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Estimate of energy consumption and CO_2 emission associated with the production, use and final disposal of sheets made of PVC-P, MDPE and bituminous materials.

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1. Summary

Materials used for waterproofing roofs on buildings include, amongst others, prefabricated sheets, and these can be divided into two major groups: those comprising bituminous materials and those of polymeric origin.

A study was made of the environmental implications of the choice of different materials for manufacture of waterproofing sheets, based on a life cycle assessment of them, which considered the stages of extraction and supply of materials, production of the sheet, installation, use, recycling where this is possible, final disposal and the different stages of transport of materials.

The methodology used is based on a procedure of environmental accounting of energy consumption and CO_2 emission values, in which these indicators have been estimated in each of the stages of the life cycle of the sheet. The end results signify the sum of the energy consumption and CO_2 emission figures equivalent to each of these stages.

Due to the great diversity of possible materials, uses and formations for waterproofing sheets, it was decided to limit the framework of this study to sheets for waterproofing flat, weight-bearing roofs with heavy-duty protection.

Three commercial models of sheets of these characteristics were selected, made of the most representative materials: PVC-P (plasticized polyvinyl chloride), MDPE (ethylene propylene rubber) and SBS elastomer-modified bitumen (polystyrene-butadiene-styrene). The PVC-P and bituminous sheets are shielded with fibreglass.

The sheets made of polymeric materials can include up to 50% recycled materials in their composition.

This study also considers the possibility of producing the polymer sheets out of totally new materials, although this situation is becoming less and less habitual.

Although bituminous materials are susceptible to recycling or re-use, this process tends to imply they will be used as filler material for use in other types of building materials. Using recycled bitumen in the stage of manufacturing the sheet has not, therefore, been taken into consideration.

The impact was evaluated taking two fundamental indicators into account: (1) estimate of energy consumption; and (2) emission of carbon dioxide (CO_2) attributable to the manufacture, use, recycling and final waste disposal of the sheets listed above. The calculation base used was 1 m^2 of sheet. The simplest case was considered: flat roof with no special construction details, such as gutters, structural joints, drains or meets with vertical walls.

Given that the sheets analysed present different mean lifetimes depending on the material, 30 years for PVC-P, 15 years for SBS-modified bitumen and 15 years for MDPE, correction factors have been introduced in order to obtain comparable results, considering a usage period for all of them of 30 years, with

the corresponding replacements in the cases of SBS-modified bitumen sheets and MDPE sheets.

The results obtained indicate that, for the PVC-P sheets with 50% recycled material in their composition, the stage signifying the largest energy consumption and the greatest contribution to CO_2 emissions is that of extraction and supply of materials, representing 57% of the total energy and 55% of emissions.

Next come the stages of production of the sheet (approximately 29-31% of energy consumption and CO_2 emissions) and recycling (11% of energy consumption and 10% of CO_2 emissions).

In the case of MDPE sheets with 50% recycled material, extraction and supply of materials is also the stage with the largest contribution to overall energy consumption, in the region of 54%. Once again, the next stages in terms of importance are production of the sheet (29%) and the recycling process (11%). In all the cases mentioned, the associated CO_2 emissions behave similarly.

The cases considered where the sheets are manufactured with totally new materials display the same trend, although the contribution of the stage of extraction and supply of materials is much greater (in the region of 70%).

Lastly, for the SBS elastomer-modified bitumen sheets, it is noted that the stage with the largest energy consumption is extraction and supply of materials, signifying 50% of the total, followed by the stage of production of the sheet, which takes up 21%.

The sheet presenting the least energy consumption throughout the life cycle is the PVC-P sheet with fibreglass film and 50% recycled material, signifying consumption of 9.5 kWh m^{-2} and emission of 2.7 kg of CO_2 m^{-2}.

The MDPE sheet with 50% recycled material signifies consumption of 22.7 kWh m^{-2} throughout the life cycle, and emission of 6.4 kg of CO_2. 139% and 136% more, respectively, than the corresponding figures for the reference case (PVC-P sheet with 50% recycled material).

In last place, we find the SBS-modified bitumen sheets, signifying consumption of 42.7 kWh m^{-2} after 30 years, and emission of 11.2 kg of CO_2.

In order to evaluate the influence of the use of recycled materials in the composition of the sheet, two cases were studied with totally unused material: PVC-P sheets and MDPE sheets with totally new material. An improvement was noted in the results in the region of 55% when 50% recycled PVC-P is used, in terms of both energy consumption and associated CO_2 emissions, and in the region of 35% for the MDPE sheets with 50% recycled material for both indicators.

2. Background

In waterproofing buildings and civil works generally, membranes and sheets made of different materials are extremely important. They can be classified in two major groups: prefabricated and formed in situ.

This document will consider solely prefabricated sheets, which are in turn subject to multiple classifications, depending on the material they are made of and the use they have been designed for.

A distinction is made, according to their purpose, between sheets for waterproofing roofs in building, sheets for waterproofing ponds and swimming pools, and sheets for waterproofing tunnels and underground construction works.

As far as sheets for waterproofing roofs are concerned, there are in turn two major groups of materials: polymerics (which include PVC-P, MDPE, PE, etc.) and bituminous materials (oxyasphalts, elastomer-modified bitumens, etc.).

In view of the great diversity of uses and materials, it was decided to limit this study to roof waterproofing sheets in building. More specifically, to those used on weight-bearing roofs with heavy-duty protection, with shielding, non-sloping, and not-adhered.

2.1. Objective and calculation bases

This document presents an estimate of energy consumption and carbon dioxide (CO_2) emission attributable to the manufacture, use, recycling and final waste disposal, of sheets made of PVC-P, MDPE and SBS elastomer-modified bitumen.

This focus is based on the consideration of all the stages of a Life Cycle Assessment (LCA), although the scope focuses on the two indicators listed above.

In order to make it possible to produce an analysis enabling comparative results to be obtained, the unit of assessment (the functional unit in an LCA study) used is 1 m^2 of waterproofing sheet for weight-bearing roofs with heavy-duty protection.

The results are intended to be representative for the Iberian Peninsula, whereby the analysis set out below gives priority to the information and conditions for this area.

The sheets chosen were commercially available, and are compliant with the different UNE standards and the NBE-QB-90 standard.

2.2. Contents of the document

A description is given of the stages comprising the life cycle of the sheet, as well as the calculation hypotheses and scenarios for the comparative analysis. The most significant energy consumption figures are indicated, and likewise the make-up of the energy sources defining the CO_2 emission factors.

The results obtained are included in detail and summary form. The estimates obtained are analysed, identifying the alternatives with least energy consumption and CO_2 emissions, in ascending order.

3. The life cycle of a sheet

Figure 3.1 presents the typical life cycle of a sheet, focusing on use of energy and the corresponding emissions into the atmosphere.

The first stage corresponds to extraction of raw materials and supply of materials for production of the sheet.

The next stages to be considered are transport, installation and use of the sheet. It is estimated that PVC-P sheets have a mean lifetime of 30 years, whereas MDPE and bituminous sheets have a mean lifetime of 15 years, with no maintenance-related energy consumption.

Once the sheet's usage period is over, it is then dismantled and transported to a recycling centre. The unrecyclable part is send to a final waste-disposal management site.

Depending on the material, the production stage of the sheet varies. The additives included are different and, in the case of the PVC-P and the elastomer bitumen, a fibreglass support has to be inserted.

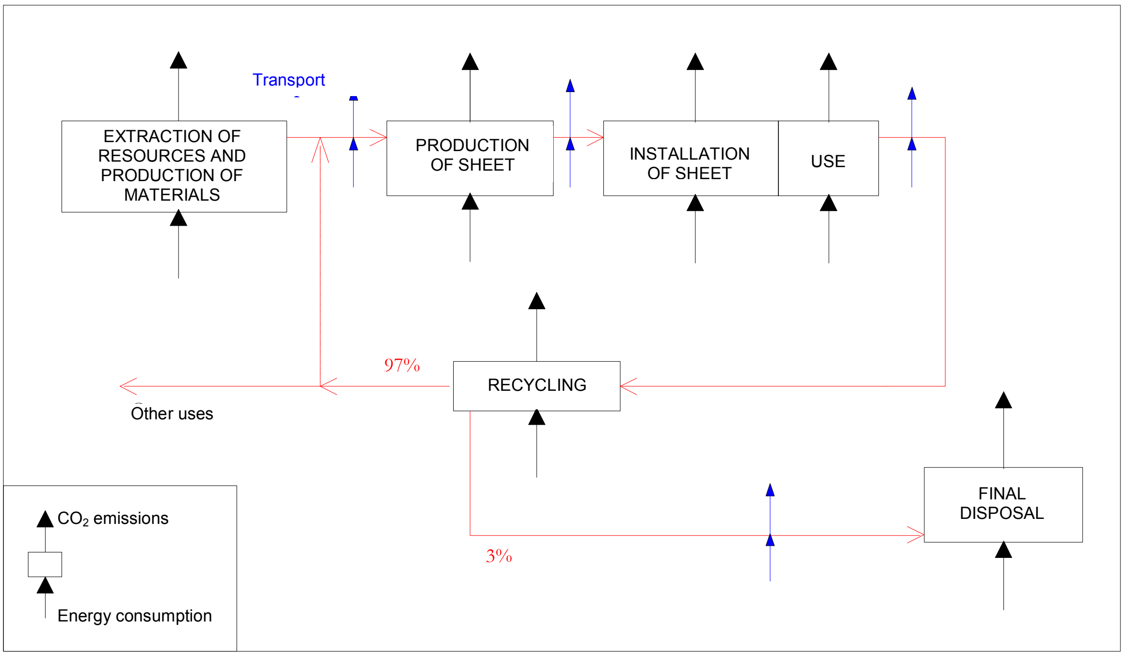

Figure 3.1. Life cycle of a sheet

4. Estimate of energy consumption and CO_2 emission attributable to 1 m^2 of roof waterproofing sheet.

4.1. Calculation base

4.1.1. Dimensions

In order to obtain comparable results, 1 m^2 of commercial sheet in the different materials was chosen.

4.1.2. Materials

The analysis focuses on the estimate of energy consumption and the corresponding CO_2, emissions per square metre of sheets made of:

- *Plasticized PVC* (PVC, chiefly phthalate (DIDP) as plasticizer) *with fibreglass film*.
- *MDPE* (ethylene propylene rubber)
- *SBS elastomer-modified bitumen* (polystyrene-butadiene-styrene) *shielded with fibreglass felt*.

4.1.3. Scenarios analysed

The following cases are analysed:

1) PVC-P sheet with fibreglass film, no recycled PVC.
2) PVC-P sheet with fibreglass film, with 50% recycled material.
3) MDPE sheet, no recycled material.
4) MDPE sheet, with 50% recycled material.
5) Elastomer-modified bitumen sheet (SBS) with fibreglass felt shield.

Figure 4.1 shows an example of sheets of each of these materials.

PVC-P membrane

MDPE membrane

SBS elastomer-modified bitumen membrane

Figure 4.1. Roof waterproofing membranes made of different materials.

It is becoming more and more frequent to include large percentages of recycled material in polymer sheets. Even so, it was decided to use polymer sheets with no recycled material in their composition as the reference standards, in order to enable an analysis of the variation in the results brought about by this factor.

In the case of the bituminous materials, using recycled material for forming the sheet was not considered. The usual practice of recycling rubbers and bituminous materials involves them being used as filler materials in construction, or their recovery in mass for producing road surfacing (CESCA, 2005).

Commercially available sheets were chosen, with the characteristics shown in Table 4.1.

Table 4.1. Characteristics of the roof waterproofing sheets chosen.

	Thickness (mm)	Composition	(% in weight)	Weight (kg m^{-2})
PVC-P sheet	1,2	PVC	60	1.5
		Plasticizer (phthalate)	30	
		Additives	7	
		Fibreglass film	3	
MDPE sheet	1,5	MDPE	100	1.9
SBS elastomer-modified bitumen sheet	40	Bitumen	79	4.3
		SBS	14	
		Fibreglass felt	7	

Sources:
http://www.alkor.es
http://www.firestonebpco.com/roofing/MDPE/rubbergard.aspx
http://www.roofhelp.com/choices/modified/
http://www.chova.com
www.jdkoontz.com/articles/aging.pdf

4.2. Extraction and production of materials

Extraction and production of materials includes the energy required for the extraction of natural resources, transport to the factory and production of the materials used in the sheet, chiefly: PVC, plasticizers for the PVC (phthalate), MDPE (ethylene propylene rubber), bitumen, SBS elastomer (polystyrene-butadiene-styrene), fibreglass and other additives.

For the case of PVC, the energy consumption and CO_2 emission presented in the document "*Estimate of the energy consumption and CO_2 emission associated with unit production of PVC*" (Baldasano and Parra, 2005) were used. The values of the calculation criterion that considers the joint obtention of PVC and caustic soda are used. The energy consumption for the manufacture of PVC is 7.2 kWh kg^{-1} and the associated CO_2 emission factor is 2.0 CO_2 kg^{-1}.

The energy consumption figures for the other materials correspond to the production of MDPE, phthalate, SBS elastomer-modified bitumen and fibreglass, and these were taken from the SimaPro5 database and APME (2004).

For the MDPE, a mean value was taken between production of polyethylene and polypropylene, both of which were taken from the mean values estimated for production of these in Europe, signifying 7.3 kWh kg^{-1} and emissions of 1.7 kg of CO_2 kg^{-1}, and 5.6 kWh kg^{-1} and 1.7 kg of CO_2 kg^{-1} (APME, 2004). The energy consumption for producing MDPE is 6.4 kWh kg^{-1}, and the associated CO_2 emissions are 1.7 kg CO_2 kg^{-1}.

The energy requirement for production of SBS-modified bitumen was estimated based on the energy consumption for producing asphalt and bituminous by-products (SimaPro5), resulting in 0.2 kWh kg^{-1}. It was considered that the energy used to produce it comes from diesel/fuel-oil, in order to quantify the CO_2 emissions into the atmosphere.

For the fibreglass, the energy costs of production were taken from the SimaPro5 database, with estimated consumption of 0.1 kWh kg^{-1}.

It was assumed that the energy consumption for production of SBS polymer can be estimated based on the consumption requirement for producing polystyrene and polybutadiene, as set out in the Eco Profiles for the Plastics Industry (APME, 2004), with the resulting consumption of 13.7 kWh kg^{-1} and emission of 3.0 kg of CO_2 per kg of polymer produced.

The energy consumption for the production of phthalate was estimated based on the "ECO PROFILE of High Volume commodity phthalate esters (DEHP,DINP,DIDP)", (ECPI,2001), with a resulting unit consumption of 7.1 kWh kg^{-1} and emission of 1.8 kg of CO_2 kg^{-1}.

For the additives for the MDPE, these were assimilated to the estimated values for producing these materials, it being considered that their contribution to the overall energy balance was insignificant.

The energy consumption figures for the materials are summarized in Table 4.2.

Table 4.2 Energy consumption figures for extraction of natural resources and production of materials.

Material	Energy consumption (kWh kg^{-1})	Source
PVC	7.19	(Baldasano y Parra, 2005)
MDPE	6.42	(APME, 2004). Eco-profile Polyolefins (APME, 2004). Eco-profile Conversion processes for polyolefins
Phthalate	7.12	(ECPI, 2001)
Fibreglass	0.10	(SimaPro5)
Bitumen	0.18	(SimaPro5)
SBS	13.73	(APME, 2004). Eco-profile Polyolefins (APME, 2004). Eco-profile Conversion processes for polyolefins

4.3. Production of the sheet.

Prefabricated sheets were considered in every case.

The production process is normally performed by extrusion in the case of polymer membranes.

Elastomer bitumen sheets are produced by impregnation. The usual system involves saturation with the bituminous material of a pre-formed shield made of different materials (polymerics, fibreglass, etc.) and subsequent pressing of the product.

The energy consumption for the case of forming PVC-P sheets is estimated at 0.81 kWh kg^{-1}, provided by electricity, and 0.95 kWh kg^{-1}, from natural gas (personal communication Alkor Draka, October 2004).

For MDPE membranes, since the production process involves mixing materials and extrusion, as for the PVC-P, the same energy consumption was taken.

In the case of the bitumen sheets, we have been unable to find a value for the energy consumption for the impregnation and pressing process in the literature consulted. Although the energy consumption for this process does not differ from the estimate for the extrusion process, it was decided not to penalize any sheet in this section, and to assume similar energy consumption figures, by default of more detailed information.

The CO_2 emissions associated with this process are estimated taking into consideration the source of the energy used: electricity and natural gas.

4.4. Installation of the sheet.

Installing waterproofing sheets is a complex process which is regulated in basic building regulations. It depends on the type of roof being considered and on the waterproofing material to be used. The three most commonly used methods are mechanical attachment, use of adhesives, and thermo-welding.

The simplest case of installation was considered: a flat roof, with no special elements (joints, meets with vertical walls, drains or gutters, etc.).

The dimensions of the commercial sheets considered are shown in Table 4.3. The degree of overlap of the sheets depends on the material.

Table 4.3. Dimensions of the commercial sheets taken as the reference standard.

Material	Length (m)	Width (m)	Thickness (mm)
PVC-P	20	1.6	1.2
MDPE	15.2	2	1.5
Elastomer bitumen (SBS)	10	1	40

The usual procedure for installing PVC sheets is thermo-welding, normally using hot air. The estimated energy consumption for this process is 0.01 kWh m^{-2} of sheet, taken from the mean energy consumption of a commercial welding machine. The characteristics of the machine selected are shown in Table 4.4

Table 4.4. Characteristics of the hot-air welding machine taken for reference purposes for installation of the PVC-P sheet.

Automatic COMET welding machine with wedge Company: LEISTER	Thickness of the PVC-P sheet (mm)	Mean welding time (m min^{-1})	Output (W)
General characteristics	1.0 - 2.0	0.8 - 3.2	1200
Characteristics chosen for PVC-P sheet	1.2	1.0	1200

Sheets made of bituminous materials are installed by application of heat, normally using gas blowtorches. The energy consumption associated with this process was estimated based on the mean gas consumption of a commercial blowtorch indicated for this application, and on the estimated mean time required to install 1 m of sheet.

A mean installation speed was estimated of 1.6 m min^{-1}, a commercial gas blowtorch was considered with consumption of 10 kg h^{-1} at 3 bar (Express, 2005). Bearing in mind the lower heating value of butane, 12.7 kWh kg^{-1} (MITYC, 2005), and the time needed to weld a sheet, the consumption figure determined was 1.5 kWh m^{-2} to install the SBS-modified bitumen sheet. The associated CO_2 emissions are estimated based on the emission factor of LPGs, signifying 0.22 kg of CO_2 kWh^{-1}.

For the MDPE sheets, the commonest procedure consists of application of adhesives and silicones. It is assumed that the energy consumption associated with this procedure is limited solely to the energy required to produce the adhesives, normally with a base of polyisobutylene, the consumption associated with its application by the operator being considered negligible.

Installation of non-adhered sheets with heavy-duty protection involves joining the sheets to each other, with a degree of overlap estimated at 150 mm (http://www.firestonebpe.com/roofing/rubbergard/tech_data/tech_manual/_es/, November 2005).

The amount of adhesive required is estimated based on the consumption figures indicated by the actual manufacturers, which results in the need for approximately 0.01 kg of adhesive per m^{-2} of sheet (the overlap adhesive chosen was SA-008, from Giscosa, http://www.giscosa.com/, November 2005). The energy consumption required to produce this compound is considered as 16.6 kWh kg^{-1}, and the associated CO_2 emissions 0.2 kg of CO_2 kWh^{-1}.

The rest of the sheet is ballasted, normally with gravel, as we are considering roofs with heavy-duty protection. The energy consumption consequent to this operation has not been considered; it is assumed to be similar for the three types of sheets analysed.

In special elements and edges of roofs, the installation is usually reinforced using adhesives or priming substances in the case of bituminous materials. As indicated earlier, the energy consumption requirement for this kind of element is not taken into account, nor is its contribution to CO_2 emissions.

The details of the results obtained for installation of the sheet are shown in Table 4.5.

Table 4.5. Estimate of energy consumption and CO_2 emissions consequent to installation of the sheet.

Energy consumption by installation	Installation	Sheet thickness (mm)	Dimensions of commercial reels		Energy consumption (kWh m^{-2})	CO_2 emissions (kg CO_2 m^{-2})
			Width (m)	Length (m)		
PVC-P sheet	Hot-air thermo-welding	1.2	1.6	20	0.01	0.01
MDPE sheet	Adhesive with silicone	1.5	2	15.2	0.18	0.04
Elastomer-modified bitumen sheet (SBS)	Gas blowtorch	40	1	10	1.5	0.3

It must be born in mind that the estimates made signify an approximation to the energy consumption and CO_2 emissions associated with this stage of the life cycle.

4.5. Use of the sheet

The mean lifetime depends on the material the sheet is made of, and on its application.

In the case of weight-bearing roofs with heavy-duty protection, it is estimated that the mean lifetime for PVC is approximately 30 years, for bituminous materials it is around 15 years, since they undergo aging processes (the material cracks and splits), and for the MDPE sheets, 15 years, consequent to the aging of the adhesives used in their installation. This data was supplied by Alkor Draka (personal communication).

Energy consumption consequent to maintenance operations during the usage period of the sheet is considered negligible.

It is, however, born in mind that the sheets present very different lifetimes depending on the material they are made of, and a correction factor will therefore be applied, to offset this difference.
The correction factor consequent to the usage period is detailed in Table 4.6; a period of 30 years is taken for reference purposes, so that, in the case of the MDPE and SBS-modified bitumen sheets, the sheet has to be replaced.

Table 4.6. Correction factors consequent to the different mean lifetimes of the materials.

Material	Mean lifetime	Correction factor (F)
PVC	30 years	1
MDPE	15 years	2
SBS-modified bitumen	15 years	2

4.6. Dismantling

This activity, which is construed as the dismantling (deconstruction) of the sheet, with the aim of making maximum use of the materials through recycling, might require solely labour, and perhaps minor energy consumption.

The basic procedure for polymer sheets consists of disassembling the sheet, washing it, and then crushing it to make the material suitable for the recycling processes.

It is assumed that the energy consumption in this stage is irrelevant.

4.7. Recycling

It is assumed that 97% of the PVC-P, MDPE and SBS-modified bitumen contained in the sheet are recyclable. The remaining 3% is waste which is deposited in a waste disposal site.

The recycling process for any of the sheets is carried out using mechanical methods. To recycle PVC sheets, the electricity consumption used is 0.25 kWh kg^{-1}. A similar energy consumption will be considered for the other materials.

4.8. Final disposal

Energy consumption of 0.155 kWh per kg of waste deposited in a waste disposal site is assumed (Choate and Ferland, 2004). It is considered that the energy is 100% diesel/fuel-oil.

4.9. Transport

It is assumed that the transport connecting the different stages of the life cycle is performed with cargo trucks which run on diesel, and which have an energy demand of 0.00073 kWh km^{-1} kg^{-1} (WEC, 2004). This value is applicable to Western Europe.

A mean distance of 100 km was considered for transport in all the trips required: transport of materials to the production plant, transport of the formed sheet to the installation site, transport for recycling and transport for final waste disposal.

4.10. Emission factors

Table 4.7 shows the basic CO_2 emission factors used in each stage, according to the make-up or type of energy supply as indicated for each case.

Table 4.7. CO_2 emission factors.

Energy source / fuel	Emission factor $t\ C\ TJ^{-1}$ (IPCC, 1996)	$t\ CO_2\ TJ^{-1}$	$t\ CO_2\ MWh^{-1}$
Spanish electrical mix			0.443*
PVC production at Hispavic - Vinilis (Martorell)			0.284*
Production of SBS		2.9	0.220
Production of MDPE		1.7	0.270
Diesel / fuel-oil	20.2	74.1	0.267
Natural gas	15.3	56.1	0.202
Coal	26.2	96.1	0.346

* Deduced in the document: "Estimate of the energy consumption and CO_2 emission associated with unit production of PVC", JM Baldasano and R. Parra. January 2005".
¶ Corresponds to the calculation criterion that considers the objective of joint obtention of PVC and caustic soda.

5. Results and comparative analysis

5.1. Estimate of energy consumption and CO_2 emission figures

The energy consumption and associated CO_2 emission figures for each of the cases studied are shown in Tables 5.1 to 5.5.

The different life cycle stages with the estimated energy consumption figures and corresponding CO_2 emissions are shown in diagram form in Figures 5.1 to 5.5.

Tables 5.6 to 5.8 show a summary of the results obtained for each of the materials.

It is noted that, in the case of the PVC-P sheet, the stage presenting the largest energy consumption is extraction and supply of materials, signifying 72% for sheets made of completely new material, and 57% for sheets with 50% recycled material. The associated CO_2 emissions behave similarly, signifying 71% and 55% of the total in each of the cases.

Next comes the stage of production of the sheet, with a contribution to the overall energy consumption of 18% for sheets with totally new material, and 29% for sheets with 50% recycled material. The relative importance of the energy consumption for recycling is also worth highlighting: around 7% in the first case and 11% in the second. The CO_2 emissions behave similarly.

For the MDPE sheets, either with new materials or with inclusion of recycled material, the relative importance of the different stages remains the same. Assuming extraction and supply of materials to be in the region of 70% of the energy consumption for new MDPE sheets, and in the region of 54% for sheets with 50% recycled material.

In all the cases indicated, the associated CO_2 emissions behave similarly; although there is a certain variation in the value of the exact contribution, the order of the stages in terms of their contribution to it is the same.

Lastly, for the elastomer-modified bitumen, SBS, sheets, it is noted that the stage with the largest energy consumption is extraction and supply of materials, although it signifies just 42% of the total, followed by production of the sheet, which takes up 35%. The CO_2 emissions associated with this stage signify 35% and 42% of the total, respectively.

The sheet presenting the lowest energy consumption throughout the life cycle is the PVC-P sheet with fibreglass film and 50% recycled material,; it signifies consumption of 9.5 kWh m^{-2} and emission of 2.7 kg of CO_2 m^{-2}.

With overall energy consumption 19% higher, we find the PVC-P sheet with no recycled material in its composition, with an energy requirement of 11.3 kWh m^{-2} and emission of 3.2 kg of CO_2 m^{-2}.

Next comes the MDPE sheet with 50% recycled material, which signifies energy consumption of 22.7 kWh m^{-2}, 139% higher than the PVC-P sheet with recycled material (the case taken as the reference standard for the comparison), and emission of 6.4 kg of CO_2 m^{-2}, 136% higher than the reference case.

The MDPE sheets with no recycled material signify consumption of 34.9 kWh m^{-2} and emission of 9.7 kg of CO_2. The variation in comparison with the reference standard, the PVC-P sheet with 50% recycled material, signifies energy consumption 267% higher and CO_2 emissions in the region of 258% higher.

Lastly, we find the SBS-modified bitumen sheets, which require 42.7 kWh m^{-2} and signify emission of 11.2 kg of CO_2. 350% and 314% higher, respectively, than the figures for the reference standard.

Table 5.1. Estimated energy consumption and CO_2 emissions for the different life cycle stages of 1 m² of a PVC-P sheet with fibreglass film for waterproofing roofs.

	Energy consumption (kWh m-2)	%	CO_2 emissions (kg of CO_2)	%
Extraction and supply of materials	10.76	72.32	2.95	70.63
Transport of materials to the production plant	0.11	0.76	0.03	0.72
Production of the sheet	2.73	18.31	0.85	20.40
Transport of the sheet for installation	0.11	0.76	0.03	0.72
Installation	0.01	0.10	0.01	0.15
Use (mean lifetime of 30 years)	--	--	--	--
Dismantling	--	--	--	--
Transport to recycling	0.11	0.76	0.03	0.72
Recycling	1.02	6.85	0.27	6.51
Transport to final disposal	0.01	0.04	0.00	0.04
Final disposal	0.01	0.10	0.00	0.09
TOTAL	14.88	100.00	4.17	100.00
Applying the correction factor consequent to usage time (F=1)	14.88	--	4.17	--

Table 5.2. Estimated energy consumption and CO_2 emissions for the different life cycle stages of 1 m² of a PVC-P sheet with fibreglass film for waterproofing roofs, using 50% recycled material.

	Energy consumption (kWh m-2)	%	CO_2 emissions (kg of CO_2)	%
Extraction and supply of materials	5.38	56.67	1.48	54.64
Transport of materials to the production plant	0.11	1.19	0.03	1.12
Production of the sheet	2.72	28.65	0.85	31.50
Transport of the sheet for installation	0.11	1.19	0.03	1.12
Installation	0.01	0.15	0.01	0.24
Use (mean lifetime of 30 years)	--	--	--	--
Dismantling	--	--	--	--
Transport to recycling	0.11	1.19	0.03	1.12
Recycling	1.02	10.73	0.27	10.07
Transport to final disposal	0.01	0.07	0.00	0.07
Final disposal	0.01	0.15	0.00	0.14
TOTAL	9.50	100.00	2.70	100.00
Applying the correction factor consequent to usage time (F=1)	9.50	--	2.70	--

Table 5.3. Estimated energy consumption and CO_2 emissions for the different life cycle stages of 1 m^2 of an MDPE sheet for waterproofing roofs.

	Energy consumption (kWh m^{-2})	%	CO_2 emissions (kg of CO_2)	%
Extraction and supply of materials	12.20	69.95	3.29	68.15
Transport of materials to the production plant	0.14	0.80	0.04	0.77
Production of the sheet	3.34	19.16	1.04	21.61
Transport of the sheet for installation	0.14	0.80	0.04	0.77
Installation	0.18	1.03	0.04	0.74
Use (mean lifetime: 15 years)	--	--	--	--
Dismantling	--	--	--	--
Transport to recycling	0.14	0.80	0.04	0.77
Recycling	1.29	7.40	0.34	7.12
Transport to final disposal	0.00	0.02	0.00	0.02
Final disposal	0.01	0.05	0.00	0.05
TOTAL	17.44	100.00	4.83	100.00
Applying the correction factor consequent to usage time (F=2)	34.87	--	9.66	--

Table 5.4. Estimated energy consumption and CO_2 emissions for the different life cycle stages of 1 m^2 of an MDPE sheet for waterproofing roofs, using 50% recycled material.

	Energy consumption (kWh m^{-2})	%	CO_2 emissions (kg of CO_2)	%
Extraction and supply of materials	6.10	53.79	1.65	51.69
Transport of materials to the production plant	0.14	1.22	0.04	1.16
Production of the sheet	3.34	29.46	1.04	32.79
Transport of the sheet for installation	0.14	1.22	0.04	1.16
Installation	0.18	1.58	0.04	1.12
Use (mean lifetime: 15 years)	--	--	--	--
Dismantling	--	--	--	--
Transport to recycling	0.14	1.22	0.04	1.16
Recycling	1.29	11.38	0.34	10.81
Transport to final disposal	0.00	0.04	0.00	0.03
Final disposal	0.01	0.08	0.00	0.07
TOTAL	11.34	100.00	3.18	100.00
Applying the correction factor consequent to usage time (F=2)	22.68	--	6.37	--

Table 5.5. Estimated energy consumption and CO_2 emissions for the different life cycle stages of 1 m² of an SBS elastomer-modified bitumen sheet with fibreglass felt shield for waterproofing roofs.

	Energy consumption (kWh m⁻²)	**%**	**CO_2 emissions (kg of CO_2)**	**%**
Extraction and supply of materials	8.9	42	2.0	35.39
Transport of materials to the production plant	0.3	1	0.1	1.50
Production of the sheet	7.6	35	2.4	42.28
Transport of the sheet for installation	0.3	1	0.1	1.50
Installation	1.5	7	0.3	5.73
Use (mean lifetime: 15 years)	--	--	--	--
Dismantling	--	--	--	--
Transport to recycling	0.3	1	0.1	1.50
Recycling	2.3	11	0.6	11.02
Transport to final disposal	0.1	0	0.0	0.35
Final disposal	0.2	1	0.0	0.74
TOTAL	21.4	100	5.6	100.00
Applying the correction factor consequent to usage time (F=2)	42.73	--	11.17	--

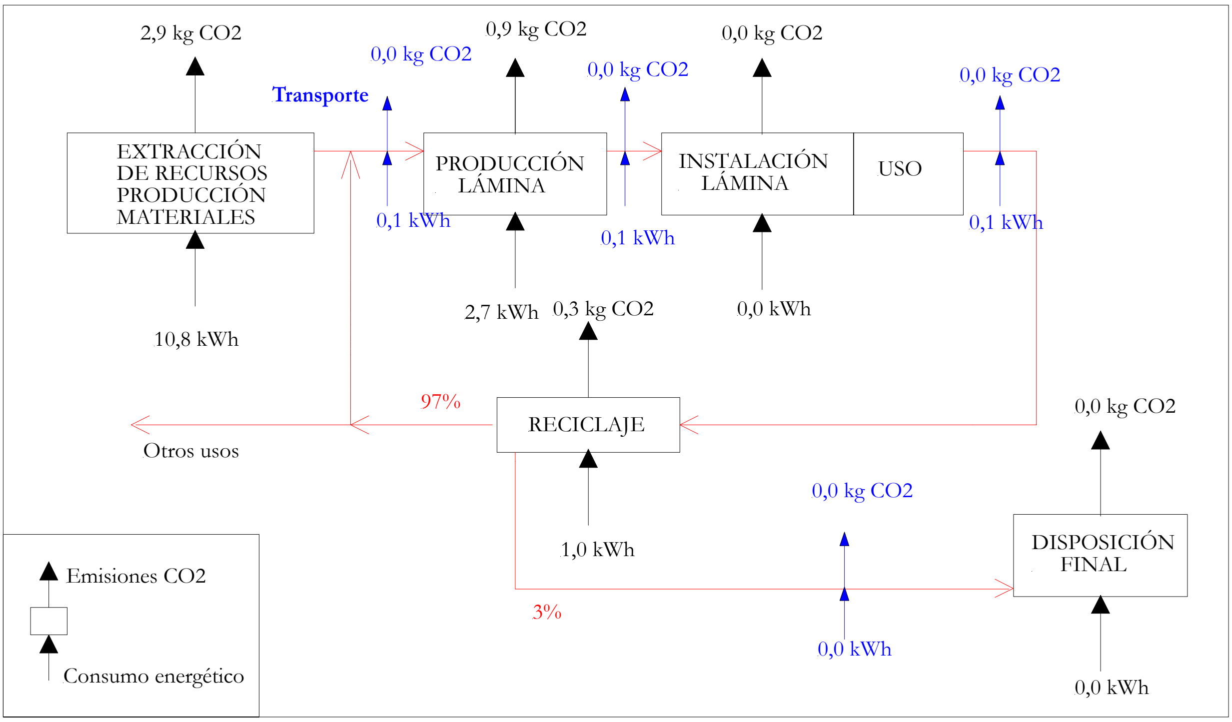

Figure 5.1. Estimate of energy consumption and CO_2 emissions associated with the life cycle of PVC-P sheets for roofs.

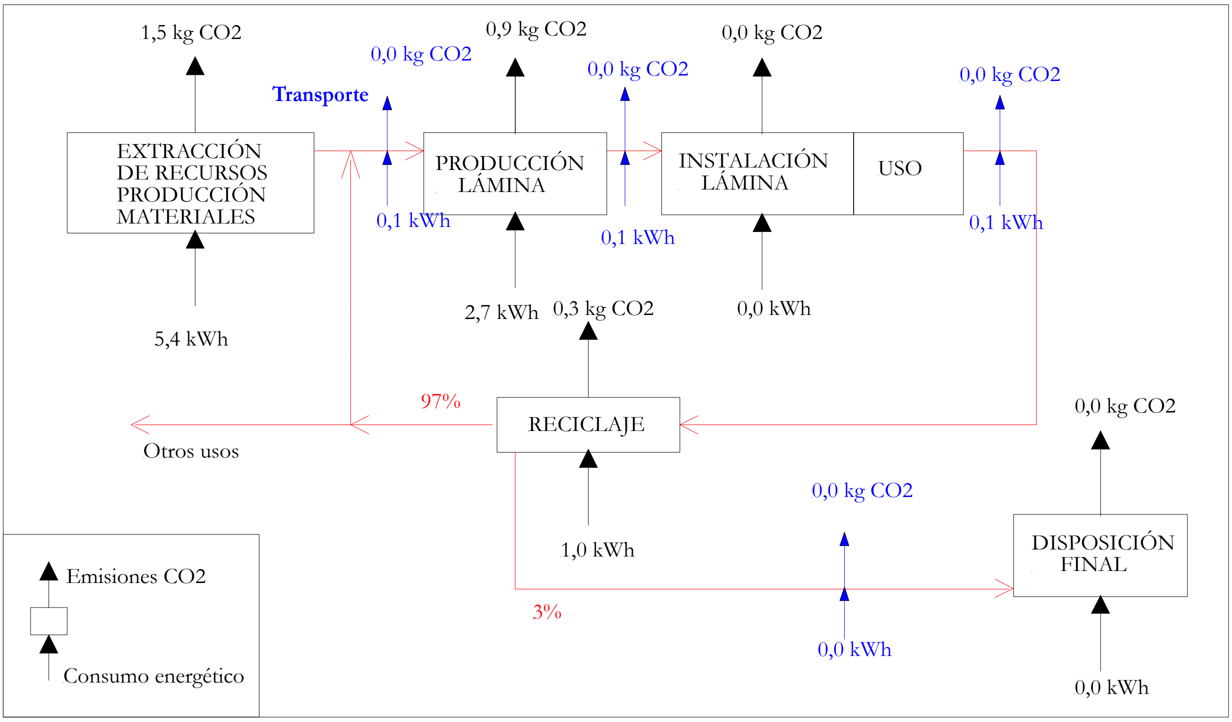

Figure 5.2. Estimate of energy consumption and CO_2 emissions associated with the life cycle of PVC-P sheets for roofs, using 50% recycled material

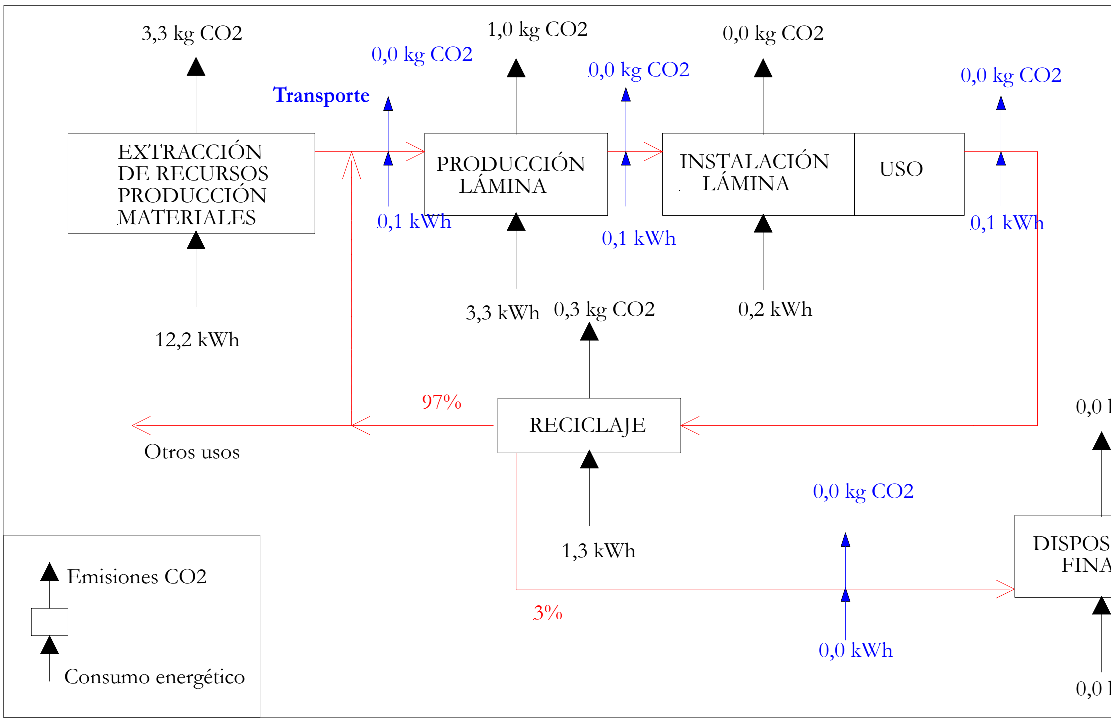

Figure 5.3. Estimate of energy consumption and CO_2 emissions associated with the life cycle of MDPE sheets for roofs.

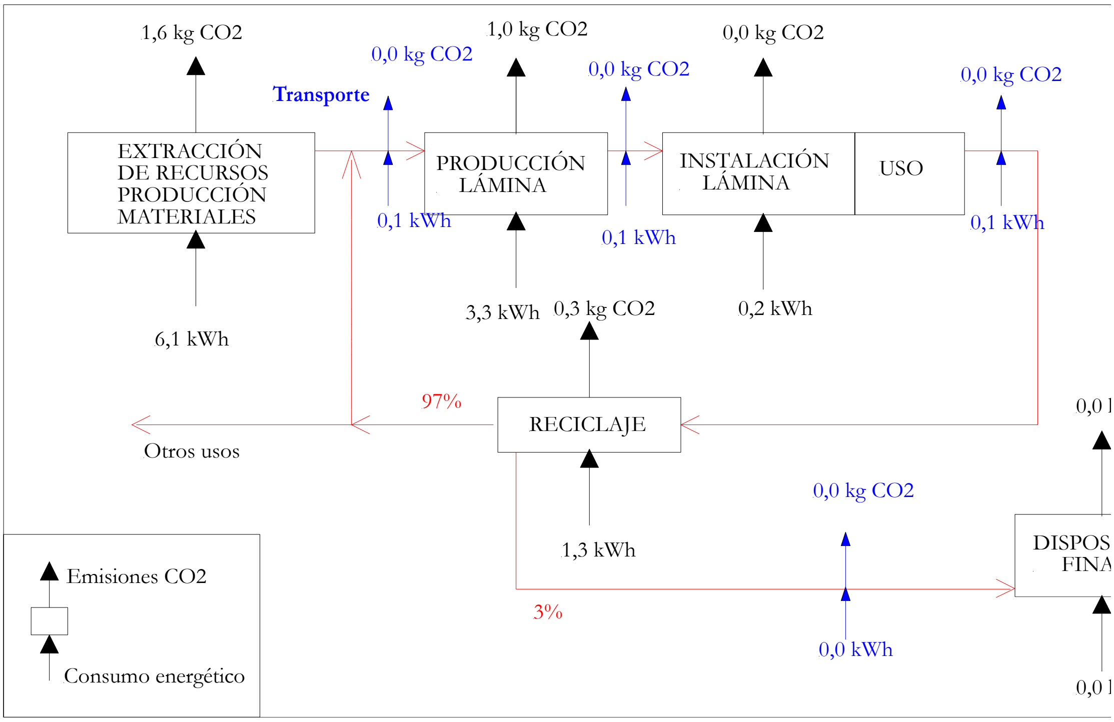

Figure 5.4. Estimate of energy consumption and CO_2 emissions associated with the life cycle of MDPE sheets for roofs, using 50% recycled material

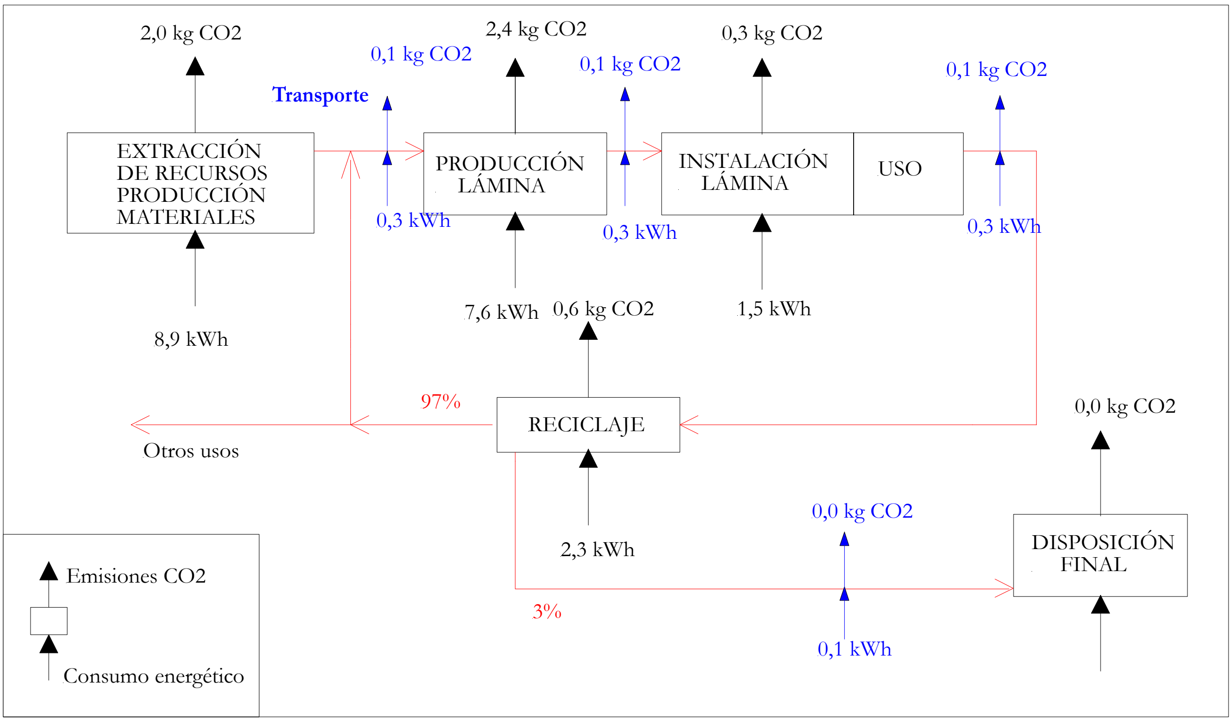

Figure 5.5. Estimate of energy consumption and CO_2 emissions associated with the life cycle of SBS elastomer-modified bitumen sheets for roofs

Table 5.6. Estimated energy consumption for each of the life cycle stages of sheets made of different materials. Summary.

1m² of sheet for waterproofing roofs	Energy consumption (kWh m⁻²)				
	PVC	**PVC with 50% recycled material**	**MDPE**	**MDPE with 50% recycled material**	**SBS-modified bitumen**
Extraction and supply of materials	10.8	5.4	12.2	6.1	8.9
Transport of materials to the production plant	0.1	0.1	0.1	0.1	0.3
Production of the sheet	2.7	2.7	3.3	3.3	7.6
Transport of the sheet for installation	0.1	0.1	0.1	0.1	0.3
Installation	0.0	0.0	0.2	0.2	1.5
Use (mean lifetime)	30 years	30 years	15 years	15 years	15 years
Dismantling	negligible	negligible	negligible	negligible	negligible
Transport to recycling	0.1	0.1	0.1	0.1	0.3
Recycling	1.0	1.0	1.3	1.3	2.3
Transport to final disposal	0.0	0.0	0.0	0.0	0.1
Final disposal	0.0	0.0	0.0	0.0	0.2
Total	14.9	9.5	17.4	11.3	21.4
TOTAL (Taking 30 years as the reference standard)	**14.9**	**9.5**	**34.9**	**22.7**	**42.7**

Table 5.7. Estimated CO_2 emissions for each of the life cycle stages of waterproofing sheets made of made different materials. Summary.

1m² of sheet for waterproofing roofs	CO_2 emissions (kg CO_2 m^{-2})				
	PVC	**PVC with 50% recycled material**	**MDPE**	**MDPE with 50% recycled material**	**SBS-modified bitumen**
Extraction and supply of materials	2.9	1.5	3.3	1.6	2.0
Transport of materials to the production plant	0.0	0.0	0.0	0.0	0.1
Production of the sheet	0.9	0.9	1.0	1.0	2.4
Transport of the sheet for installation	0.0	0.0	0.0	0.0	0.1
Installation	0.0	0.0	0.0	0.0	0.3
Use (mean lifetime)	30 years	30 years	15 years	15 years	15 years
Dismantling	negligible	negligible	negligible	negligible	negligible
Transport to recycling	0.0	0.0	0.0	0.0	0.1
Recycling	0.3	0.3	0.3	0.3	0.6
Transport to final disposal	0.0	0.0	0.0	0.0	0.0
Final disposal	0.0	0.0	0.0	0.0	0.0
Total	4.2	2.7	4.8	3.2	5.6
TOTAL (Taking 30 years as the reference standard)	**4.2**	**2.7**	**9.7**	**6.4**	**11.2**

Table 5.8. Summary of energy consumption figures and associated CO_2 emissions for 1 m² of roof waterproofing sheets made of different materials.

Material	**Weight (kg m^{-2})**	**Sheet thickness (mm)**	**Energy consumption (kWh m^{-2})**	**% variation vs. PVC-P**	**CO_2 emissions (kg CO_2)**	**% variation vs. PVC-P**
PVC-P (50% recycled material)	1.5	1.2	9.5	reference	2.7	reference
PVC-P	1.5	1.2	14.9	56.7	4.2	54.6
MDPE (50% recycled material)	1.9	1.5	22.7	138.7	6.4	135.8
MDPE	1.9	1.5	34.9	267.1	9.7	257.7
Elastomer bitumen (SBS)	4.3	40.0	42.7	349.8	11.2	313.9

6. Conclusions

This document presents the estimates of energy consumption and of CO_2 emissions associated with the production, use, recycling and final waste disposal attributable to sheets for waterproofing roofs on buildings, which are weight-bearing, flat, non-adhered and with heavy-duty protection, made of PVC-P, MDPE and SBS elastomer-modified bitumen.

In every case, the calculation base taken was 1 m^2 of sheet.

The focus covers all the stages of a Life Cycle Assessment, although solely the two environmental aspects indicated above are analysed; and it aims for the results to be representative for the Iberian Peninsula, in terms of both consumption figures and the make-up of energy sources. To this end, priority has been given to the information for this area; however, the analysis is complemented with information on a European or international scale.

The characteristics of the different sheets analysed were taken from available commercial products intended for the purpose described.

The sheets considered were PVC-P and MDPE sheets produced with 50% recycled materials, and SBS-modified bitumen sheets. The study also included the cases in which the sheet is made of completely new PVC-P and MDPE, although nowadays, larger percentages of recycled polymeric material are more and more frequently being included.

The mean lifetimes estimated for each sheet vary greatly depending on the material, being around 15 years for the MDPE and the SBS elastomer-modified bitumen sheets, and 30 years for the PVC. In view of this, the PVC-P sheet was chosen as the reference standard for calculation of the energy consumption and the CO_2 emissions associated with the life cycle, applying correction factors to the sheets made of the other two materials, in order to establish the results based on the same period of time (30 years).

The sheet presenting the best results in terms of the above indicators is the PVC-P sheet with 50% recycled material in its composition. It is followed by the totally new PVC-P sheet.

Next come the MDPE sheets with 50% recycled material and MDPE sheets with totally new materials, signifying energy consumption figures after 30 years in the region of 140% and 270% higher than the case taken as the reference standard: PVC-P sheet with 50% recycled material. In parallel to this, the associated CO_2 emissions would be 140% and 260% higher.

The most unfavourable case in terms of the environmental indicators considered is the SBS-modified bitumen sheet.

In general, it is noted that using recycled materials for production of the sheet signifies an improvement in the results. In the case of the PVC-P, using 50% recycled material signifies a 57% reduction of energy consumption, and 55% in terms of CO_2 emissions.

In the case of the MDPE sheets, improvements are obtained in the region of 34% for energy consumption and 35% for the associated CO_2 emissions when 50% recycled materials are used.

Production of this type of sheeting with totally new materials is becoming less and less common at industrial level.

7. References

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