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Weed control on pavements

Inputs, costs and environmental impacts of weed control methods in The Netherlands and Flanders, Belgium

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Content

1. Introduction

Evea and partners will carry out a study on costs and side-effects of weed control techniques on hard surfaces. Side-effects will be evaluated with a Life Cycle Analysis (LCA). To this purpose Evea and her partners are collecting data on current weed control methods in order to quantify and compare costs and side-effects of the methods. Evea has asked Plant Research International (PRI) to deliver an overview of relevant data on current weed control methods in the Netherlands and Flanders (Belgium). Data to be delivered per method are efficacy, capacity, required frequencies in relation to target levels of control, energy and/or herbicide use and other relevant inputs. Furthermore PRI will give an overview of costs per square meter and summarize results of recent LCA's based on Dutch and Flanders data.

Considerable discussion is currently taking place in the Netherlands and Flanders on the professional and private use of pesticides in the public area. For the non-agricultural sector the Dutch government aims to ban all professional and non-professional pesticide use. This includes a prohibition on the use of herbicides on paved surfaces per November 2015. In 2003, Flanders started to phase out the use of pesticides in public areas. Since 1 January 2004, the use of herbicides on pavements was prohibited unless the municipal government submitted a reduction plan in which was motivated why the use of herbicides could not be terminated in 2015.

To generate scientific data for the discussions and debats on the use of herbicides on pavements, both in the Dutch speaking part of Belgium and in the Netherlands several studies were conducted on the efficacy, application rate, cost and environmental impact of chemical and non-chemical weed control techniques. This report summarizes the results of these studies.

2. Weed control techniques

For curative weed control on pavements a choice can be made between completely non-chemical methods, complete chemical methods, and an integrated approach with combinations of methods. All methods vary largely in efficacy, inputs and costs. In this chapter, most common weed control methods used in the Netherlands and Flanders, Belgium are described with as much as possible quantitative information

2.1 Efficacy

Common non-chemical techniques include hot water, hot air, burning (or flaming) and brushing. With these techniques only the above-ground parts of weeds are removed. Therefore, a quick regrowth can be expected and will be observed. In general, during the growing season, every 6 to 8 weeks an application of these techniques is required, depending on the weed (re)growth. These methods are only useful for mild to moderate weed growth. Only brushing machines can remove heavy weed growth.

In the Netherlands chemical pesticides (herbicides) may by law only be applied with a selective spraying equipment, such as the selectspray or Weed-IT. These techniques have sensors for weed detection on the pavements, herbicide is almost exclusively sprayed on the weeds. Controlled droplet application and weed wiper technology, when applied selectively, may be used on pavements. One or two herbicide treatments per year are generally sufficient to effectively control weed growth. Chemical pesticides control weeds both above and below ground, and are effective in situations with mild to heavy weed growth.

The required frequency of application depends on the maximum allowable level of weed covering. Municipalities in the Netherlands and Belgium often use the CROW Quality guide with five levels (A^+ , A, B, C and D) for determining the desired level of weed covering. The quality guide has recently been reviewed (CROW, 2013). The assessment criteria for weed control on pavements are percentage weed cover and number of plants higher than 20 cm (Figure 1). These criteria apply to all types of pavements.

Weed on pavements				
A+	A	B	C	D
				
There is no weed	There is little weed	There is a limited amount of weed	There is a reasonable amount of weed	There is much weed
No. of weeds higher than 20 cm	**No. of weeds higher than 20 cm**	**No. of weeds higher than 20 cm**	**No. of weeds higher than 20 cm**	**No. of weeds higher than 20 cm**
0 per 100 m²	≤ 10 per 100 m²	≤ 20 per 100 m²	≤ 30 per 100 m²	> 30 per 100 m²
Covering	**Covering**	**Covering**	**Covering**	**Covering**
0 %	≤ 2 %	≤ 4 %	≤ 8 %	> 8 %

Figure 1. CROW Quality guide with five levels (A^+ , A, B, C and D) for determining the required maximum allowable level of weed covering

In the Netherlands estimated frequencies for achieving the required level of weed covering on pavements are based on expert judgment, in which recent results of Dutch research (CROW, 2008) and practical information from the field are taken into account.

In Flanders the efficacy of various non-chemical control methods were recently determined (Boonen *et al.*, 2013). On the test site weeds were controlled by brushing, hot air, hot water, burning and two scenarios with alternating brushing and hot air during two seasons (2010-2011). In the first season the frequency for the hot water technique was lower than for the other methods. After the second season, however, the differences between techniques, more or less vanished. For each of the techniques the same number of treatments was needed to keep the weed covering at an acceptable level. The increase of the number of hot water treatments was attributed to the increase in the proportion of dandelion in time. The control of this species by the hot water technique became less effective compared to the other techniques.

All scientific data we found in studies on application frequencies in The Netherlands and Flanders are summarized in Table 1. The Dutch frequencies for achieving a B-level of weed covering (according to Figure 1, 'There is a limited amount of weed') were used for calculating costs (section 2.1) and the Life Cycle Analysis (section 3.1).

Table 1. Application frequencies for different chemical and non-chemical weed control methods in relation to the required level of weed covering on hard surfaces in the Netherlands (Van Dijk & Kempenaar, 2012) and Flanders, Belgium (Boonen et al.*, 2013).*

Method	Frequencies					
	A+	A	B	B	C	D
	Netherl.	Netherl.	Netherl.	Belgium	Netherl.	Netherl.
Brushing (full-field)	5	4.5	3.5	4-6	3	-
Burning (full-field)	10	9	7		4	-
Hor air (full-field)	10	9	7	4-5	4	-
Hot air+infra-red +hot water (full-field)	-	6	5		3	-
Hot water (selective)	-	5	3.5	2-5	2	-
Hot water (full-field)	-	5	3.5		2	-
Chemical (selective)	3	3	2.5		1	-
Brushing/hot air alternating (full-field)				4-5		

2.1 Inputs and costs 1 (The Netherlands)

For comparing costs of different weed control techniques it is important to distinguish between cost prices and market prices. For an objective comparison actual cost prices are more relevant because market prices are more sensitive to economic fluctuations.

In a recent study PRI calculated cost prices for different techniques of weed control on pavements in the Netherlands (Van Dijk & Kempenaar, 2012). A standard cost price calculation method was used, commonly used in the field of civil engineering and landscape maintenance. The calculated costs were based on the replacement value of the machines (including the carrier vehicle), resale value, depreciation, interest, repairs and maintenance, direct insurance, fuel, lubricants and other resources. For labour a standard hourly rate was used according to the collective labour agreement (CAO Hoveniers). Depending on the technique the cost item 'materials' was included into the calculation (use of fuel, replacement brushes, use of water, gas or pesticide).

Standard, pre-set input values were used for interest values and costs expressed as a percentage from the replacement value. Information about the variable inputs such as capacity, usability over the year, consumption of fuel, water or herbicide was provided by various landscaping contractors and manufacturers of weed control equipment (Table 3). Costs for transport of equipment and (traffic) safety measurements were not taken into account. These costs are mainly related to the location where the weed control should be applied and can vary widely. The cost price for brushing does not include sweeping and removal of sweeping waste, because this is often performed in combination with regular street sweeping.

The study shows that cost prices are mainly determined by the replacement value of machines, the usability over the year and capacity (ha/h). The calculated prices range from about 1 to 8 eurocents per square meter depending on the technique (Table 2).

Subsequently, the calculated costs were put in perspective for a year round weed control, assuming a required 'B-level' of weed covering. With chemical weed control the required level of weed covering can be achieved with about two applications per year. For non-chemical methods, the frequency is at least 3 to 4 applications per yea, but this estimate is probably on the conservative side. For burning and hot air frequencies from 6 to 8 occur, or higher if the required weed level is A or A+. In practice hot water is applied not more than 4 times, probably due to the relatively high costs. The calculated annual costs range from 4 till 29 eurocents per m^2 and are largely depending on the technique chosen. The results show that in 2012, when the study was conducted, there was a relatively large difference between costs for chemical and non-chemical techniques of approximately 10 cents per m^2.

The calculated cost prices were on average slightly lower than the cost of a previous inventory (CROW, 2008) based mainly on surveys of market prices (Table 2).

Table 2. Cost prices (€/m^2/year) for different weed control methods on pavements assuming a required 'B-level' of weed covering (From: Van Dijk & Kempenaar, 2012)

Weed control technique	Level of weed covering	Frequency	Cost price (€/m^2)	Cost price (€/m^2/year)	Market prices (€/m^2/year) From: CROW, 2008
Brushing (full-field)	B	3-4	0.045	0.13-0.18	0.19-0.38*
Burning (full-field)	B	6-8	0.023	0.14-0.18	0.21-0.35
Hor air (full-field)	B	6-8	0.024	0.15-0.19	-
Hot air+infra-red +hot water (full-field)	B	4-6	0.032	0.13-0.19	-
Hot water (full-field)	B	3-4	0.072	0.22-0.29	-
Hot water (selective)	B	3-4	0.053	0.16-0.21	0.22-0.32
Chemical (selective)	B	2-3	0.018**	0.04-0.05	0.05-0.08

* including € 0,02 for landfill costs

** cost price of € 0.014 with a 25% raise for using non-chemical techniques on run-off sensitive locations

Tabel 3. Input values and calculated cost prices (€/ha) for different weed control techniques on pavements (From: Van Dijk & Kempenaar, 2012).

Description	**Unit**	**Brushing**	**Burning**	**Hot air**	**Hot air+infra-red +hot water**	**Hot water**	**Hot water**	**Chemical, sensors at 20 cm**	**Chemical, sensors at 8 cm**	**Chemical, wiper**	**Chemical, controlled droplet application**
General											
Vehicle carrier		-	LM Trac	-	LM Trac	-	Egholm 2200	Quad	Quad	Stiga ready	Quad
Power	KW	37	-	35	-	264	35	-	-	-	13
Capacity	ha/hour	0.20	0.40	0.35	0.30	0.25	0.13	0.45	0.50	0.50	0.50
Application		selective	full field	full field	full field	selective	full field	selective	selective	selective	selective
Working width	Cm	-	120	100	120	-	-	100	100	100	100
Values direct costs											
Replacement value (RV)	€	67000	75000	64135	91000	155250	85000	24000	25000	12500	11000
Hours of use	Hours	500/800	500/800	500/800	500/800	500/800	500/800	500/800	500/800	500/800	500/800
Fuel consumption	liter/hour	3	3	3	2	15	7	2	2	1	2
Price of fuel	€/liter	1.05	1.05	1.05	1.05	1.05	1.05	1.50	1.50	1.50	1.50
Hours of use parts subject to wear (eg brush)	Hours	14	Not apply	Not apply	Not apply	Not apply	Not apply	Not apply	Not apply	Not apply	Not apply
acquisition value parts subject to wear	€	115	115	115	115	115	115	115	115	115	115
Water consumption	m3/hour	Not apply	Not apply	Not apply	0.1	0.8	0.7	0.012	0.005	0	0
Price of water	€/m3	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19
Gas, propane consumption	kg/hour	n.v.t.	15	12	14	n.v.t.	0	Not apply	Not apply	Not apply.	Not apply
Price of Gas, propane	€/kg	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Glyphosate consumption	liter/hour	n.v.t.	Not apply	Not apply	Not apply	Not apply	Not apply	0.54	0.42	0.33	0.50
Price glyphosate	€/liter	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Lubricants	%	10	10	10	10	10	10	10	10	10	10
Residual value	% of RV	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Depriciation	Years	7	7	7	7	7	7	7	7	7	7
inetrest[1]	% of RV	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Repair and maintenance[2]	% of RV	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
Labor maintenance	% of RV	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Insurance[3]	% of RV	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Labor	€/hour	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Values indirect costs											
Housing	€	750	750	750	750	750	750	750	750	750	750
Overhead	€x1000	10	10.0	10	10	10.0	10	10.75	10.75	10.75	10.75
business risk	%	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Price at 500 hours of use	**€/ha**	**498**	**255**	**272**	**362**	**605**	**816**	**179**	**158**	**139**	**146**
Price at 800 hours of use	**€/ha**	**392**	**199**	**214**	**277**	**454**	**628**	**149**	**130**	**116**	**124**

[1] 5.5% interest for a 5-year lone (Source: Rabo bank, 2010)

[2] An average of 5,3 % of the replacement value; variation agricultural/civil 3,9 % - 6,5 % (Source: CUMELA Kompas Analyse 2009)

[3] An average of 1,3 % of the replacement value; variation 0,7% - 2,0% (Source: CUMELA Kompas Analyse 2009)

2.2 Inputs and costs 2 (Flanders)

During the two-year efficacy test of various non-chemical weed control methods in Flanders (section 2.1) various input parameters were collected for a cost analysis (values not reported). The calculations were based on the cost of labour (fixed hourly rate), energy consumption (diesel and/or LPG), write-down of the machine (replacement value without the carrier vehicle), maintenance and insurance (as a fixed percentage of the replacement value). The processing of the sweeping and/or brushing waste was taken into account, input values were based on measurements or gathered information. The consumption inputs of the carrier vehicle was also taken into account, but not the investment itself because the carrier is interchangeable and can also be used for other purposes. In this it is different from the cost calculation by PRI, in which the investment for the carrier vehicle was included into the calculation.

The average costs per treatment for brushing, hot air (with sweeping) and alternating brushing/hot air were comparable and amounted to circa 4 cents per square meter (Figure 2). Costs were mainly determined by the costs of labour and energy, independently from the type of paving stone. The costs per treatment of selective hot water technique (with a sweeping turn) is with 5 cents per square meter about 25% higher. The higher cost is caused by a high fuel consumption and a high investment value.

The total cost per year was depending on the number of treatments needed in relation to the required level of weed covering. The average cost per year (calculated over two seasons) of € 0.20 m2 was similar for all techniques tested (Figure 3). That the total cost per year for the hot water technique was similar to that of the other non-chemical techniques could be explained by the lower number of treatments in the first season.

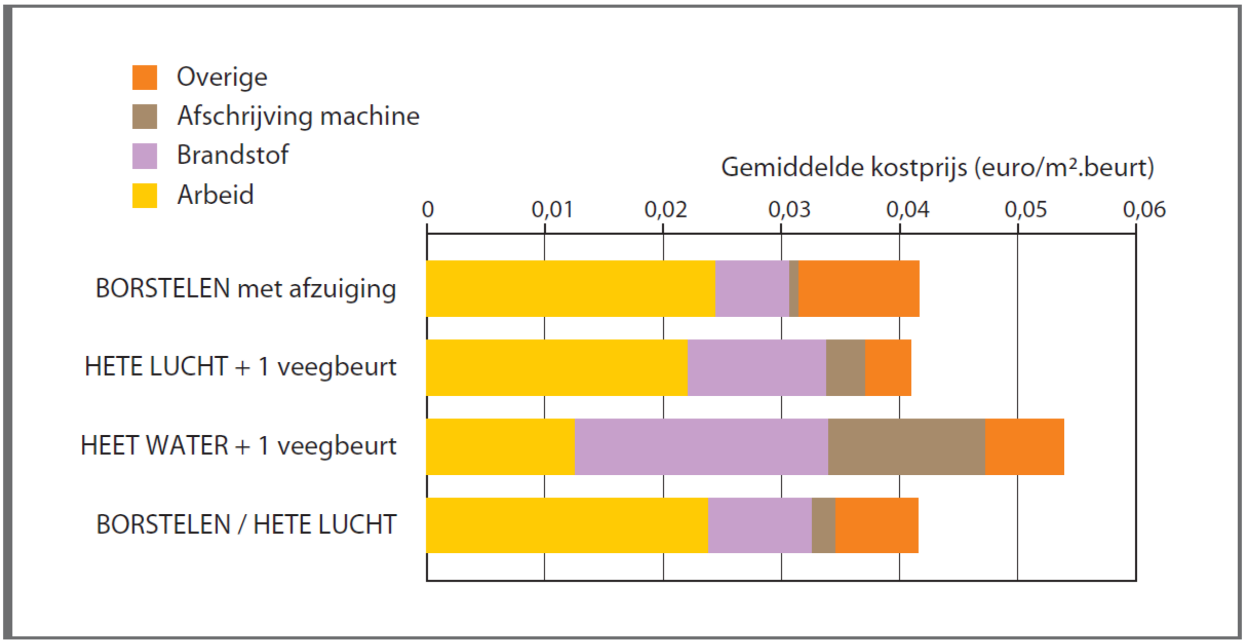

Figure 2. Average cost prices per treatment (€/m²) for the weed control methods brushing, hot air, hot water, and alternating brushing and hot air (from top to bottom) on concrete paving stones with enlarged joints. Costs broken down into labour, fuel, depreciation value and 'other' (horizontal bars from left to right). The energy dose (ED80) was similar for all techniques (From: Boonen et al.*, 2013).*

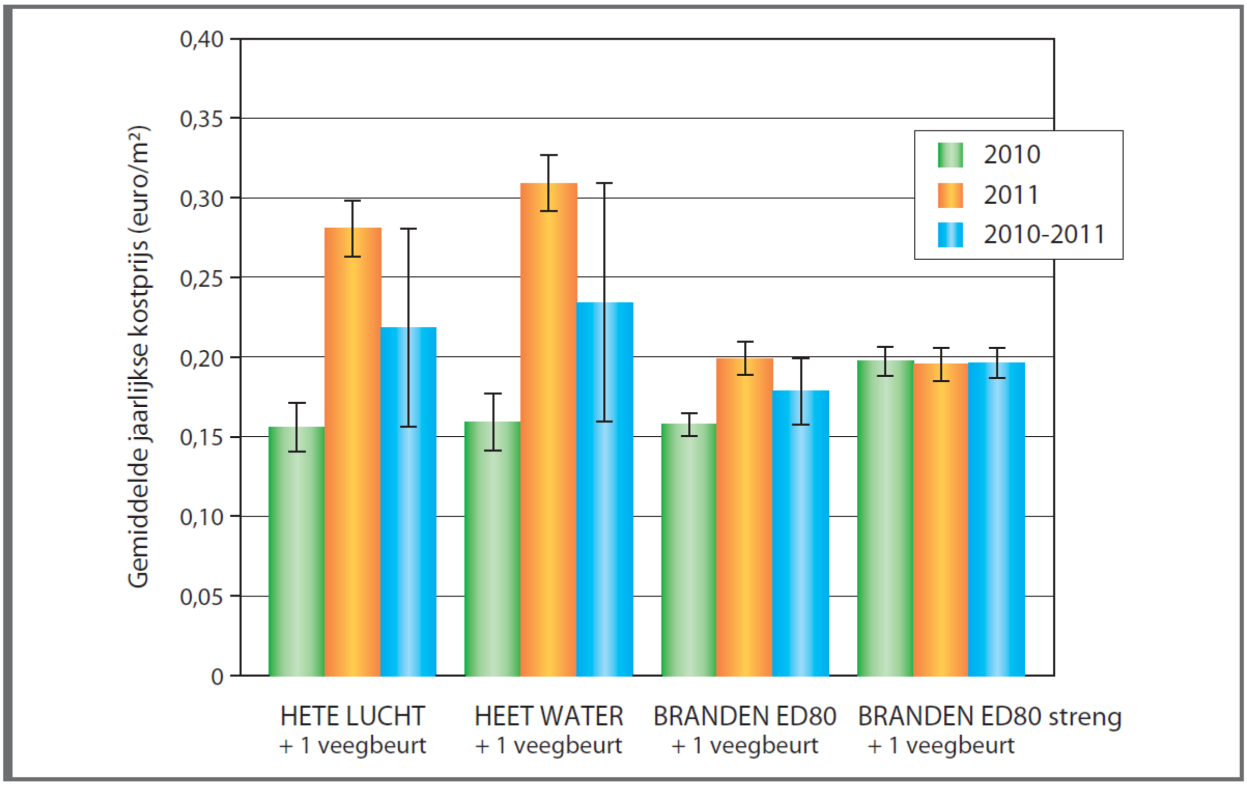

Figure 3. *Cost prices per year (€/m²/year) for the weed control methods hot air, hot water and burning to achieve a B-level of weed covering, and burning to achieve an A-level (from left to right) on concrete paving stones with enlarged joints in 2010, 2011 and on average. The energy dose (ED80) was similar for all techniques (From: Boonen* et al.*, 2013).*

2.3 Interaction with sweeping

Before starting to control weeds it is recommended to pay attention to prevention. Preventive measures in the design and construction phase will prevent weed growth and leads to less use of resources and a significant reduction in costs for weed control measurements.

Prevention also includes regular sweeping of pavements. By sweeping dirt and sand is removed from the pavements which prevents creating a feeding ground where weeds can grow. Small weeds will be removed immediately by the sweeping brushes. A good balance between sweeping and weed management will lead to less weeds and therefore to less cost, and a reduction on the environmental impact. In the Netherlands, recent trials have shown that frequent sweeping inhibits weed growth and the number of required treatments decreased significantly (Kempenaar et al, 2009). For non-chemical weed control methods, sweeping more than 4 times per year financially benefits because fewer treatments are needed to achieve the required level of weed covering. The maximum benefit is achieved by sweeping 12 times if an A-level of weed covering is required and eight times when a B-level is required (A and B level according to Figure 1). For chemical weed control more sweeping has only a limited effect on the number of treatments and therefore no immediate financial benefit.

3. Environmental impact of weed control methods

3.1 Life-cycle analysis 1 (The Netherlands)

In 2012 IVAM Research and Consultancy Agency (University of Amsterdam) determined, in collaboration with PRI, the environmental side-effects of the most common weed control methods on paved surfaces using a Life-cycle analysis quickscan (Jonkers, 2012). The Life-cycle analysis (LCA) focuses on the entire life cycle, from the production of machines and materials to waste processing.

The LCA calculation method (ReCiPe) has been developed at the request of the Dutch Ministry of Housing and Environment (VROM, 2009) and is one of the existing calculation methods in which environmental interventions are translated into environmental effects. The LCA score consists of 17 environmental impact categories (Table 4) that are compared individually, standardised and weighed and then totalled. The scores are expressed in LCA points; the higher the LCA score, the poorer the method's performance. In this way, emissions, consumption of commodities and other data can be translated into a limited series of environmental impacts which are better to interpret. The weighting of the environmental effects makes it possible to compare the relative seriousness of different environmental impacts and with the total LCA score techniques can be compared. The ReCiPe method is a combined successor to the international commonly used methods CML2 and Ecoindicator99 and represents the state-of-the-art in LCA calculations. Generally in an LCA comparison quickscan differences between scenarios scores less than 25% are regarded as not significant.

Table 4. Environmental impact categories of the LCA calculation method (ReCiPe).

Climate Change - Human Health and Ecosystems
Ozone depletion
Terrestrial acidification
Freshwater eutrophication
Human toxicity
Photochemical oxidant formation
Particulate matter formation
Ecotoxicity – Terrestrial, Freshwater and Marine
Ionising radiation
Land occupation – Agricultural and Urban
Natural land transformation
Metal and Fossil depletion

For calculating the LCA scores of weed control methods on pavements (see Table 5 for a description) the input values from the Dutch costs study were used, regarding application frequencies, capacity, hours of use and the consumption of fuels, water and glyphosate (Table 6). The LCA calculation refers to weed control on 1000 m^2 pavements for 1 year, with a required B-level of weed covering (according to Figure 1). The environmental impact of the different weed control methods is mainly depending on the required level of weed covering and the corresponding frequencies. Based on the total LCA scores, chemical weed control methods using glyphosate have a much lower impact on the environment than non-chemical methods (Figure 4). Chemical techniques had a total score of 0.3 - 0.5 LCA points. The environmental impact of brushing is mainly determined by the extra wear of the pavement as a result of the rotating brushes. As a result, the LCA score of brushing varies from 2.8 for no wear to 7.0 for a 25% shorter life span of the pavement. Burning, hot air and hot water have the largest impact on the environment as a result of the use of fossil fuels. The scores for these methods range between 7 and 11 LCA points.

In view of the individual environmental categories, the chemical methods have the highest impact on fresh and salt water ecotoxicity as a result of toxicity and nutritional value. Brushing methods have the highest score for human toxicity, land use and mineral depletion. The highest score for the inducing of particles goes to the hot water method, while burning has the highest score in the categories climate change and fossil depletion, followed by hot air. None of the methods score the best or worst in all environmental categories.

Table 5 Description of the weed control methods on pavements for which a LCA score has been calculated.

No.	Description of the method	Details
1	Chemical, standard sensor controlled application (sensors at 30 cm) and controlled droplet application technology; herbicide use approx. 1 l/ha, 50% run off	selective application; 50% glyphosate run off, of which 83% enters a sewage treatment plant (STP) where it is partially converted to AMPA.
2	Chemical, standard sensor controlled application (sensors at 30 cm) and controlled droplet application technology; herbicide use approx. 1 l/ha, 9% run off	selective application; 9% glyphosate run off, of which 83% enters a sewage treatment plant (STP) where it is partially converted to AMPA.
3	Chemical, innovative sensor controlled application (sensors at 8 cm); herbicide use approx. 0.8 l/ha, 50% run off	selective application; 50% glyphosate run off, of which 83% enters a sewage treatment plant (STP) where it is partially converted to AMPA.
4	Chemical, innovative sensor controlled application (sensors at 8 cm); herbicide use approx. 0.8 l/ha, 9% run off	selective application; 9% glyphosate run off, of which 83% enters a sewage treatment plant (STP) where it is partially converted to AMPA.
5	Chemical, weed wiper; herbicide use approx. 0.9 l/ha, 50% run off	selective application; 50% glyphosate run off, of which 83% enters a sewage treatment plant (STP) where it is partially converted to AMPA.
6	Chemical, weed wiper; herbicide use approx. 0.9 l/ha, 9% run off	selective application; 9% glyphosate run off, of which 83% enters a sewage treatment plant (STP) where it is partially converted to AMPA.
7	Brushing, no wear of pavements	full field application; possible wear of pavements is not taken into account
8	Brushing, 10% shorter life span	full field application; assuming a 10% shorter life span of pavement due to wear. Production of additional pavements is taken into account.
9	Brushing, 25% shorter life span	full field application; assuming a 25% shorter life span of pavement due to wear. Production of additional pavements is taken into account.
10	Hot water	full field application
11	Hot water	selective application
12	Hot air+infra-red +hot water	full-field application
13	Burning/flaming	full field application
14	Hot air	full field application

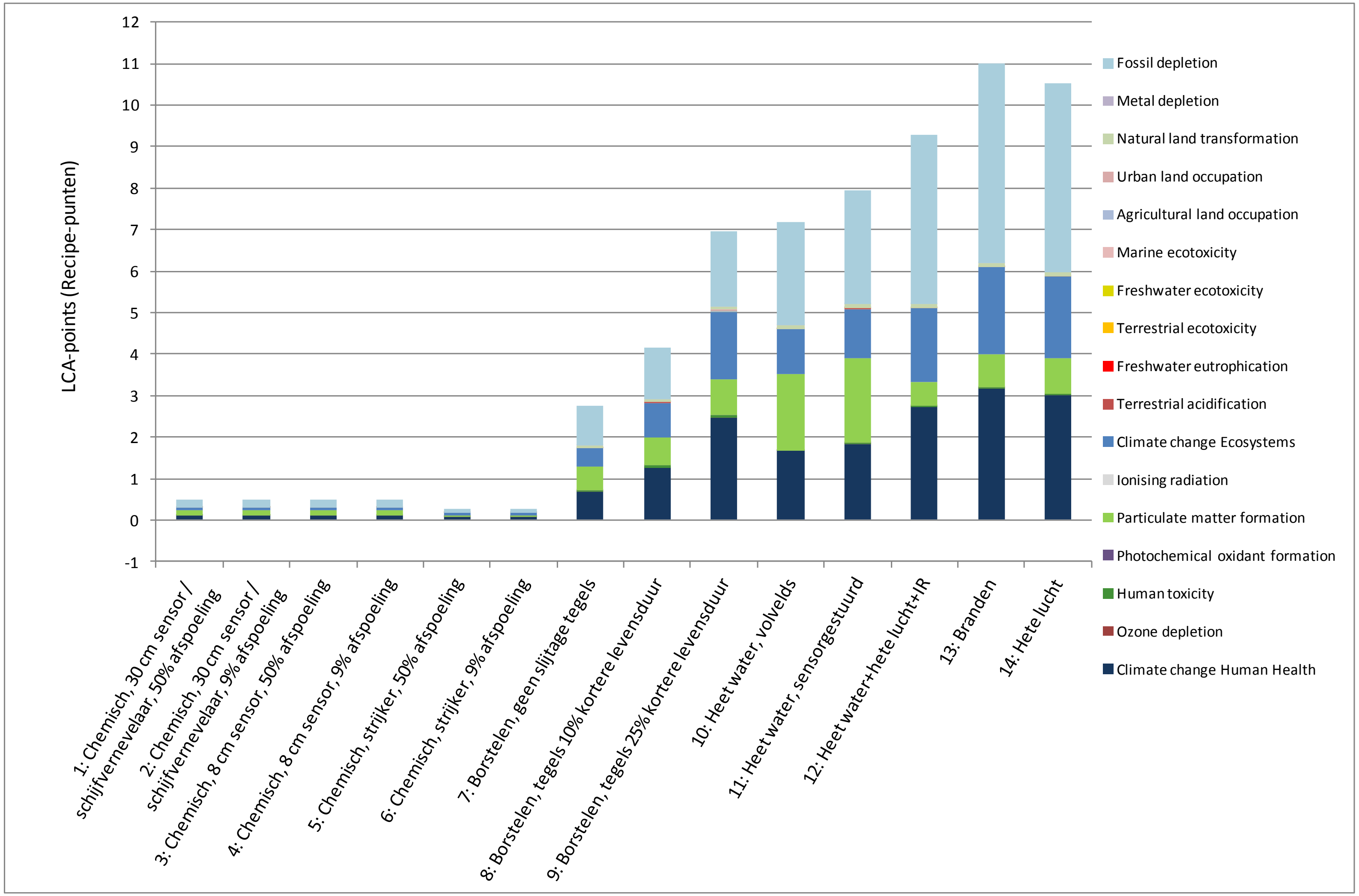

Figure 4. Total environmental impact (LCA scores) of different weed control methods (see Table 5 for translation of x-axis values). The LCA calculation according to the ReCiPe-method refers to weed control on 1000 m² pavements for 1 year, with a required B-level of weed covering. The colors indicate the contributions of the different environmental impact categories to the total score (From: Jonkers, 2012)

Table 6. Input values for different weed control techniques on pavements used for calculating LCA scores (From: Jonkers, 2012).

Description	**Unit**	**Chemical, sensors at 30 cm/ controlled droplet application**	**Chemical, sensors at 8 cm**	**Chemical, Weed wiper**	**Brushing**	**Hot water**	**Hot water**	**Hot air+infra-red +hot water**	**Burning**	**Hot air**
Carrier vehicle		Quad	Quad	Stiga ready		Egholm 2200		LM Trac	LM Trac	
Power	kW				37	35	264			35
Application		selective	selective	selective	selective	full field	selective	full field	full field	full field
Working width	cm	100	100	100	-	-	-	120	120	100
Capacity	ha/hour	0.50	0.50	0.50	0.20	0.13	0.25	0.30	0.40	0.35
Application frequenty range (B-level)		2-3	2-3	2-3	3-4	3-4	3-4	4-6	6-8	6-8
Application frequenty in model		2.5	2.5	2.5	3.5	3.5	3.5	5	7	7
Hours of use, range	Hour	500/800	500/800	500/800	500/800	500/800	500/800	500/800	500/800	500/800
Hours of use in model	Hour	650	650	650	650	650	650	650	650	650
Fuel consumption	liter/hour	2	2	1	3	7	15	2	3	3
Hours of use parts subject to wear (eg brush)	Hour	Not apply	Not apply	Not apply	14	Not apply	Not apply	Not apply	Not apply	Not apply
Water consumption	m^3/ hour	0.007	0.005	0	Not apply	0.7	0.8	0.1	Not apply	Not apply
Gas, propane consumption	kg/hour	Not apply	Not apply	Not apply	Not apply	Not apply	Not apply	14	15	12
Glyphosate – diluted product	liter/hour	0,45	0,42	0,33	Not apply	Not apply	Not apply	Not apply	Not apply	Not apply
Glyphosate – active ingredient	kg/hour	0,162	0,151	0,119	Not apply	Not apply	Not apply	Not apply	Not apply	Not apply

3.2 Life-cycle analysis 2 (Flanders)

In Flanders, the environmental impacts of various non-chemical control methods were determined by the same LCA calculation method (ReCiPe) as used in the Dutch study (Boonen *et al.*, 2013). Additionally the environmental score per technique was calculated for different types of pavements .

The results show that per treatment brushing has the lowest environmental score, followed by hot air and burning Hot air and burning have a similar effect. Selective treatment with hot water had the highest environmental impact on both types of pavements (Figure 5). These higher scores were mainly due to the relatively high fuel consumption for heating water and fine dust emissions from diesel combustion. The type of pavement proves to be hardly of influence on the environmental impact per treatment, with the exception of the sensor-controlled hot water technique. On concrete stones with wide joints and stones with drainage holes, the hot water technique had a significantly higher environmental score than on commonly used paving stones with small joints. This difference is explained by more and larger weeds on pavements with wide joints for which more hot water per unit of surface area was consumed. The overall environmental impact of all weed control methods were mainly determined by the impact categories climate change (human health and ecosystems), fine dust emissions and fossil depletion. Generally, to reduce the environmental impact per treatment of non-chemical weed control methods the technological developments should focus on reducing fossil energy consumption.

The LCA analyses have also shown that the contribution of the carrier vehicle in the overall environmental score can vary from 10 % to 70 %, depending on the weed control method used. The contribution of the carrier vehicle to the total score is important because the type of carrier in some cases is interchangeable. The environmental impact of the fuel consumption of the carrier is of greater importance than the production of the carrier itself.

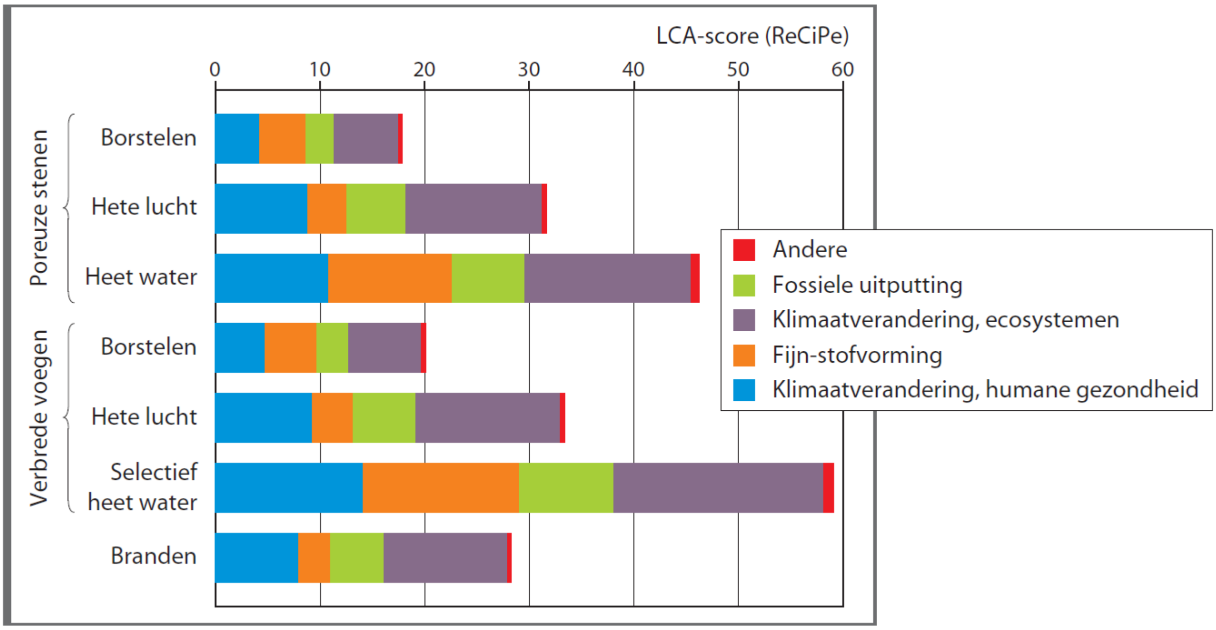

Figure 5. Environmental impact (LCA scores) of different weed control methods per treatment (from top to bottom: brushing, hot air and hot water on porous pavements and brushing, hot air, hot water and burning on stones with wide joints). The colors indicate the different environmental impact categories (from left to right: climate change – human health, fine dust emissions, climate change-ecosystems, fossil depletion and 'others') (From: Boonen et al.*, 2013)*

The LCA calculation for weed control on 1000 m^2 pavements for 1 year, with a required weed covering level B (according to Figure 1) shows that the environmental performance strongly depends on the type of pavement (Figure 6). On porous stones significantly fewer treatments were needed to maintain the required level of weed covering, resulting in a relatively low environmental impact compared to the number of treatments needed on the other types of pavements (Table 7).

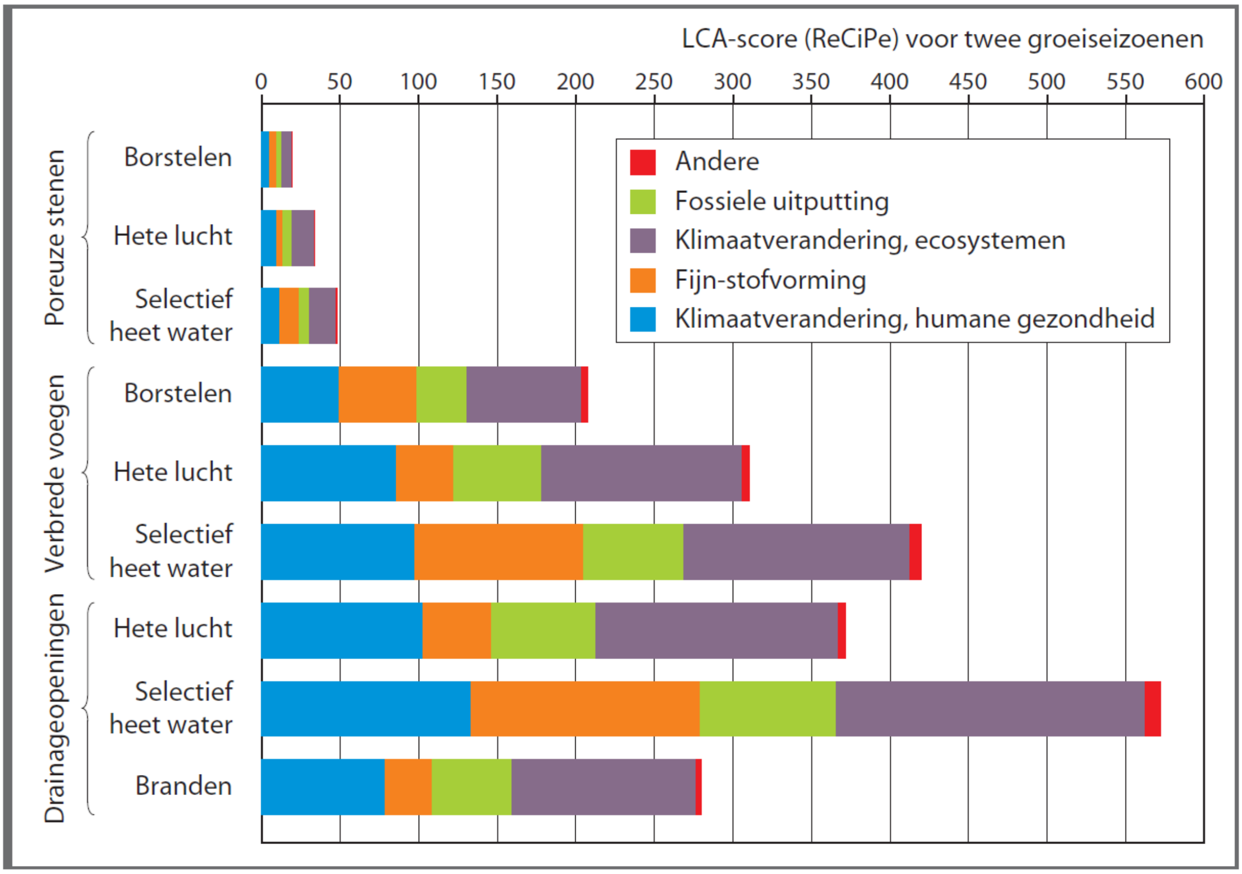

Figure 6 *Environmental impact (LCA scores) of different weed control methods for two seasons (from top to bottom: brushing, hot air and hot water on porous stones; brushing, hot air and hot water on stones with wide joints; hot air, hot water and burning on stones with drainage holes). The colors indicate the different environmental impact (from left to right: climate change - human health, fine dust emissions, climate change-ecosystems, fossil depletion and 'others') (From: Boonen* et al.*, 2013)*

Table 7. *Application frequencies for non-chemical weed control on different types of pavements during two seasons in relation to the required weed covering level B (From: Boonen* et al.*, 2013).*

Weed control method	Type of pavement			
	Porous	wide joints	drainage holes	small joints (commonly used)
Brushing (full-field)	1	10	-	9
Hor air (full-field)	1	9	11	9
Hot water (selective)	1	7	9	-
Brushing/hot air alternating (full-field)	1	9	-	-

-: not tested

4. Conclusions

For curative weed control on pavements a choice can be made from a pallet of methods, ranging from completely non-chemical methods, complete chemical methods or an integrated approach with combinations of methods can be applied. All methods vary largely in efficacy, inputs and costs.

Calculated cost prices have shown that prices are mainly determined by the replacement value of machines, the usability over the year and capacity (ha/h). In the Netherlands calculated prices range from about 1 to 8 eurocents per square meter per application depending on the technique, chemical or non-chemical. When costs were put in perspective for a year round weed control strategy, assuming a required 'B-level' of weed covering the annual costs range from 4 till 29 eurocents per m^2, and are largely depending on the technique chosen. There was a relatively large difference between costs for chemical and non-chemical techniques of approximately 10 cents per m^2. In Flanders an average cost per year of 20 eurocents per m^2 was calculated for different non-chemical methods.

Both in the Netherlands and in Flanders the environmental side-effects of the most common weed control methods on paved surfaces were determined using a standard Life-cycle analysis. The LCA calculation method (ReCiPe) used for both studies focuses on the entire life cycle, from the production of machines and materials to waste processing. The results showed that the environmental impact of the different weed control methods were mainly depending on the required level of weed covering and the corresponding frequencies. The Dutch study showed that, based on the total LCA scores, chemical weed control methods using glyphosate have a much lower impact on the environment than non-chemical methods. The higher LCA scores for non-chemical methods could be explained by the high fuel consumption and the corresponding fine dust emissions. In the Flanders LCA study only non-chemical methods were analysed. In general, high LCA scores were found also related to the relatively high fuel consumption and fine dust emissions from diesel combustion. These results confirmed the high LCA scores for non-chemical methods from the Dutch study.

Considerable discussion is currently taking place in the Netherlands on the Dutch government's proposal aiming at a ban of all professional and private use of pesticides in the non-agricultural sector, including herbicides on paved surfaces. Life-cycle analysis (LCA) shows that the careful use of chemicals on pavements has better results from an environmental perspective than non-chemical methods such as burning, brushing, hot air and hot water. Therefore, prohibiting chemical weed control on paving will not improve the environment. Furthermore the costs will increase significantly.

The scientific data presented in this study can be used in a planned LCA study for weed control on pavements. Data on inputs and efficacy of weed control methods under Dutch and Flandrian conditions can be extrapolated to the French situation by Evea experts and other stakeholders that will contribute to the study.

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