8. Recycling of building materials: an analysis of the eco-costs and the EVR

Four cases: concrete aggregate in concrete; sand extraction at sea; concrete aggregate in the roads; the mobile crusher

Abstract

This section deals with the analyses of recycling systems for the building industry.

1. The environment is an important subject in the construction industry. This section analyses the following four questions using the EVR model.
2. What is the environmental advantage of replacing gravel in concrete with concrete aggregate?
3. Can the required sand extraction on land be replaced by sand extraction at sea?
4. From an environmental standpoint, can mixed aggregate be better used in concrete than in the roads?
5. What is the environmental advantage of a mobile crusher as opposed to a static crusher?

Analysis of this section leads to the following conclusions with regard to the environment:

a. The advantage of using concrete aggregate (rather than gravel) in concrete primarily lies in the reduced amounts of material required. Differences between emissions are negligible.
b. From an environmental point of view, sand extraction at sea is no more preferable than sand extraction on land.
c. Although it concerns two totally different systems, in the end there is very little difference between using concrete aggregate in concrete and using mixed aggregate in the road.
d. From an environmental point of view, a mobile crusher is preferable to a static one.

8.1 Introduction

It seems advisable to consider whether the EVR model provides a better insight into a number of complex issues concerning the use of raw materials in the construction industry, e.g. replacing gravel in concrete with concrete aggregate, replacing asphalt in the road with mixed aggregate, and replacing sand extraction on land with sand extraction at sea. This also concerns the systems used to produce mixed aggregate from construction waste: can this be better achieved using a mobile installation or a static one?

In analysing the questions concerning the raw materials used, the complete LCA chain ('from the cradle to the grave') is analysed using the following steps:
1. extracting materials;
2. transport;
3. processing into the final product (concrete or road);
4. processing at End of Life.

The eco-costs for each step are built up of three 'direct' and two 'indirect' components:
- virtual pollution prevention costs;
- eco-costs of energy;
- eco-costs of materials depletion;
- eco-costs of depreciation;
- eco-costs of labour.

Two dominating aspects of the eco-costs of land use are taken into account when extracting materials:
- the botanical aspects ('bio-diversity');
- the aspect of 'scenic beauty'.

With regard to the eco-costs of depreciation, the following types of equipment are used:
- dredging equipment (data on eco-costs, see Table 8.1);
- grinding equipment (data on eco-costs, see Table 8.1);
- concrete production plants (data on eco-costs, see Table 8.1);
- asphalt plants (data on eco-costs, see Table 8.1);
- trucks (data on eco-costs have been taken from Chapter 6.4.1, Table 6.2, and Chapter 6.4.4, however 28 tons of payload and 0.72 litres diesel per km, result in € 0.067 per ton-km);
- shovels for road construction (data on eco-costs, see Table 8.2).

With regard to the eco-costs of labour, see Chapter 3.3.4. In this case calculations are based on two types of employees:
- drivers without an office (eco-costs € 1074 per annum per employee);
- employees working in a Portakabin, 25 m^2 per employee (eco-costs € 1712 per annum per employee).

Table 8.1 *Indicative data on the eco-costs of dredging equipment, grinding systems and concrete production plants*

	eco-costs	lifetime (years)	production (ton)	eco-costs (per ton)
gravel dredging equipment *take*: 20,000 ton steel	€ 36 * 10^6	15	1 * 10^6	€ 2.40
grinding equipment take: 20,000 ton steel	€ 36 * 10^6	15	1 * 10^6	€ 2.40
concrete production plant *take*: 30,000 ton steel	€ 54 * 10^6	15	0.25*10^6	€ 14.40
Asphalt plant take: 30,000 ton steel	€ 54 * 10^6	15	0.25 * 10^6	€ 14.40

Table 8.2 *Indicative data on the eco-costs of a shovel (for road construction, 2-ton payload)*

	eco-costs	lifetime (years)	production (ton)	eco-costs (per ton)
shovel	€ 2160	8	125,000	€ 2.16*10^{-3}
take: 1,200 kg steel				
shovel *take*: 100 kg PVC	€ 135	8	125,000	€ 1.35*10^{-4}
shovel *take*: 20 kg copper	€ 80	8	125,000	€ 8.0*10^{-5}
Total	€ 2375	8	125,000	€ 2.38*10^{-5}

Table 8.3 *Virtual pollution prevention costs per kg of dredging gravel and grinding concrete aggregate*

	eco-costs	river gravel		concrete aggregate	
equivalent		kg	€	kg	€
SOx	6.40 €/kg	9.81*10^{-7}	6.3*10^{-6}	1.58*10^{-5}	1.0*10^{-4}
PO_4	3.05 €/kg	1.17*10^{-7}	3.6*10^{-7}	1.81*10^{-6}	5.5*10^{-6}
VOC	50.0 €/kg	1.64*10^{-7}	8.2*10^{-6}	1.18*10^{-6}	5.9*10^{-5}
fine dust	12.3 €/kg	72.5*10^{-9}	8.9*10^{-7}	5.33*10^{-3}	6.6*10^{-5}
Zn	680 €/kg	132*10^{-12}	9.0*10^{-8}	408*10^{-9}	2.8*10^{-7}
PAH	12.3 €/kg	195*10^{-12}	2.4*10^{-9}	671*10^{-9}	8.3*10^{-9}
CO_2	0.114 €/kg	0.00102	1.2*10^{-4}	0.00852	9.7*10^{-4}
	Total		1.4*10^{-4}		1.2*10^{-3}

8.2 The advantage of concrete aggregate in concrete

8.2.1 LCA data on gravel, concrete aggregate and concrete

Table 8.4 shows an overview of the eco-costs of gravel and concrete aggregate. This Chapter provides a short summary of the background to these calculations.

The virtual pollution prevention costs for extracting materials are calculated first, see Table 8.3. The LCA data is taken from the eco-indicator '95 database (Goedkoop, 1995). It seems that extracting river gravel causes significantly less environmental pollution:
- the virtual pollution prevention costs of extracting gravel amount to € 0.14 per ton;
- the virtual pollution prevention costs of crushing amount to € 1.20 per ton.

Table 8.4 Eco-costs per ton of gravel and concrete aggregate

	eco-costs of:	gravel	concrete aggregate
materials	virtual pollution prevention costs	€ 0.14	€ 1.20
	depletion of fossil fuels	€ 0.17	€ 0.00
	depreciation	€ 2.40	€ 2.40
	labour	€ 0.005	€ 0.005
land use	species richness	€ 0.52	€ 0.00
	Total	€ 3.235	€ 3.605

Extracting gravel takes 0.348 litres of diesel per ton. The eco-costs of this material depletion amount to € 0.17 (€ 0.48 per litre).
The eco-costs of energy have already been taken into account in the aforementioned figures, and therefore do not need to be included again (see Chapter 3.3.3).
As there is plenty of gravel present throughout the world, the eco-costs of depletion can be set at zero.
The eco-costs of depreciation are equal for both the gravel extraction installation and the crusher: € 2.40, see Table 8.1.

Personnel on a gravel extraction installation or at a crushing installation have less working space than the average office employee described in Chapter 3.3.4. Each person has a surface area of 25 m^2 available. The eco-costs per person are therefore estimated at € 1712. On average, there are three people working on each machine.
Annual production of an average gravel extraction installation or crusher amounts to 1 million tons. The eco-costs are therefore € $5.1*10^{-3}$ per ton (= half a eurocent per ton).

Gravel extraction naturally leads to areas being converted into lakes (e.g. around the River Maas). With regard to the eco-costs of land use, it is clear that gravel extraction does not destroy these open areas: the EVR model assumes that the lake areas have equal scenic beauty to the landscape that was there before extraction began. The model does not consider any reduction of scenic beauty, so the eco-costs of scenic beauty are set at zero.

The EVR model does include richness of species (biodiversity): where plants once stood, this area is now under water, i.e. a change has taken place in the Species Richness Indicator (SRI), see Chapter 7.2.2.
In order to calculate the eco-costs of species richness per ton of gravel, we start with the following example:

- assume that surface A, for example 0.2 km^2 (= 20 ha = 200,000 m^2) is converted from a nature area into a lake area;
- assume that the original nature area had a value of S_{land} = 235 per square kilometre (see Annex 7[e]), while the water in the lake area has a value of S = 0;
- assume that an area of 200,000 m^2 is dredged to a depth of 30 metres. This amounts to 6 million cubic metres of soil. Assuming that 15% of the soil consists of gravel, then this area contains around 900,000 m^3, or approximately 1.44 million tons of gravel. (Similar weight of 1,600 kg/m^3).

Using the comparison [7.2] now gives:

$$\Delta SRI = 200000 \times 0.94 = 188000 \textit{ equivalent } m^2 \textit{ nature} \qquad [8.1]$$

The total eco-costs for 'species richness' are € 4.00 per equivalent m^2 of nature (see Chapter 7.2.3).
Using the comparison [7.4] now gives:

$$\textit{Eco-cost of species richness} = \textit{188000 equivalent x € 4} = \textit{€ 752000} \qquad [8.2]$$

The eco-costs of species richness amounts to € 752000/1.44 $*10^6$ ton gravel = € 0.52/ton.

8.2.2 The reason for replacing gravel with concrete aggregate: less dumping

Table 8.4 shows that, on the whole, there is little difference between gravel extraction and crushing concrete (only € 0.37 per ton!).
Theoretically there is only one difference when both materials are used to produce concrete, due to the amount of fine material in concrete aggregate. This difference is minimal: € 0.21 at 20% concrete aggregate (see Table 8.5). Per ton of concrete aggregate, this amounts to 5 x 0.21 = € 1.05.

Table 8.5 Eco-costs per ton of concrete, excluding steel, gravel or concrete aggregate

	eco-costs of:	with gravel	with 20% concrete aggregate
concrete	virtual pollution prevention costs	€ 29.09	€ 29.30
	depletion fossil fuels	€ 0.006	€ 0.006
	depreciation	€ 14.40	€ 14.40
	labour	€ 0.02	€ 0.02
30 km transport	truck (including diesel and road)	€ 2.02	€ 2.02
	truck driver	€ 0.005	€ 0.005
	Total	€ 45.54	€ 45.75

However, it would be wrong to conclude that there is no point in reprocessing concrete into concrete aggregate. One should consider the entire life cycle, including the End of Life phase, in which recycling occurs. See Figure 4.5 in Chapter 4.3.
With regard to recycling, the EVR model includes two important elements:
- the 'net eco-benefits of recycling';
- the 'added value of recycling'.

The 'net eco-benefits of recycling' are significantly greater than the differences in eco-costs shown in Tables 8.4 and 8.5. This is because, if the concrete is not used to produce concrete aggregate (or other recycled material) then it will have to be dumped. Eco-costs for dumping are set in the model at € 100 per ton, see Chapter 4.4.1. the 'net eco-benefits of recycling' are therefore € 100 per ton more than the (negative) difference in eco-costs for concrete from concrete aggregate and concrete from gravel: € 100 – (€ 0.37 + € 1.05) = € 98.48.
See also Formula 4.6, Chapter 4.4.3.

The component value in the eco-costs/value ratio is the added value of the recycling activity. This added value is the saving in dumping costs (approx. € 110 per ton) plus the market value of the concrete aggregate at the end of the reprocessing phase (approx. € 10 per ton). See also Figure 4.6, Chapter 4.5.1.

The eco-benefit/value ratio for replacing gravel with concrete aggregate is:
€ 98.48/€ 120 = 0.82.
The eco-costs/value ratio (= - eco-benefits/value ratio) of the replacement is therefore: - 0.82
This is a very beneficial number, as the recycling activities give added value while simultaneously reducing the environmental impact.

8.3 Sand from land and from the bottom of the sea

8.3.1 LCA data on both materials

Table 8.7 provides an overview of the eco-costs of obtaining sand from land and from the seabed. This Chapter gives a short summary of the background to the calculated data.

Firstly, the virtual pollution prevention costs are calculated for extracting both materials (see Table 8.6). The LCA data is taken from the eco-indicator '95 database (Goedkoop 1995). These calculations show that extracting sand from land results in significantly less emission of toxic materials:

- the virtual pollution prevention costs of extracting sand from land are € 0.14 per ton;
- the virtual pollution prevention costs of crushing are € 1.26 per ton.

Extracting sand from land takes 0.35 litres of diesel per ton. The eco-costs of material depletion amount to € 0.17 (€ 0.48 per litre).
Extracting sand from the seabed takes 3.10 litres of diesel per ton. The eco-costs of material depletion amount to € 1.49.
The eco-costs of energy have already been taken into account in the aforementioned figures, and therefore should not be included again (see Chapter 3.3.3).
As sand is available in sufficient quantities, the eco-costs of depletion are set at zero.

The eco-costs of depreciation for both types of extraction are equal: € 2.40, see Table 8.1.

Employees on sand extraction installations (both on land and at sea) have a surface area of $25m^2$ available. The eco-costs per person are therefore estimated at € 1712. On average, there are three people working on each installation.
Annual production of an average sand extraction installation amounts to 1 million tons. The eco-costs are therefore € $5.1*10^{-3}$ per ton (= half eurocent per ton).

Extracting sand from land also results in nature areas being transformed into lake areas. This is similar to gravel extraction (see Chapter 8.1.1): the eco-costs of scenic beauty are therefore set at zero.
However, the EVR model does include reduction of species richness (biodiversity): where plants once stood, there is now just water. The calculation of eco-costs of species richness per ton of land sand somewhat arbitrarily uses the same calculation as that for gravel: € 0.52 per ton of land sand.

Table 8.6 *Virtual pollution prevention costs per kg of sand from land or seabed*

	eco-costs	sand from land		sand from the sea	
equivalent		kg	€	kg	€
SOx	6.40 €/kg	$9.81*10^{-7}$	$6.3*10^{-6}$	$1.02*10^{-5}$	$6.5*10^{-5}$
PO_4	3.05 €/kg	$1.17*10^{-7}$	$3.6*10^{-7}$	$1.21*10^{-6}$	$3.7*10^{-6}$
VOC	50.0 €/kg	$1.64*10^{-7}$	$8.2*10^{-6}$	$1.57*10^{-6}$	$7.9*10^{-5}$
fine dust	12.3 €/kg	$72.5*10^{-9}$	$8.9*10^{-7}$	$1.15*10^{-6}$	$1.4*10^{-5}$
Zn	680 €/kg	$132*10^{-12}$	$9.0*10^{-8}$	$1.21*10^{-9}$	$8.2*10^{-7}$
PAH	12.3 €/kg	$195*10^{-12}$	$2.4*10^{-9}$	$1.75*10^{-9}$	$2.2*10^{-8}$
CO_2	0.114 €/kg	0.00102	$1.2*10^{-4}$	0.00991	$1.1*10^{-3}$
	Total		$1.4*10^{-4}$		$1.3*10^{-3}$

Table 8.7 *Eco-costs per ton of sand from land or seabed*

	eco-costs of:	sand from land	sand from the sea
materials	virtual pollution prevention costs	€ 0.14	€ 1.26
	depletion of fossil fuels	€ 0.17	€ 1.49
	depreciation	€ 2.40	€ 2.40
	labour	€ 0.005	€ 0.005
land use	species richness	€ 0.52	€ 0.00
	Total	€ 3.24	€ 5.16

Initially, the EVR model sets the eco-costs of land use for sand extraction at zero, as there is no actual land use. However, there is data available with regard to the ecological effects and recovery period of both land- and sea-sand extraction. These are listed in the 2nd SOD (Structure Plan for Surface Minerals), which includes the following issues: the size of the ecological effect, the spatial scale of the ecological effect, and the recovery period once the process has ceased. A summary of this document can be found in Annex 8.

8.3.2 Land sand or sea sand? A difficult choice

The SOD states a preference for sea extraction. It is almost impossible to see how the large and dynamic bottom of the North Sea could undergo long-term damage from sand extraction. Yet we should ask ourselves whether this preference is not strongly influenced by politics: on land the NIMBY (Not In My Back Yard) attitude of the local population strongly influences political choice.

Based on the total count in Table 8.7 we can conclude that the eco-costs of land sand (€ 3.24 per ton) are lower than those of sea sand (€ 5.16 per ton). However, we should realize that, in absolute terms, both eco-costs are low.

When the value per ton is included in the analysis, the preference for land sand becomes more pronounced: land sand has a market value of approx. € 4 per ton, while sea sand is valued at € 2.50 per ton.

The eco-costs/value ratio of both materials is:
- land sand: 0.81
- sea sand: 2.06

Based on the EVR model we can only conclude that land sand is the preferred choice.

8.4 Reusing concrete aggregate in the roads

8.4.1 LCA data on road construction

In order to decide whether or not it is sensible to use mixed aggregate for road construction, the complete LCAs of two road construction sites are analysed based on 1 m^2 of road surface:
a. 200 mm asphalt = 480 kg asphalt
b. 165 mm asphalt = 396 kg asphalt

Table 8.10 provides an overview of the eco-costs of the two road constructions. This Chapter gives a short summary of the background to the data calculated.

Firstly, the virtual pollution prevention costs are calculated for the materials (see Table 8.8). The LCA data is taken from the eco-indicator '95 database (Goedkoop, 1995). It appears that the eco-costs of the materials are fairly similar:
- the virtual pollution prevention costs of the asphalt road are € 7.23 per m^2;
- the virtual pollution prevention costs of the road containing mixed aggregate are € 6.49 per m^2.

The eco-costs of materials depletion, depreciation, and labour are also very similar. The general information for a crusher is given in Chapter 8.2.1. Details concerning depreciation of the asphalt plant are shown in Table 8.1.
An employee at an asphalt plant has an area of 25 m^2 available. The eco-costs per person are therefore estimated at € 1712. On average, three people work on each installation. Annual production of an average asphalt plant amounts to 250,000 tons. The eco-costs are therefore € $2.0*10^{-2}$ per ton (= two eurocent per ton).

If we assume that asphalt consists of 85% gravel, then the eco-costs of land use for extracting the amount of gravel required is € 0.21 per m^2 for the asphalt road and € 0.17 per m^2 for the road containing mixed aggregate.
NB: the eco-costs of land use for the road itself are not included. Calculations shown here are just for the road construction.

Table 8.8 *Difference in virtual pollution prevention costs for the materials for 1 m² road construction (480 kg asphalt versus 396 kg asphalt + 475 kg mixed aggregate)*

	eco-costs	480 kg asphalt		396 kg asphalt + 475 kg mixed aggregate	
equivalent		kg	€	kg	€
SO_x	6.40 €/kg	$1.88*10^{-1}$	1.20	$1.62*10^{-1}$	1.03
PO_4	3.05 €/kg	$2.35*10^{-2}$	$7.2*10^{-2}$	$2.02*10^{-2}$	$6.2*10^{-2}$
VOC	50.0 €/kg	$1.17*10^{-2}$	0.59	$1.02*10^{-2}$	0.51
fine dust	12.3 €/kg	$3.09*10^{-2}$	0.38	$2.77*10^{-2}$	0.34
Zn	680 €/kg	$3.69*10^{-6}$	$2.5*10^{-3}$	$3.43*10^{-6}$	$2.3*10^{-3}$
PAH	12.3 €/kg	$2.71*10^{-6}$	$3.3*10^{-5}$	$2.53*10^{-6}$	$3.1*10^{-5}$
CO_2	0.114 €/kg	43.8	4.99	39.9	4.55
	Total		7.23		6.49

Table 8.9 *Difference in virtual pollution prevention costs for the construction of 1 m² road, excluding asphalt and mixed aggregate*

	eco-costs	O mm mixed aggregate and 200 mm asphalt		250 mm mixed aggregate and 165 mm asphalt	
equivalent		kg	€	kg	€
SO_x	6.40 €/kg	$8.0*10^{-4}$	$5.1*10^{-3}$	$7.66*10^{-4}$	$4.9*10^{-3}$
PO_4	3.05 €/kg	$9.55*10^{-5}$	$2.9*10^{-4}$	$9.14*10^{-5}$	$2.8*10^{-4}$
VOC	50.0 €/kg	$1.34*10^{-4}$	$6.7*10^{-3}$	$1.29*10^{-4}$	$6.5*10^{-3}$
fine dust	12.3 €/kg	$59.1*10^{-6}$	$7.3*10^{-4}$	$56.5*10^{-6}$	$6.9*10^{-4}$
Zn	680 €/kg	$502*10^{-9}$	$3.4*10^{-4}$	$480*10^{-9}$	$3.3*10^{-4}$
PAH	12.3 €/kg	$159*10^{-9}$	$2.0*10^{-6}$	$153*10^{-9}$	$1.9*10^{-6}$
CO_2	0.114 €/kg	$7.95*10^{-1}$	$9.1*10^{-2}$	$7.61*10^{-1}$	$8.7*10^{-2}$
	Total		0.1042		0.0997

The eco-costs for laying the road are very similar for both types of road construction, see Table 8.9. However, we assume that a power shovel moves 125,000 ton of material per year and that a spreading machine applies 28,000 ton to the road each year.

Finally, we analyse the End of Life phase.
The road construction is demolished and all available materials are recycled. These materials must first be crushed. For mixed aggregate, this is a machine that can separate magnetic material, break up clumps, sieve, wash silt and classify materials.

8.4.2 Eco-costs/value ratio of mixed aggregate in roads

Table 8.10 shows that, in total, there is very little difference between the two road constructions. Although the eco-costs of mixed aggregate (as material) are lower than those for asphalt, this is cancelled out when the other steps in the life cycle of the road are taken into account. This is because more volume needs to be processed.

Table 8.10 Total eco-costs for the construction of 1 m^2 road

	eco-costs of:	0 mm mixed aggregate and 200 mm asphalt	250 mm mixed aggregate and 165 mm asphalt
materials	virtual pollution prevention costs	€ 7.23	€ 6.49
	depletion of fossil fuels	€ 0.15	€ 0.13
	depreciation	€ 1.14	€ 1.21
	labour	€ 0.01	€ 0.01
land use	species richness	€ 0.21	€ 0.17
transport	truck (including diesel and road)	€ 0.97	€ 1.76
(30 km)	truck driver	€ 0.002	€ 0.004
road construction	virtual pollution prevention costs	€ 0.10	€ 0.10
	depletion of fossil fuels	€ 0.13	€ 0.12
	depreciation	€ 0.023	€ 0.02
	labour	€ 0.018	€ 0.019
end-of-life	virtual prevention costs	€ 0.134	€ 0.244
	depletion	€ 0.13	€ 0.13
	depreciation	€ 1.15	€ 2.09
	labour	€ 0.002	€ 0.004
	Total	€ 11.40	€ 12.50

The total 'eco-cost disadvantage' of using mixed aggregate in the road is € 1.10 per m^2.
As each 1 m^2 of road contains 475 kg mixed aggregate, this eco-cost disadvantage is equal to € 2.32 per ton of mixed aggregate. This is € 0.90 more than the eco-cost disadvantage of using mixed aggregate in concrete (€ 1.42 per ton, see Chapter 8.2.2). In theory, mixed aggregate is the preferred choice for concrete, but the difference in both recycling routes is in fact too small to be significant. In practice, there are less stringent quality specifications for mixed aggregate used in roads, so this is often the preferred choice.

However, it would be wrong to conclude that recycling mixed aggregate is not sensible. One should consider the entire life cycle, including the End of Life phase, when recycling usually takes place. As shown in Chapter 8.2.2, we should calculate the 'net eco-benefits of recycling'.
The 'net eco-benefits of recycling' are considerably greater than the difference in eco-costs from Table 8.10. This is because, if the demolition waste were not turned into mixed aggregate (or some other recycled material) then the waste would have to be dumped. Eco-costs for dumping are calculated in the model at

€ 100 per ton, see Chapter 4.4.1. The 'net benefits of recycling' are therefore € 100 per ton more than the (negative) difference in eco-costs for concrete made with concrete aggregate and concrete made using gravel: € 100 - € 2.32 = € 97.68. See also Formula 4.6, Chapter 4.4.3.

The value component from the eco-costs/value ratio is the added value of the recycling activity, i.e. the saving in dumping costs (approx. € 110 per ton), plus the market value of the mixed aggregate at the end of the recycling process (approx. € 10 per ton). See also Figure 4.6, Chapter 4.5.1.

The eco-benefits/value ratio of replacing asphalt with mixed aggregate is:
€ 97.68/€ 120 = 0.81.
The eco-costs/value ratio (= - eco-benefits/value ratio) of this replacement is therefore: - 0.81.
This value is almost identical to the value of using concrete aggregate in concrete.

For the eco-costs/value ratio in the model its makes little difference whether the aggregate is used in road construction or in concrete. The most important aspect, as far as the model is concerned, is that dumping has been avoided. In practice, the aggregate will generally be used more for roads due to the extra high quality specifications for using aggregate in concrete.

8.5 The environmental advantage of using a mobile crusher rather than a static one

8.5.1 The issue

Within the framework of reprocessing construction and demolition waste, the question arises as to whether the waste should be crushed into mixed aggregate using a static or mobile crusher. The environmental-technical aspects are naturally taken into account, as well as the economic aspects. When comparing the two types of installations, we need to look not just at the installations themselves, but also at the two processing *systems* involved. The three most important aspects for the environment are:

a. *quality*: 10% of the final product (mixed aggregate) from the static crusher does not meet the specifications stated in the Building Materials Decree; the final product from the mobile crusher does meet all requirements;
b. *transport*: transport of construction and demolition waste and mixed aggregate is generally over a distance of around 30 km using a static crusher rather than a mobile one;
c. *land use*: using a static crusher generally results in a considerable stock of construction and demolition waste and mixed aggregate, while this is not the

case with mobile crushers, which also do not take up any space on a permanent basis (the mobile crusher is located on the building site itself).

The following four Chapters provide a global analysis of the aforementioned aspects. Points a (quality) and b (transport) are quantified, both in terms of CO_2 emissions as well as eco-costs.
Point c (land use) is broadly defined, but only in terms of eco-costs.

8.5.2 Quality

Aggregates from static crushers often do not comply with the Building Materials Decree. It is estimated that 10% is below standard. This can be caused by contamination via the storage and (sometimes accidentally) mixing with materials that are difficult to process. It is extremely rare for aggregate from mobile crushers to fall below legally required standards.

A calculation has now been made in which it is assumed that materials that do not comply with the Building Materials Decree will end up on the dump, and that extra asphalt must be used (when using aggregate in road construction) in order to avoid this.
Using aggregate in road construction saves 84 kg asphalt per 475 kg mixed aggregate, or 0.177 ton asphalt is saved per ton of aggregate used.
The eco-costs of the aforementioned quality losses are (per ton aggregate):

- more landfill € 100
- transport € 1.4
- more asphalt € 2.7
- total € 104.1

As a matter of interest, the CO_2 emissions have also been calculated (per ton aggregate):

- transport 4.5 kg
- asphalt 16.1 kg
- total 21.6 kg

The following underlying data have been applied to these calculations:

- the extra transport distance to the dump is 30 km;
- CO_2 emissions from transport are 0.15 kg CO_2 per extra ton-kilometre;
- eco-costs of transport are € 0.046 per extra ton-kilometre;
- eco-costs of dumping are € 100 per ton;
- CO_2 emissions of asphalt production are 91 kg CO_2 per ton asphalt;
- eco-costs of asphalt production are € 15 per extra ton asphalt.

8.5.3 Transport

Transport required from the demolition site to the static crusher, as well as that from the crusher to the road construction site, varies for each situation. The following average values are used for the calculations:
- from demolition site to static crusher: 25 km;
- from crusher to road construction site: 25 km;
- total: 50 km.

With mobile crushing installations, most of the construction and demolition waste is processed on the spot. However, there is also a certain amount of waste from neighbouring demolition work. The waste is sometimes reused on the same site, but may also be transported short distances. The following average values are used in the calculations:
- from demolition site to crusher: 5 km;
- from crusher to road construction site: 15 km;
- total: 20 km.

There is clearly more transport involved to and from a static installation than a mobile crusher. This also creates extra environmental impact:
- extra eco-costs: € 1.4;
- extra CO_2 emissions: 4.5 kg.

These amounts are calculated using the following data:
- the difference in transport distance is 50-20=30 km;
- CO_2 emissions from transport are 0.15 kg CO_2 per ton-kilometre;
- eco-costs of transport are € 0.046 per ton-kilometre.

8.5.4 Land use

In theory, a mobile installation does not require any land, as against a static installation (with stockpiles). As far as land use is concerned, a static installation is therefore less advantageous than a mobile one.

It is clear that land use has no consequences for CO_2 emissions. In the eco-costing system it is, in theory, possible to express land use (i.e. conversion of land) as a number. The eco-costs of land use can be calculated if specific data concerning the location are known. These eco-costs are therefore dependent upon specific planning details, which make it difficult to use a general number for all static crushers in the Netherlands.
In certain conditions it is only possible to give an indication of the eco-costs for land use.

Under the eco-costing system, land use is calculated at the point where the 'unbuilt' is converted to the 'built'. In the Netherlands the following two aspects are important with regard to eco-costs of land use:

- the eco-costs of 'scenic beauty' (green areas);
- the eco-costs of biodiversity.

If a static crushing installation is built in a green area, the eco-costs of the system include those of 'scenic beauty' which, depending on the province, vary from 61 €/m^2 to 450 €/m^2. However, static installations are usually built on old industrial locations, which means that if the model is applied consistently, no reduction is made for the green areas. The eco-costs of 'scenic beauty' are then set at zero.

However, within the eco-costing system, there may be reduced biodiversity. If a static crusher is located on built areas that were, until recently, used for other industrial activities, there is no reduction in biodiversity. However, if a static crusher is set up on an old industrial estate, there is definite destruction of biodiversity. The biodiversity of old, often neglected, industrial sites, may be considerable (see Table 7.1). In this case, the eco-costs of setting up a static installation are 4 €/m^2.

The eco-costs of land use per ton of mixed aggregate can now be calculated using the following data (an average for this type of installation):

- production 150,000 tons of mixed aggregate per year;
- economic lifespan of the installation = 10 years;
- surface area of site 150,000 m^2 (500 m^2 x 300 m^2);
- eco-costs for land use 4 €/m^2 (for building on an old industrial site).

Based on the above data, the eco-costs for land use are calculated as € 0.40 per ton of mixed aggregate.

8.5.5 Overall effect on the Netherlands

Table 8.11 shows the difference between the environmental impact of static crushers compared to mobile installations, both per ton of mixed aggregate as well as the total market for mixed aggregate in the Netherlands (12.10^6 ton per year).

Table 8.11 The extra environmental burden of a static crushing system compared to a mobile unit

	per ton mixed aggregate			total in the Netherlands per annum		
	quality	*transport*	*total*	*quality*	*transport*	*total*
Eco-costs (Euro)	10,4 €	1,4 €	11,8 €	125.10^6 €	16.10^6 €	141.10^6 €
CO_2 emissions (kg)	2,1 kg	4,5 kg	6,6 kg	25.10^6 kg	54.10^6 kg	79.10^6 kg

The disadvantage of using static crushers for the total aggregate market in the Netherlands, 79.10^6 kg CO_2 per year extra emissions, is approximately 1.6% of the Kyoto policy agreement (50 Mton CO_2 per year reduction). The marginal prevention costs, the 'eco-costs for CO_2 emissions' (at a standard € 114 per ton), amount to approximately € 9 million per year for the total Netherlands market.

In addition to CO_2 emissions, there are many other factors that play a role in the integral eco-costs. The disadvantage of a static crusher, expressed in eco-costs, is primarily determined by the loss of quality, assuming that 10% of the material produced is below the quality required by the Building Materials Decree and will eventually be rejected and dumped. The total eco-costs for the total Netherlands market therefore amount to € 141 million per year.

Since the eco-costs of land use depend on the planning situation, it is not possible to give a general national figure for land use. If we assume that most static crushers are set up on old industrial sites (eco-costs of land use approx. € 0.4 per ton mixed aggregate), then the total eco-costs of land use for the entire country can be estimated as approx. € 5 million per year.
The eco-costs of land use for mobile installations amount to € 0 per ton because, in theory, there is no land use involved.

8.6 Conclusions and discussion

In addition to the practical conclusions discussed in the previous Chapters, a number of more model-related conclusions can be drawn with regard to the EVR model:

1. Methods that only consider emissions (e.g. the 'environmental profile' and 'environmental measures' that are often used in the Netherlands) are insufficient on which to base a comprehensive decision; the tables show that emissions form just a part of the integral environmental problem.
2. Methods that exclude the indirect environmental pollution that exists when manufacturing equipment are insufficient on which to base a comprehensive decision. NB: This indirect form of environmental impact is often neglected in the classic LCA methodology, as the standard allocation procedure has not been sufficiently developed; the EVR model provide a solution here.
3. Although the character of the cases is such that it primarily concerns an analysis of the eco-costs, in a number of cases the EVR provides additional insight (e.g. when comparing several different cases).

It is also important to conclude that, in practice, more multi-criteria decisions are being made. Alongside the quantifiable environmental impact, other aspects often play a role, such as quality requirements and design specifications. Additional aspects concerning sustainability in the construction phase that should also be taken in account include:

- design for recycling;
- design for disassembly;
- high value;
- degradation.