable benefit value (for road operators)	Costs (EUR)	**Benfit value per 1.000 EUR costs**	Average achievable benefit value (for road operators)	Costs (EUR)	**Benfit value per 1.000 EUR costs**
Standard methods	Mulching	2,0	63	**31,7**	2,6	562	**4,6**	3,4	3.322	**1,0**
	Mowing + disposal	2,0	84	**23,8**	2,6	1.221	**2,1**	3,4	7.500	**0,5**
	Hand removal + disposal	3,6	71	**50,5**	3,8	823	**4,6**	4,0	4.977	**0,8**
	Digging + disposal	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Herbicides (glyphosate)	3,6	52	**69,3**	3,8	213	**17,8**	4,0	1.103	**3,6**
Alternative Methods	Natural pro-ducts (Pelargo-nic acid)	3,6	91	**39,7**	3,8	1.436	**2,6**	4,0	8.868	**0,5**
	Thermal control (Hot foam)	3,6	670	**5,4**	3,8	2.539	**1,5**	4,0	10.431	**0,4**
	Infrared	3,6	626	**5,7**	3,8	1.786	**2,1**	4,0	5.843	**0,7**
	Electroherb (Zasso)	3,6	591	**6,1**	3,8	657	**5,8**	4,0	3.295	**1,2**
	Competitive seed mixture	0,6	109	**5,5**	1,2	709	**1,7**	1,8	4.026	**0,4**

n.a. not applicable

The above results give the following ranking for the relevant benefit value per costs per method:

Table 35: Ranking of methods, *Ambrosia artemisiifolia*

Control/eradiction of ***A. artemisiifolia*** **Ranking of benfits, costs and benefits per costs** Benefit values (relevant for road operators) per costs Measures for control of invasive alien plants along roads Costs: netpresent value (discount rate: 2%) in EUR for a time of 10 years per road-km for one side of the road				
		Low plant density 1m treatment width upper efficiency level	Medium plant density 3m treatment width medium efficiency level	High plant density 10m treatment width low efficiency level
		Benfit value per 1.000 EUR costs	**Benfit value per 1.000 EUR costs**	**Benfit value per 1.000 EUR costs**
Standard methods	Mulching	**4**	**3**	**3**
	Mowing + disposal	**5**	**6**	**6**
	Hand removal + disposal	**2**	**4**	**4**
	Digging + disposal	n.a.	n.a.	n.a.
	Herbicides (glyphosate)	**1**	**1**	**1**
Alternative Methods	Natural products (Pelargonic acid)	**3**	**5**	**7**
	Thermal control (Hot foam)	**9**	**9**	**9**
	Infrared	**7**	**7**	**5**
	Electroherb (Zasso)	**6**	**2**	**2**
	Competitive seed mixture	**8**	**8**	**8**
n.a. not applicable				

For *A. artemisiifolia* the standard method of herbicide use has the best cost-benefit ratio in all scenarios. The selection of the best alternative depends on scenario: For the minimum scenario (low plant density, 1m treatment area along the roadside and upper effectiveness (within the selected effectiveness class)) the application of hand removal including disposal is the best alternative. For all other scenarios the Electroherb^{TM} method is the best alternative to the use of herbicides.

Summing up the detailed results on costs, benefits and the linkage of these two to a cost benefit ratio (expressed in benefits per 1.000 EUR costs) it is possible to suggest specific control methods that bring the highest benefits for road operators for the costs they have to bear when applying these methods.

The following table presents those two methods with the highest benefits per 1.000 EUR of costs not taking into account the use of herbicides which is in almost all cases (scenarios and plants) the method with the highest benefits per 1.000 EUR.
These two methods are therefore the best alternative for the use of herbicides.

Table 36: Recommendation of control method to be used instead of herbicides

Recommendation of control method to be used instead of herbicides (glyphosate) Based on the calulation of a cost benefit ratio (by using a cost effectiviness analysis)						
	Scenario					
	Minimum		Main		Maximum	
	Low plant density, 1m treatment width, upper value of effectiveness range (regarding effectiveness range between 90% and 100%)		Medium plant density, 3m treatment width, medium value of effectiveness range (regarding effectiveness range between 50% and 90%)		High plant density, 10m treatment width, lower value of effectiveness range (regarding effectiveness range up to 50%)	
	sugested method	Benefit per 1.000 EUR	sugested method	Benefit per 1.000 EUR	sugested method	Benefit per 1.000 EUR
H. mante-gazzianum	1. Hand removal (+disposal)	75,0	1. Hand removal (+disposal)	26,3	1. Hand removal (+disposal)	5,9
	2. Mulching	54,1	2. Mulching	7,4	2. Mulching	1,6
Fallopia spp.	1. Digging (+disposal)	42,8	1. Digging (+disposal)	3,1	1. Electroherb	0,5
	2. Mowing + dispoal	30,3	2. Electroherb	2,1	2. Digging (+disposal)	0,4
A. arte-misiifolia	1. Hand removal (+disposal)	50,5	1. Electroherb	4,6	1. Electroherb	0,8
	2. Natural products	39,7	2. Mulching	2,6	2. Mulching	0,5

The benefit values are decreasing from the minimum to the maximum scenario in all cases. This is due to the fact that costs are increasing with increasing plant density and treatment width and benefits are decreasing with decreasing efficiency.

The results show that it is important to evaluate the situation along the roads regarding plant density and to fix treatment width and treatment area before deciding upon a control method. This is true especially for *Fallopia* spp. and *A. artemisiifolia.* For these two plants the suggested control methods differ between scenarios.

8 Appraisal of results

The presented results – especially the ranking of methods to be used instead of herbicides – strongly depend on the input values for costs and benefits. The quality of the input values influences the quality of results.

Different circumstances in different countries and in more detail at specific sites can influence this input data and therefore also the results of the cost benefit valuation. The presented input values and costs are not based on specific circumstances for one specific site but are based on average values. The calculation of three scenarios aims to show the influence of the variation of input values on the results. It is therefore strongly recommended to conduct specific cost benefit valuations when deciding on the control method to be used for a specific side and a specific IAP. The result of this report can be used for pre-selection of potential methods. Those methods that are out of range regarding benefits per cost values compared to other investigated control methods can be neglected when doing cost benefit valuations for specific sites and specific IAPs.

Nevertheless, it is important to know about the weaknesses and strengths of the presented cost benefit valuation and its results. The following built points try to give an overview on these weaknesses and strengths:

- Strengths
    - The chosen cost effectiveness analysis allows a comparison of control methods on an ordinal scale. This enables a ranking of control methods as well as a statement regarding the relative difference of the cost effectiveness of methods
    - The CEA can provide assessment results without monetizing the benefits. This increases the possibility of using this analysis for the evaluation, since monetary performance values often do not exist. The presented valuation is a reliable model for assessment of control methods to be used in certain locations with certain circumstances and known specific input data. As the quality of the input data increases (due to the analysis being restricted to a particular site), liability for results increases. Input data on costs is documented very well and can be used for applying the presented CEA for specific sites.
- Weaknesses
    - The targeted comparison of the control method is only possible taking into account a period of at least 10 years. For most control methods and IAPs, there is no empirical evidence regarding the number of successive treatment years required to achieve the highest possible effectiveness. This is due to the fact that long-term field studies are missing. It is therefore necessary to make the best possible guesses, which affects the quality of the results. It is recommended to initiate such long-term studies for the most promising control methods and the most relevant IAPs.
    - The existing literature and the results of the field tests within the project do not allow a precise definition of the effectiveness of the control methods. Broad discussions at the stakeholder workshop showed different assessments of the effectiveness of control methods, even among the experts. Because effectiveness has a great impact on the final results, this uncertainty about effectiveness reduces the quality of the results. Due to the relatively high cost of performing cost-benefit assessments, it is not possible to generate assessments for a large number of different IAPs within the project. A simple

switch to other IAPs is not possible due to the need for very specific input data that differ between species. High variation of the input values (different treatment frequencies, different treatment breadth, different plant density, rather broad areas of activity) leads to a high number of possible results. The chosen way of displaying three scenarios along these variations enables the display of result ranges. In fact, a much larger number of different scenarios may be required to display all possible results.

In summary, it should be noted that the cost-benefit assessment carried out requires long-term field trials on the effects of different control methods on different IAPs under certain circumstances in order to increase the ratings to select the appropriate control method. Nevertheless, the results presented provide a good first indication of which control methods are suitable under certain circumstances (scenarios) and can serve as a starting point for detailed location-specific assessments.

9 Abbreviations, Definitions, Glossary

A	*Ambrosia artemisiifolia*
CBA	Cost benefit analysis
CEA	Cost-effectiveness analysis
D	Deliverable
F	*Fallopia* spp.
FGSV	Deutsche Forschungsgesellschaft für Straßen- und Verkehrswesen e. V. (German Road and Transportation Research Association
FSV	Österreichische Forschungsgesellschaft Straße - Schiene – Verkehr (Austrian Research Association for Roads, Railways and Transport)
h	hours
H	*Heracleum mantegazzianum*
IA	Impact analysis (or Effect analysis)
IAP	Invasive alien plant
km	kilometres
m	metres
max	maximum
min	minimum
n.a.	not applicable
RVS	Richtlinien und Vorschriften für das Straßenwesen (Guidelines and directives for road issues)
VBA	Value benefit analysis
WP	Work package

10 Sources

10.1 Deliverables

Deliverable 2.2 – List of invasive alien plants along roadsides

Deliverable 2.2 – Booklet with IAP and Description

Deliverable 3.1 – Alternative methods in road construction, operation and maintenance in relation to Invasive Alien Plants (IAPs)

Deliverable 3.2 – Greenhouse assays

Deliverable 3.3 – Field trial

Deliverable 4.2 – Best practice guide based on current practices

10.2 References

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10.3 Links

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