



Departament de Projectes
d'Enginyeria

UNIVERSITAT POLITÈCNICA DE CATALUNYA

Environmental Modelling Laboratory

Estimate of energy consumption and CO₂ emission associated with the production, use and final disposal of PVC, HDPE, PP, ductile iron and concrete pipes

Dr. José María Baldasano Recio

Dr. Pedro Jiménez Guerrero

María Gonçalves Ageitos

Dr. René Parra Narváez

Report: PVC-Tub-200512-2

Barcelona, December 2005

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1. Summary

Pipes are a fundamental element in engineering and construction. They are used to carry all kinds of fluids, and the material they are made of depends on the purposes they are intended for. In view of this large variety, we wanted to limit the framework of this study to the two commonest types of pipes: pipes for carrying drinking water and drainage and sanitation pipes.

The environmental impact of the choice of the construction material of these two types of pipes was determined; to this end, a life cycle assessment was made, considering the stages of extraction and supply of materials, production of the pipe, installation and use, recycling in the cases where this is possible, and final disposal of waste materials.

The reference materials taken for the comparative study were polyvinyl chloride (PVC), high-density polyethylene (HDPE), polypropylene (PP), concrete and ductile iron, the latter two being historically the most widely used for the two types of pipes analysed. In the case of the PVC, pipes made of conventional PVC and of bioriented PVC (product in which the polymer chains are stretched in two directions of space, resulting in a higher-performance material) were taken into consideration.

In all cases, the pipes were considered to be underground pipes with an average lifetime of 50 years, with a maintenance protocol which would involve two checks per year. Schedule 1 considers a stage of recovery or recycling of the pipe material, except in the case of the concrete, where it was considered that the entire pipe is taken for final disposal.

The impact was evaluated taking two fundamental indicators into consideration: (1) estimate of energy consumption; and (2) emission of carbon dioxide (CO₂) attributable to the manufacture, use, recycling and final waste disposal, of the pipes divided into the two groups indicated above: pipes for carrying drinking water and sanitation pipes.

The calculation base used was sections of pipe 3 m in length, free from accessories in every case.

The methodology used is based on a procedure of environmental accounting of energy consumption and CO₂ emission values, in which these indicators have been estimated in each of the stages of the life cycle of drinking water and sanitation pipes (extraction and supply of material, production of the pipe, transport for installation and use). The end results signify the sum of the energy consumption and CO₂ emission figures equivalent to each of these stages.

RP10 pipes for carrying drinking water with a rated diameter of 110 mm (RD) were chosen for PVC and bioriented PVC, and the corresponding diameters in ductile iron and HDPE pipes involving an inner diameter greater than or equal to same, to ensure they will carry the same flow at the same or a lower speed. The resulting commercial rated diameters are 125 mm for both HDPE and ductile iron pipes.

It should be born in mind that the RD110 bioriented PVC pipe has a greater hydraulic capacity than the conventional PVC taken for reference purposes, and the material thickness is less.

In the case of sanitation pipes, in which the flow of fluid takes place at atmospheric pressure and without propulsion, an RD315 PVC pipe was taken for reference purposes, with the following elements for comparison: bioriented PVC pipes with a rated diameter of 315 mm, corrugated PP pipes and corrugated HDPE pipes with a rated diameter of 400 mm, and bulk concrete pipes with a rated diameter of 400 mm, without taking their different deformation behaviour into account.

For the PVC, corrugated PE and corrugated PE pipes for sanitation* and the ductile iron pipe for supply, an additional analysis was made of the variation of the results in the event 80% in weight of recycled materials are used to manufacture the pipes.

In considering pipes for carrying drinking water, the most important stage in terms of energy consumption and CO₂ emissions for all of them, except the ductile iron with 80% recycled material, is that of use of the pipe, in which the consumption and emission figures for pumping a flow-rate of 0.012 m³ s⁻¹, obtained as the flow-rate conveyed along an RD110 PVC pipe for a typical speed of 1.5 m s⁻¹ fluid displacement, were taken into consideration.

In the case of sanitation pipes, the fluid is not usually pump-driven, whereby the energy consumption in the usage stage is limited to maintenance operations, the contribution of which was considered negligible in respect of the whole.

The determinant stage of energy consumption and CO₂ emissions into the atmosphere in this case is extraction and supply of materials (signifying in the region of 80% of the total), except for concrete. Even in cases where 80% recycled materials were used, this stage signifies between 50 and 70% of the total. In the case of concrete, the largest energy consumption stage is production of the pipe, amounting to 53% of the total. The intermediate stages of transport become highly important in this case, consequent to the high specific gravity of the material.

In the case of **pipes for carrying drinking water**, the bioriented PVC pipe is the one with the least energy consumption, 828 kWh, and least CO₂ emissions, 363 kg of CO₂ for each 3 m section of pipe, without accessories. The conventional PVC pipe signifies energy consumption of 1,041 kWh, and emission of 452 kg of CO₂ for each 3 m section of pipe.

The pipe showing the next most favourable results is the HDPE pipe, with energy consumption of 1,055 kWh and CO₂ emissions of 454 kg; i.e. 1.3% and 0.4% more than the PVC.

* Pursuant to the Technical Provisions for Supply Pipes, recycled HDPE or PVC may not be used for pipes intended to carry drinking water (MOPU, 1974)

The unrecycled ductile iron pipe shows the poorest results from the perspective of energy consumption and CO₂ emissions, requiring 1,620 kWh per 3 m of pipe, and generating emissions of 681 kg of CO₂ into the atmosphere.

In terms of **sanitation pipes**, the best results for energy consumption correspond to the RD400 corrugated PP pipe, using 80% recycled material for manufacture, with energy consumption for every 3 m of pipe of 60 kWh, and emissions of 22 kg of CO₂ (77% and 72% less than the base scenario chosen: the RD315 PVC pipe without recycled material).

The RD400 corrugated PE pipes with 80% recycled material show energy consumption of 64 kWh and production of 21 kg of CO₂, these values are 75% and 73% lower than for the PVC pipes without recycled material, respectively.

Next come the RD315 PVC pipes with 80% recycled material, which signify energy consumption of 69 kWh, and emission of 22 kg of CO₂ (74% and 71% less than if no recycled PVC were used to make the pipe).

As can be seen from the results shown, the behaviour of the three plastic materials is very similar compared to the base scenario, and no significant differences are appreciated in the choice of one material or another.

In the case of not considering using recycled material, and considering the energy consumption figures in ascending order, we find the corrugated PP pipes not including recycled material, the corrugated PE pipes without recycled material, the bioriented PVC pipes, the PVC pipes without recycled material and the RD400 concrete pipes. As regards associated CO₂ emissions in ascending order, we find the corrugated PE pipes, the corrugated PP pipes, the bioriented PVC pipes, the conventional PVC pipes, and lastly the concrete pipes, with an associated energy consumption of 345 kWh and 129 kg of CO₂.

It should be born in mind that, although at present the use of recycled PVC in manufacture of bioriented PVC is not usual, it is, however, a 100% recyclable material, and re-use of it seems likely in the future.

Introducing recycled material in the manufacture of this type of pipes would bring about a reduction in energy consumption as regards extraction and supply of materials. In the case of sanitation pipes, it was noted that this stage is a determinant factor in terms of energy consumption and CO₂ emissions, whereby introducing recycled materials into their manufacture, together with the low specific gravity of the material, could bring about significant changes to the results.

2. Background

Pipes are a basic element in engineering works: industries, homes, supply networks, etc. They provide a series of services, of which we could highlight:

- Distribution of all types of fluids
 - drinking water
 - natural gas and other heating fluids
 - sanitation and waste waters
 - industrial fluids
- Heating systems
- Irrigation systems

The pipe's characteristics will depend on its use, on the properties of the fluid to be conveyed, and its end purpose. This study will consider fundamentally pipes for carrying drinking water, pressurized, and pipes for carrying sanitation and waste waters, free surface flow.

To select a particular type of pipe, the most widely used and best known materials, the use of materials, and the construction and maintenance costs are taken into consideration.

The parameters that define the pipe are the construction material, the rated diameter, and its thickness, as well as specific parameters relating to these, such as the roughness of its walls, the hydraulic capacity, or the rated pressure (RP) it can withstand.

Over recent years, with the gradual implementation of more restrictive environmental legislation in terms of emissions into the atmosphere (primary pollutants and greenhouse gases), the promotion of energy efficiency, cleaner production, and the use of the best techniques available, there is interest in objectively analysing the environmental impact from the perspective of the life cycle assessment consequent to the extraction of raw materials, manufacture, use and final disposal, of pipes made of different materials.

In distribution of drinking water, the materials traditionally most commonly used are ductile iron or copper. These days, there are other types of materials conditioned for this purpose, such as high-density polyethylene (HDPE) or PVC (Krähling and Spindler, 2005).

In the case of sanitation pipes, a distinction is made between those formed in situ and prefabricated pipes. In this latter case, the materials most commonly used are concrete, PVC and corrugated PE and PP.

In both cases, bioriented PVC is currently being introduced; this material has a molecular structural arrangement in two-directions of space, which gives it improved characteristics in comparison with conventional PVC.

2.1. Objective and calculation bases

This document presents an estimate of the energy consumption and of the emission of carbon dioxide (CO₂) attributable to the manufacture, use, recycling and final waste disposal, of pipes made of PVC, bioriented PVC, HDPE, corrugated PE, corrugated PP, concrete and ductile iron.

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

In order to make it possible to produce an analysis enabling comparative results to be obtained, a unit of assessment (the functional unit in an LCA study) of each of the two basic types was selected: sanitation pipes and pipes for carrying drinking water.

Sections of standard pipe 3 m in length of the different materials were selected as the calculation base.

To carry drinking water, the pipes studied were PVC, bioriented PVC with RD 110 mm, 125 mm HDPE and 125 mm ductile iron.

For sanitation, the pipes selected were PVC and bioriented PVC with RD 315 mm, corrugated PE with RD 400 mm, corrugated PP with RD 400 mm, and bulk concrete with RD 400 mm.

The criterion applied in the choice of the diameters indicated above was to keep to a minimum hydraulic capacity for all the pipes. The reference pipes taken were the PVC pipes selected both for carrying drinking water and for sanitation, a typical fluid flow speed was assumed (1.5 m s⁻¹ for supply, 5 m s⁻¹ for plastic pipes and 3 m s⁻¹ for concrete pipes in sanitation) and, from the flow-rate obtained for the PVC pipes, the commercial diameters for the pipes made of the other materials enabling this flow-rate to be carried were chosen. Pipes were considered in the different materials with an inner diameter greater than or equal to the base PVC pipe, so that the fluid flow speed for the same flow-rate would be less than or equal to the speed in the PVC pipe.

2.2. Contents of the document

A description is given of the stages comprising the life cycle of the pipe, as well as the calculation hypotheses and scenarios for the comparative analysis. The magnitudes of the most significant energy consumption figures are indicated, as well as the composition of the energy sources defining the CO₂ emission factors.

The results obtained are set out in detail and summary form. The estimates obtained are analysed, identifying the alternatives with the lowest energy consumption and CO₂ emission values, in ascending order.

3. The life cycle of a pipe

Figure 3.1 shows the typical life cycle of a pipe, focusing on the energy use and the corresponding atmospheric emissions of CO₂. It should be born in mind that, in the case of underground pipes, the recycling and final disposal stages do not usually take place; the pipe is normally abandoned (Figure 3.2).

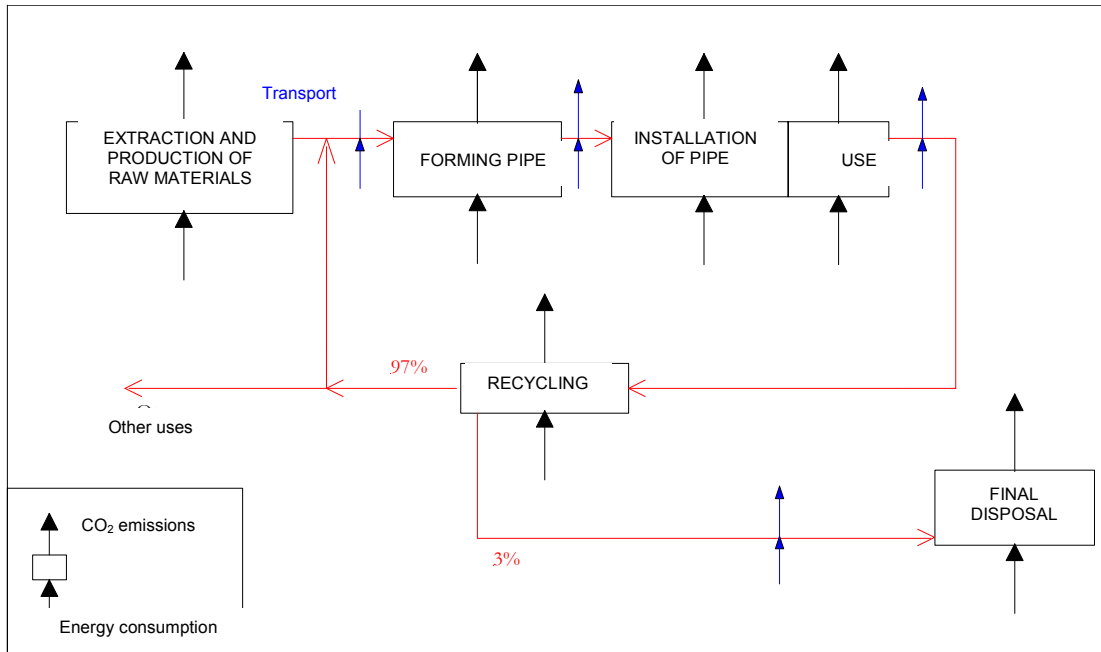


Figure 3.1. Flowchart of the theoretical life cycle of a pipe

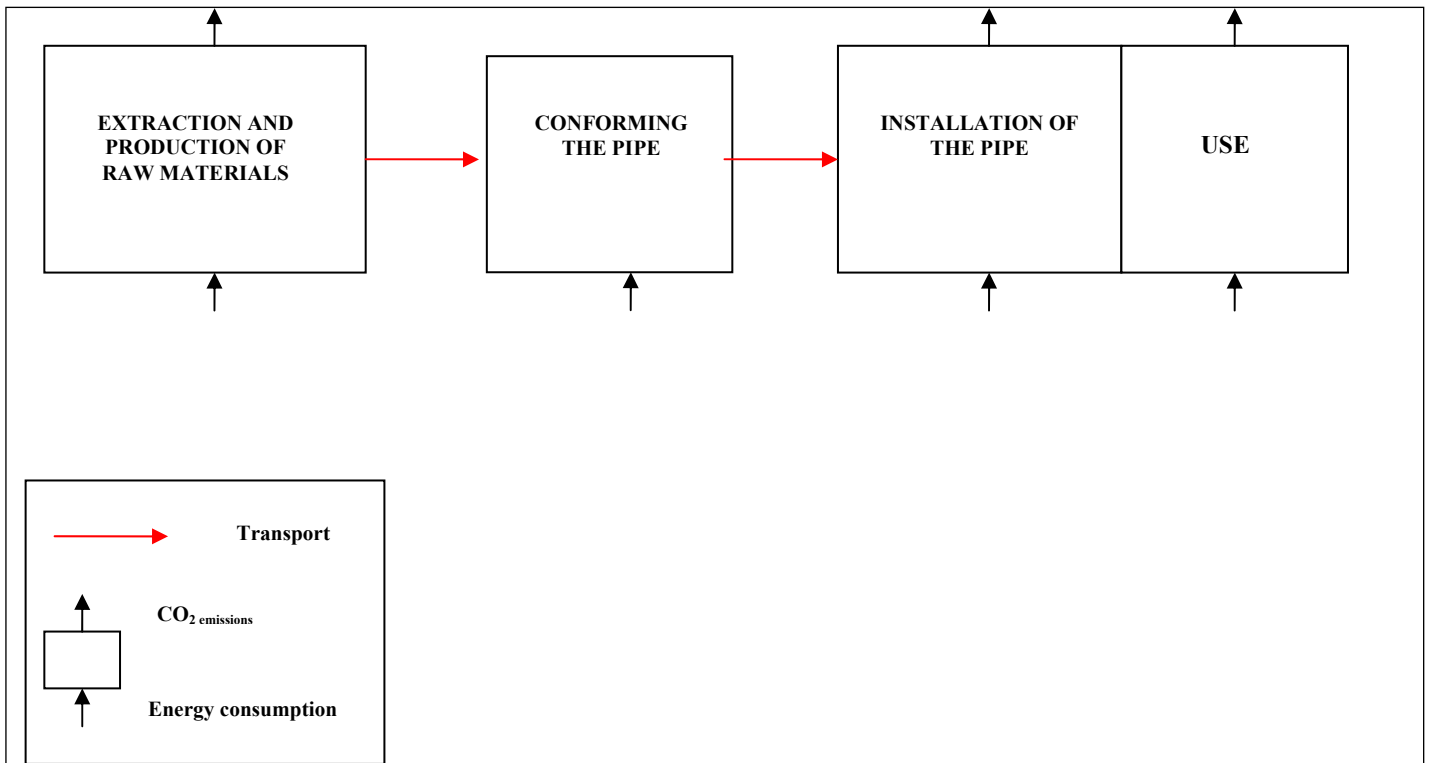


Figure 3.2. Flowchart of the life cycle of an underground pipe.

The methodology used is based on a procedure of environmental accounting of energy consumption and CO₂ emission values, in which these indicators have been estimated in each of the stages of the life cycle of drinking water pipes and sanitation pipes (extraction and supply of materials, production of the pipe, transport for installation, use, disposal in a waste disposal site; and also transport to recycling and recycling, when applicable). The end results signify the sum of the energy consumption and CO₂ emission figures equivalent to each of these stages.

The first stage consists of the stage of extraction of raw materials and forming of the pipe.

The second stage consists of the process of installing the pipe. A section of underground pipe is considered; i.e. digging the trench, laying the pipe and filling in with sand bed are considered.

The usage stage of the pipe depends on the materials used, but in general, this signifies a long period of time. The mean lifetime considered was 50 years for all the pipes.

In general, during this lifetime, periodic inspections and maintenance activities need to be carried out. It is considered that the inspections and maintenance operations required are carried out according to a set schedule, involving two checks per year.

On another note, the different roughness of the materials and the different ageing processes they undergo (build-up of incrustations, etc.) signify that the load losses throughout the length of the pipe are different, and this would need to be taken into account in its usage period.

From a theoretical viewpoint, the final stages of the life cycle correspond to the stage of removing the pipe and recycling the material wherever possible, and final disposal in a disposal site. The reality is that this occurs solely in supply and drainage pipes laid above ground, which are few in number compared to underground supply and sanitation pipes. In this case, pipes becoming obsolete are usually abandoned. This study has not taken the stages of recycling and final waste disposal into account (as was mentioned above; for purposes of illustration, they are included in Schedule 1).

Figure 3.3 presents the stages of forming and use of the PVC pipes, in detail. The PVC resin is mixed with certain additives to produce powder. This mixture is subjected to a hot-extrusion process, via which the pipe is made.

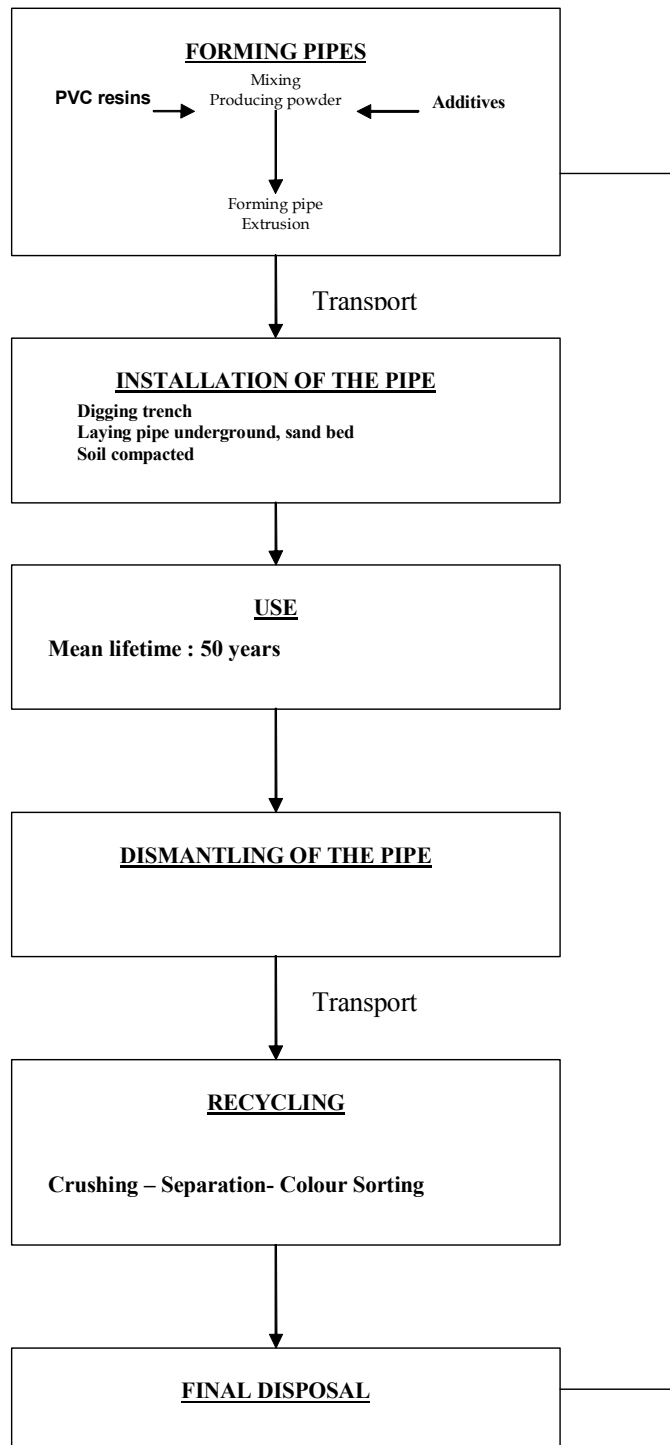


Figure 3.3. Flowchart of the theoretical life cycle of a PVC pipe

4. Estimate of energy consumption and CO₂ emission attributable to a section of pipe 3 m in length

4.1. Calculation bases

4.1.1. Dimensions

Two basic types of pipe are analysed: for carrying drinking water and for sanitation; a section of standard pipe 3 m in length, without accessories, will be selected as the reference standard.

4.1.2. Materials

The analysis focuses on the estimate of energy consumption and the corresponding CO₂ emissions for the two types of pipe considered. The construction materials selected were:

Supply:

- PVC
- Bioriented PVC
- High-density Polyethylene (HDPE)
- Ductile Iron

Sanitation:

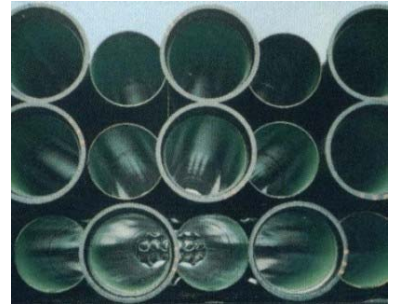
- PVC
- Bioriented PVC
- Corrugated Polyethylene (PE)
- Corrugated Polypropylene (PP)
- Concrete



PVC



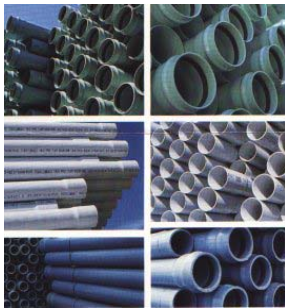
HDPE



DUCTILE IRON



Bioriented PVC



PVC



Corrugated PE/PP



CONCRETE

Figure 4.1. Pipes made of different materials.

4.2. Scenarios analysed

The following cases are analysed:

a) PIPES FOR CARRYING DRINKING WATER

- 1) 3 m of PVC pipe with a diameter of 110 mm, not including recycled PVC.
- 2) 3 m of bioriented PVC with a rated diameter of 110 mm, not including recycled material.
- 3) 3 m of HDPE pipe with a rated diameter of 125 mm, not including recycled material.
- 4) 3 m of ductile iron pipe for carrying drinking water, with a rated diameter of 125 mm.
- 5) 3 m of ductile iron pipe for carrying drinking water, with a rated diameter of 125 mm, including 80% recycled material.

b) SANITATION PIPES

- 1) 3 m of PVC pipe with a rated diameter of 315 mm, not including recycled PVC.
- 2) 3 m of PVC pipe with a rated diameter of 315 mm, including 80% recycled PVC.
- 3) 3 m of bioriented PVC with a rated diameter of 315 mm, not including recycled PVC.
- 4) 3 m of bulk concrete pipe with a diameter of 400 mm, not including any recycled component.
- 5) 3 m of corrugated HDPE pipe with a rated diameter of 400 mm, not including recycled HDPE.
- 6) 3 m of corrugated HDPE pipe with a rated diameter of 400 mm, including 80% recycled HDPE.
- 7) 3 m of corrugated PP pipe with a rated diameter of 400 mm, not including recycled PP.
- 8) 3 m of corrugated PP pipe with a rated diameter of 400 mm, including 80% recycled PP.

In this case, the Technical Provisions for supply pipes (MOPU, 1974) have been taken into consideration; these forbid the use of recycled PVC and HDPE for pipes for carrying drinking water.

In the case of the pipes for carrying drinking water, the reference standard chosen was a PVC pipe with a rated diameter of 110 mm, able to withstand a rated pressure of 10 Atm. For sanitation pipes (MOPU, 1986), in which the fluid flows at atmospheric pressure, the reference standard chosen was a PVC pipe with RD 315 mm (UNE 53 332/81).

Assuming a typical mean flow speed of 1.5 m s⁻¹ for supply and 5 m s⁻¹ for sanitation, the flow-rate conveyed in this pipe was estimated and the comparative elements selected were pipes made of the other materials, allowing this flow to be carried at the same speed or at lower speeds, in the event appropriate commercial diameters were not available. In the case of the concrete sanitation pipe, we sought to obtain speeds in the region of 3 m s⁻¹, this being the typical mean speed of these pipes. Resulting in the reference standard cases described above and specified in Table 4.1.

Table 4.1. Characteristics of the standard pipes selected.

	Material	RD (mm)	Inner Ø (mm)	Th (mm)	Outer Ø (mm)	speed (m s ⁻¹)	Q (m ³ s ⁻¹)	Weight (kg m ⁻¹ pipe)
SUPPLY PIPES								
RP 10	PVC	110	99.4	5.3	110	1.5	0.012	2.7
	Bioriented PVC	110	105.2	2.4	110	1.4	0.012	1.1 (6)
	HDPE	125	102.2	11.4	125	1.4	0.012	3.8
	Ductile iron	125	125.6	9.2 (3)	144	0.9	0.012	21.6 (5)
SANITATION PIPES								
Atm. P	PVC	315 (1)	299.6	7.7	315	5.0	0.35	11.5
	Bioriented PVC	315 (1)	301.2	6.9	315	5.0	0.35	9.4 (6)
	Corrugated PP	400 (1)	343	28.5(4)	400	3.8	0.35	9.8
	Corrugated HDPE	400 (1)	343	28.5 (4)	400	3.8	0.35	9.8
	Concrete	400 (2)	400	42	484	2.8	0.35	134.1

(1) Rated diameter = outer pipe diameter (MOPU, 1974)

(2) Rated diameter = inner pipe diameter (MOPU, 1974)

(3) 3 mm cement mortar + 6,2 mm ductile iron pipe wall.

(4) Apparent thickness. The actual thickness of the pipe wall is 2.3 mm.

(5) 18,9 kg m⁻¹ ductile iron + 2.7 kg m⁻¹ cement

(6) To calculate the weight per metre of bioriented PVC, a mean density was taken between the values established by UNE 53020 standard (1350-1460 kg m⁻³)

4.3. Extraction and production of materials

An estimate is made of the energy required for extraction of natural resources and transport to the factory.

For the case of PVC pipes, the energy consumption and CO₂ emission presented in the document "*Estimate of the energy consumption and CO₂ 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 7.19 kWh kg⁻¹ and the associated CO₂ emission factor is 2.04 t CO₂ t⁻¹.

For the HDPE pipes, the mean values estimated for producing this polymer in Europe are considered, signifying 6.23 kWh kg⁻¹ and emissions of 1.60 kg CO₂ kg⁻¹ (APME, 2004). The energy consumption to produce the PP is 5.55 kWh kg⁻¹ and the associated emissions are 1,70 kg CO₂ kg⁻¹.

In the case of bulk concrete, the typical composition for manufacturing pipes is 10-15% volume of Portland cement, between 60 and 75% aggregate (sand and gravel), and between 15 and 20% water. Bearing in mind that the maximum water/cement ratio permitted by ASTM C76 standard is 0.53 and it must be between 0.33 and 0.45 inclusively, the mean composition shown in Table 4.2 (Fernández, 1989) has been chosen. To estimate the energy consumption for production of bulk concrete, the reference value taken was 0.26 kWh kg⁻¹ (Baird *et al.*, 1997), it is considered that this energy is provided 70% by fuel-oil or diesel and 30% the Spanish electrical mix to calculate the corresponding CO₂ emissions, resulting in 0.083 kg CO₂ kg⁻¹ concrete.

Table 4.2. Typical composition of concrete for pipes.

	Composition	
	(% vol)	(% mass)
Cement	12.5	16.3
Aggregate (sand/gravel)	67.5	76.3
Water	17.5	7.5

For the ductile iron, the energy consumption is assumed as 6.70 kWh kg⁻¹, obtained from the energy consumption for production (5.03 kWh kg⁻¹), from the European BREF document on iron and steel (EPA, 2004), considering that this latter value is 75% of the energy consumption for extraction, transport and production of steel. It is assumed that the energy used comprises 92% coal and 8% electricity. The energy consumption figures for the materials are summarized in Table 4.3.

Table 4.3. Energy consumption figures for extraction of natural resources and production of materials.

Material	Energy consumption (kWh kg ⁻¹)	Source
PVC	7,19	(Baldasano and Parra, 2005)
HDPE	6,23	(APME, 2004). Eco-profile Polyolefins Conversion processes for polyolefins
PP	5,55	(APME, 2004). Eco-profile Polyolefins Conversion processes for polyolefins
Ductile iron	6,70	(EPA, 2004)
Concrete	0,26	(Baird et al., 1997)

4.4. Forming the pipe

PVC pipes are manufactured by extrusion. The energy consumption associated with this process has been estimated at 0.45 kWh (kg PVC)⁻¹, which signifies 1.2 kWh m⁻¹ in the case of pipes for carrying drinking water, and 5.2 kWh m⁻¹ for sanitation pipes.

The production process for bioriented PVC pipes signifies energy consumption of 0.8 kWh kg⁻¹, which implies a contribution of 0.9 kWh m⁻¹ in supply and 8.3 kWh m⁻¹ in sanitation.

It is estimated that, for manufacture of HDPE, corrugated PP and PE pipes by extrusion, 0.8 kWh (kg material)⁻¹ are used, which results in an energy requirement of 2.1 kWh m⁻¹ HDPE pipe for drinking water and 7.8 kWh m⁻¹ for both corrugated PE and corrugated PP applicable to sanitation.

Concrete pipes are normally processed by centrifuging or vibration. Ductile iron pipes are processed by centrifuging or vertical casting. It was considered that the energy consumption of these processes on an industrial scale is comparable to that required for extrusion of PVC, whereby we have taken a value of 0.45 kWh (kg material)⁻¹. From this, it results that, to manufacture 1 metre of RD400 concrete pipe, the consumption requirement is 60.4 kWh m⁻¹, and for RD 125 ductile iron pipes, the requirement is 12.7 kWh m⁻¹.

In every case, it is considered that the energy used in the production process is electric, which signifies a CO₂ emission factor of 0.443 kg kWh⁻¹, pursuant to the Spanish electrical mix for 2002.

4.5. Installation and use of the pipe.

Underground pipes are considered in this study. In order to install the pipe, a trench will need to be dug, the pipe will need to be laid in a sand bed and the soil compacted. The dimensions of the trench to be dug will depend on the size of the pipe. Given that we are working with similar rated diameters for each of the types of pipe analysed, it was estimated that, comparatively speaking, the energy requirement for installation of the pipes will be the same.

Installation of HDPE pipes for carrying drinking water, in which the fluid may flow under pressure, requires a stage of thermo-welding of the different sections of pipe. It was estimated that the energy consumption corresponding to this operation, based on pipe sections 12 m in length and taking as a reference commercial equipment enabling pipes up to 200 mm in diameter to be welded, with the result of 0.07 kWh m⁻¹ (<http://www.ahmcelroy.com/products.htm>).

For all the materials used, the same mean lifetime, 50 years, is assumed, and also that a similar protocol of inspections is followed. It is considered that the energy consumption associated with the maintenance will be the same, regardless of the pipe considered.

When considering pipes for carrying drinking water, which have a cost of fluid propulsion associated, it should be born in mind that the different materials have a different roughness, which involves different load losses. Moreover, in the case of ductile iron, incrustations frequently build up over time, and this would reduce the effective radius of the pipe and lead to an increase in the load losses.

To estimate the energy consumption and emission figures for use of drinking water supply pipe, the reference base taken was a typical flow speed of 1.5 m s⁻¹. The corresponding flow-rate for the RD110 PVC pipe was calculated, with a result of 0.012 m³ s⁻¹. The pumping energy consumption figures to drive this flow in the different types of supply pipes was estimated. A mean of 8 hours operation of the pump per day was assumed, as the calculation base. Straight sections of pipe, free from accessories, were considered, laid horizontally so that the pump costs are consequent solely to those required to overcome the load losses. These load losses were estimated according to the Hazen-Williams equation, the coefficients considered for each material are shown in Table 4.4. For the case of the bioriented PVC pipe, a chart provided by a business company (Pipelife, 2005) was used; in this, the load losses are tabulated according to the Prandtl-Colebrook-White formula for clean water at 20°C. The selected data are shown in Table 4.5.

Table 4.4. Hazen Williams coefficients used to calculate load losses in supply pipes (Hernández, 2000).

Material	Hazen Williams coefficients
PVC	150
HDPE	140
Ductile iron with inner coating of cement mortar, new	100

Table 4.5. Load losses in an RD110 bioriented PVC pipe, Prandtl-Colebrook-White correlation for carrying a flow-rate of 0.012 m³ s⁻¹. (Pipelife,2005)

Load loss (m/km)	RD 110	Inner D 105.2 mm
	Q (m ³ s ⁻¹)	S (m s ⁻¹)
16.00	0.012	1.4

In iron pipes, ageing processes take place, along with the formation of incrustations, which signify an increase in the load losses, and this involves a reduction of the Hazen Williams coefficient. To estimate the energy consumption due to pumping, a linear variation of this coefficient has been assumed, considering that, after 50 years, this value supposes 46% of the initial figure.

The mean energy consumption of a pump working with an RD110 PVC pipe according to the hypotheses indicated in the above paragraph is 327 kWh m⁻¹. Bioriented PVC has less roughness than conventional PVC, the energy consumption for propulsion is estimated at 267 kWh m⁻¹. For the HDPE RD125, the consumption figure obtained is 324 kWh m⁻¹. The ductile iron pipe, where a linear variation of the roughness over time has been taken into account, signifies energy consumption of 397 kWh m⁻¹. The fluid flow speeds in the HDPE and ductile iron pipes are slower than in the case of PVC, 1.4 and 0.9 m s⁻¹, because the passage sections are greater. In the case of the ductile iron, processes of ageing and build-up of incrustations over time have been considered, which signifies that the pumping consumption figures are larger than in the other pipes, despite the fact that the fluid flow speed is slower.

In pipes for sanitation, this problem has not been considered; the fluid flows at atmospheric pressure, and no propulsion systems are used in a large number of cases.

4.6. Transport

It is assumed that transport in connection with 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 all the trips required: transport of raw materials to the production plant, transport of the pipe to the installation site, and transport for final waste disposal.

4.7. Emission factors

Table 4.4 shows the base CO₂ emission factors used in each stage, according to the composition or type of energy supply already indicated for each case.

Table 4.4. CO₂ emission factors

Energy sources / fuel	Emission factor		
	† C TJ ⁻¹ (IPCC, 1996)	† CO ₂ TJ ⁻¹	† CO ₂ MWh ⁻¹
Spanish electrical mix			0.443*
PVC production at Hispavic - Vinilis (Martorell)			0.284*¶
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 CO₂ 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.

Results and comparative analysis

4.8. Estimate of energy consumption and CO₂ emission figures for pipes

Tables 5.1 to 5.13 show the estimate of the energy consumption figures and the corresponding CO₂ emissions associated with the reference cases presented in Section 4.2. The tables include the estimated values for each of the life cycle stages of a pipe. Figures 5.1 to 5.13 show the life cycle for each case in diagram form, with the estimated values for energy consumption and CO₂ emissions.

The results are shown in summary form in Tables 5.14 to 5.16.

4.9. Pipes for carrying drinking water

The stage signifying the largest energy consumption and most important CO₂ emissions is use of the pipe, consequent to the pumping consumption throughout a period of 50 years.

In the case of the plastic pipes, PVC, bioriented PVC, HDPE, this stage accounts for between 92% and 95%, signifying 980 kWh for PVC pipes, 801 kWh for the bioriented PVC, and 973 kWh for HDPE pipes. This contribution is relatively lower for ductile iron pipes, in which the stage of extraction and supply of materials becomes important, contributing 73% of total consumption for pipes made of new material, and 90% for pipes made of 80% recycled material (1191 kWh for each 3 m section of pipe in both cases).

From the viewpoint of the environmental indicators considered, the pipe presenting the best results is the RD110 bioriented PVC, with an associated energy consumption of 828 kWh and emissions of 363 kg of CO₂. The conventional PVC signifies energy consumption and CO₂ emissions which are 20% higher, in the region of 1041 kWh and 452 kg of CO₂.

Next comes the RD125 HDPE pipe, with an energy consumption 1.3% higher than the reference case (conventional PVC), of 1,055 kWh, and CO₂ emission of 454 kg (0.4% more than the PVC pipe).

If recycled material is used in manufacture of the ductile iron pipe, the energy consumption is 26% higher than for the PVC pipe, signifying 1,316 kWh, with a CO₂ emission of 581 kg.

The most unfavourable case corresponds to ductile iron pipes without recycled material, in which the energy consumption is 1,620 kWh, in the region of 56% higher than for the reference cases (conventional PVC RD110). For this type of pipe, the CO₂ emissions associated with the life cycle signify 681 kg CO₂.

4.10. Sanitation pipes

The stage of extraction and supply of materials is the one accounting for the highest energy consumption for all the pipes studied (over 80% for pipes made

of new material, and over 60% for pipes with recycled material), except for the concrete, where the pipe production stage becomes important (53%). The next most important stage in terms of energy consumption is production of the tube.

From the viewpoint of CO₂ emissions into the atmosphere, the relative importance of each of the stages remains the same.

The most favourable cases of those studied correspond to plastic pipes containing 80% recycled material. First comes the corrugated PP (60 kWh and 22 kg of CO₂), next the corrugated PE (64 kWh with associated emissions of 21 kg of CO₂), and lastly the PVC (69 kWh and emissions of 22 kg of CO₂). The weight per metre of the pipe is a determining factor in this case. Both the PE and the corrugated PP weight 15% less per metre than the PVC.

Recycled material is not normally included for production of bioriented PVC, and this option has therefore not been considered in the study cases.

Next come the pipes made of RD400 corrugated PP, RD400 corrugated PE, RD315 bioriented PVC and RD315 PVC without recycled material in their composition, signifying energy consumption of 191 kWh, 211 kWh, 223 kWh and 262 kWh and with CO₂ emissions of 61 kg, 59 kg, 67 kg and 77 kg for each 3 m section of pipe, respectively.

The energy consumption of the PP, PE and PVC pipes with recycled material is reduced by between 74 and 77% in comparison with the PVC pipe without recycled material, all the plastic pipes presenting very similar behaviour.

In terms of the CO₂ emissions, the result is most favourable for the corrugated PE pipe.

With regard to the plastic materials, the values obtained are within the same range. The main difference noted in Table 5.14 corresponds to the different scenarios in which new material is used in manufacture of the pipe or, to the contrary, 80% recycled material is used to produce it.

The most unfavourable case is the RD400 concrete pipe, which signifies energy consumption of 345 kWh and CO₂ emission of 129 kg.

Table 5.1 Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **PVC pipe for carrying drinking water**, with a rated diameter of **110 mm (without using recycled PVC)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	56.7	5.4	16.1	3.6
Transport of materials to the production plant	0.6	0.1	0.2	0.0
Production of PVC pipe	3.6	0.4	1.6	0.4
Transport of pipe for installation	0.6	0.1	0.2	0.0
Installation	--	0.0	--	0.0
Use of pipe (50 years)	979.8	94.1	433.9	96.0
TOTAL	1041.3	100.0	451.9	100.0

Table 5.2 Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **biooriented PVC pipe for carrying drinking water**, with a rated diameter of **110 mm (without using recycled PVC)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	23.9	2.9	6.8	1.9
Transport of materials to the production plant	0.2	0.0	0.1	0.0
Production of PVC pipe	2.7	0.3	1.2	0.3
Transport of pipe for installation	0.2	0.0	0.1	0.0
Installation	--	0.0	--	0.0
Use of pipe (50 years)	800.9	96.7	354.7	97.8
TOTAL	828.0	100.0	362.8	100.0

Table 5.3 Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **ductile iron pipe for carrying drinking water**, with a rated diameter of **125 mm (without using recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	390.6	24.1	138.1	20.3
Transport of materials to the production plant	4.7	0.3	1.3	0.2
Production of ductile iron pipe	29.1	1.8	12.9	1.9
Transport of pipe for installation	4.7	0.3	1.3	0.2
Installation	-	0.0	-	0.0
Maintenance of pipe (pumping)	1191.2	73.5	527.5	77.5
TOTAL	1620.4	100.0	681.1	100.0

Table 5.4 Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **ductile iron pipe for carrying drinking water**, with a rated diameter of **125 mm (using 80% recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	86.3	6.6	38.2	6.6
Transport of materials to the production plant	4.7	0.4	1.3	0.2
Production of ductile iron pipe	29.1	2.2	12.9	2.2
Transport of pipe for installation	4.7	0.4	1.3	0.2
Installation	-	0.0	-	0.0
Maintenance of pipe (pumping)	1191.2	90.5	527.5	90.8
TOTAL	1316.1	100.0	581.2	100.0

Table 5.5 Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **HDPE pipe for carrying drinking water**, with a rated diameter of **125 mm (without using recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	71.5	6.8	18.4	4.0
Transport of materials to the production plant	0.8	0.1	0.2	0.0
Production of ductile iron pipe	9.2	0.9	4.1	0.9
Transport of pipe for installation	0.8	0.1	0.2	0.0
Installation (welding pipe sections)	0.2	0.0	0.1	0.0
Maintenance of pipe	972.6	92.2	430.7	94.9
TOTAL	1055.2	100.0	453.7	100.0

Table 5.6 Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **PVC pipe for sanitation**, with a rated diameter of **315 mm (without using recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials for PVC	241.6	92.1	68.7	89.3
Transport of materials to the production plant	2.5	1.0	0.7	0.9
Production of PVC pipe	15.6	5.9	6.9	9.0
Transport of pipe for installation	2.5	1.0	0.7	0.9
TOTAL	262.2	100.0	76.9	100.0

Table 5.7 Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **PVC pipe for sanitation**, with a rated diameter of **315 mm (80% recycled PVC)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	48.4	70.1	13.8	62.6
Transport of materials to the production plant	2.5	3.7	0.7	3.1
Production of PVC pipe	15.6	22.5	6.9	31.3
Transport of pipe for installation	2.5	3.7	0.7	3.1
TOTAL	69.0	100.0	22.0	100.0

Table 5.8 Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **biooriented PVC pipe for sanitation**, with a rated diameter of **315 mm (without recycled PVC)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	196.8	88.1	55.9	83.5
Transport of materials to the production plant	2.1	0.9	0.5	0.8
Production of PVC pipe	22.5	10.1	10.0	14.9
Transport of pipe for installation	2.1	0.9	0.5	0.8
TOTAL	223.4	100.0	67.0	100.0

Table 5.9 Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **corrugated PE pipe for sanitation**, with a rated diameter of **400 mm (without recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials for PE	183.2	86.8	47.0	80.3
Transport of materials to the production plant	2.1	1.0	0.6	1.0
Production of corrugated PE pipe	23.5	11.1	10.4	17.8
Transport of pipe for installation	2.1	1.0	0.6	1.0
TOTAL	211.0	100.0	58.6	100.0

Table 5.10 Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **corrugated PE pipe for sanitation**, with a rated diameter of **400 mm**. (With **80% recycled material**)

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials for PE	36.6	56.8	9.4	44.9
Transport of materials to the production plant	2.1	3.3	0.6	2.7
Production of corrugated PE pipe	23.5	36.5	10.4	49.7
Transport of pipe for installation	2.1	3.3	0.6	2.7
TOTAL	64.4	100.0	21.0	100.0

Table 5.1. Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **corrugated PP pipe for sanitation**, with a rated diameter of **400 mm (without recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials for PP	163.2	85.4	50.0	81.2
Transport of materials to the production plant	2.1	1.1	0.6	0.9
Production of corrugated PP pipe	23.5	12.3	10.4	16.9
Transport of pipe for installation	2.1	1.1	0.6	0.9
TOTAL	191.0	100.0	61.5	100.0

Table 5.2. Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **corrugated PP pipe for sanitation**, with a rated diameter of **400 mm**. (With **80% recycled material**).

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials for PP	32.6	54.0	10.0	46.4
Transport of materials to the production plant	2.1	3.6	0.6	2.7
Production of corrugated PP pipe	23.5	38.9	10.4	48.3
Transport of pipe for installation	2.1	3.6	0.6	2.7
TOTAL	60.4	100.0	21.6	100.0

Table 5.3. Estimate of energy consumption and CO₂ emissions consequent to the production, installation and use of 3 m of **bulk concrete pipe for sanitation**, with a rated diameter of **400 mm**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials for concrete	105.1	30.5	33.6	25.9
Transport of materials to the production plant	29.4	8.5	7.8	6.1
Production of concrete pipe	181.1	52.5	80.2	62.0
Transport of pipe for installation	29.4	8.5	7.8	6.1
TOTAL	345.0	100.0	129.4	100.0

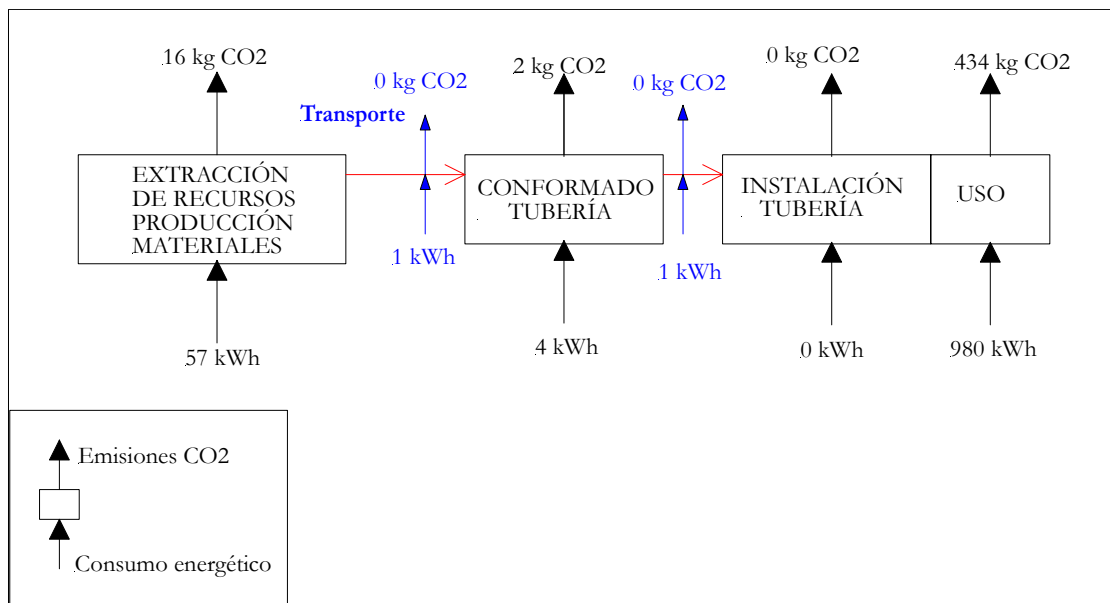


Figure 0.1. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD110 PVC supply pipe**.

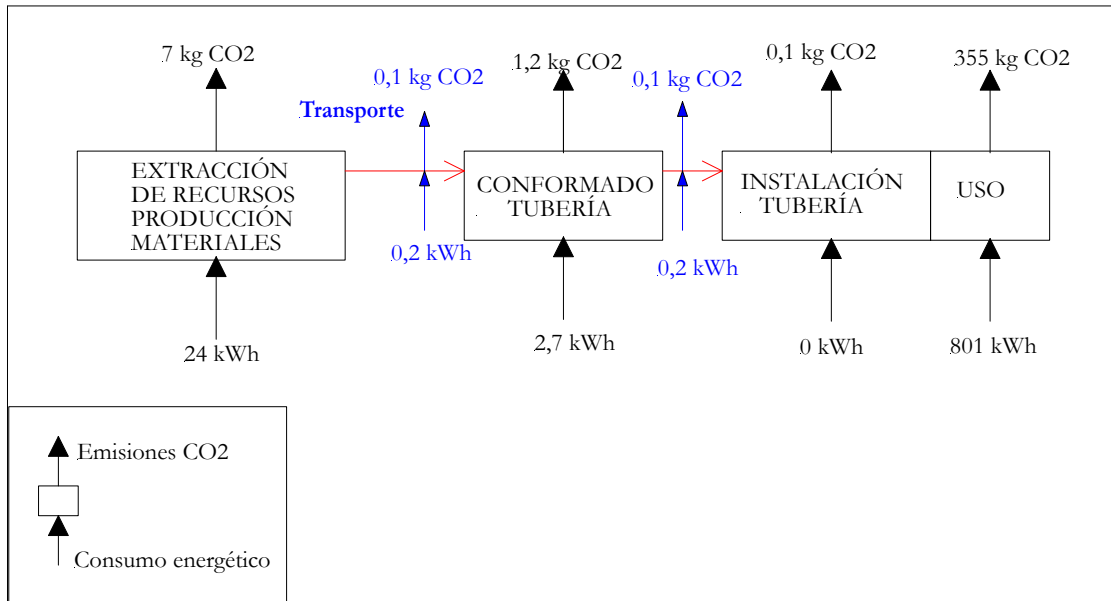


Figure 0.2. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD110 bioriented PVC supply pipe**.

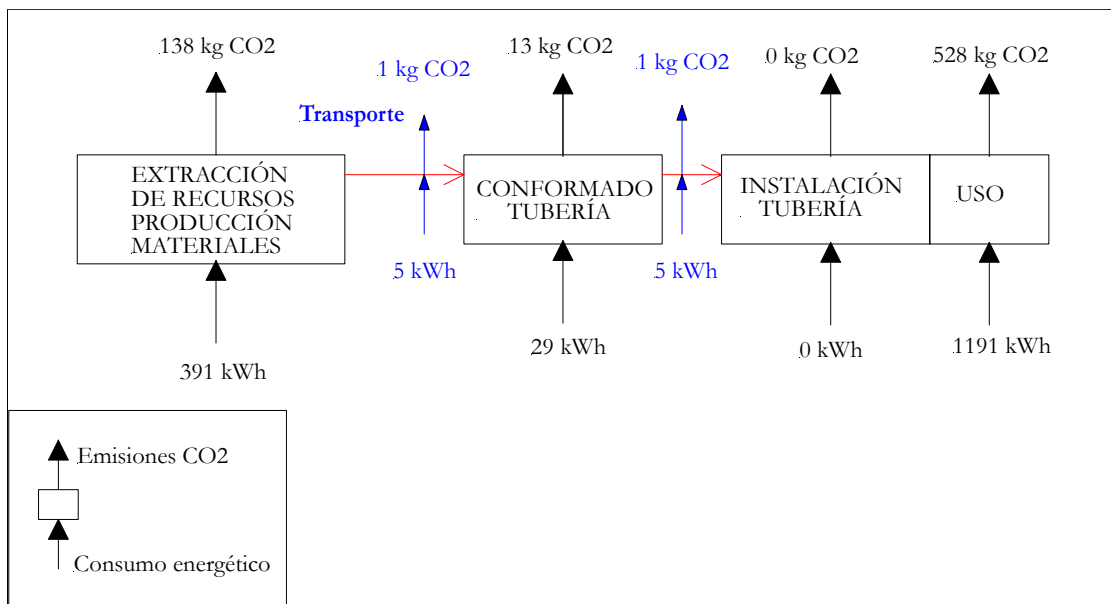


Figure 0.3. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD125 ductile iron supply pipe (without using recycled material)**.

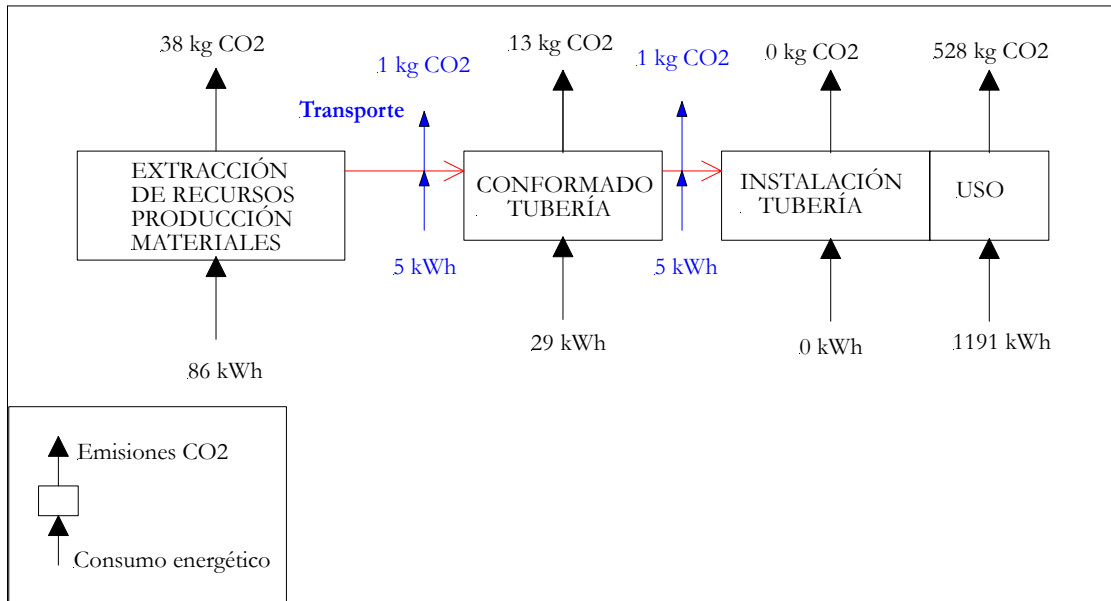


Figure 0.4. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD125 ductile iron supply pipe (with 80% recycled material)**.

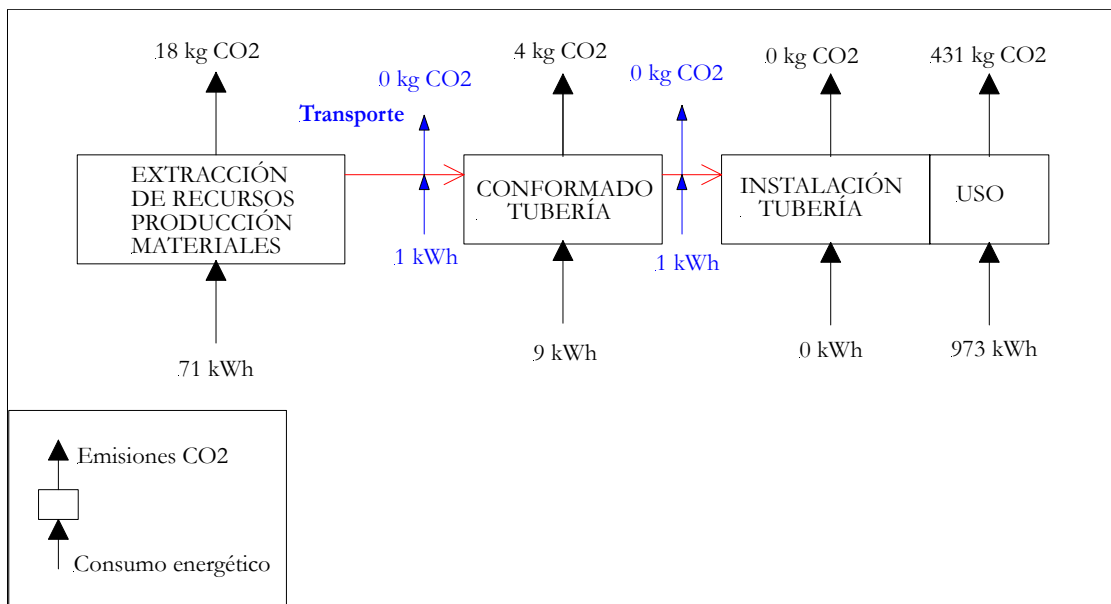


Figure 0.5. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD125 HDPE supply pipe**.

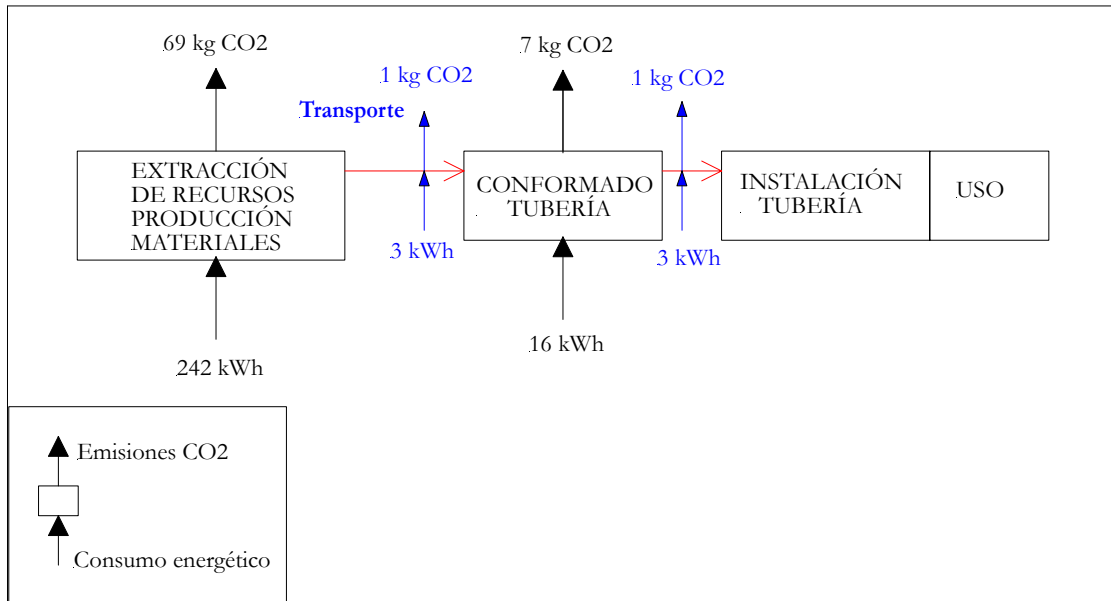


Figure 0.6. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD315 PVC sanitation pipe (without using recycled material)**.

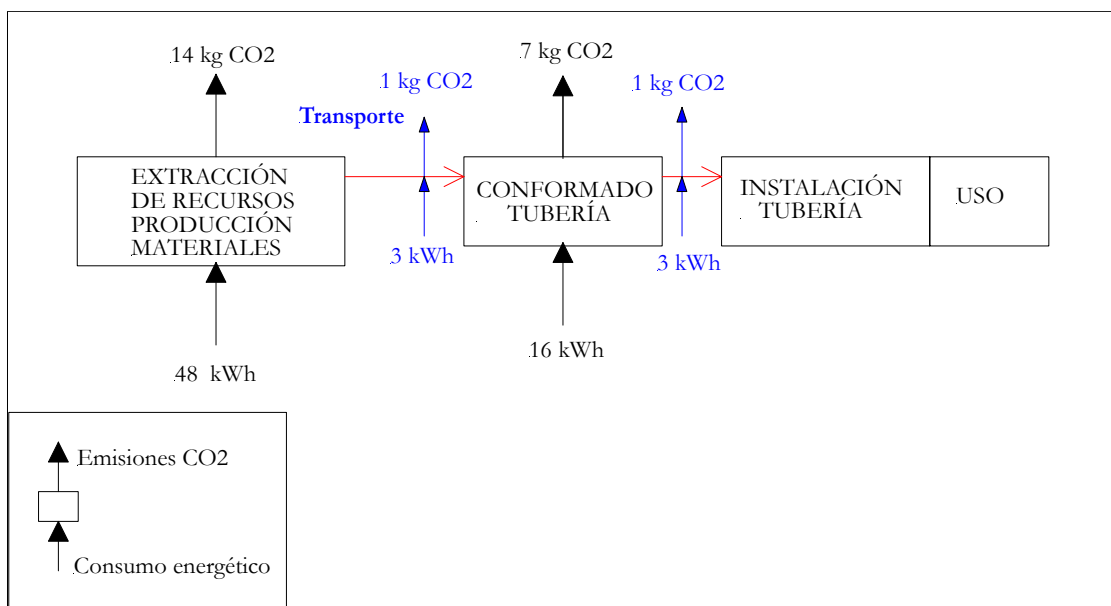


Figure 0.7. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD315 PVC sanitation pipe (with 80% recycled material)**.

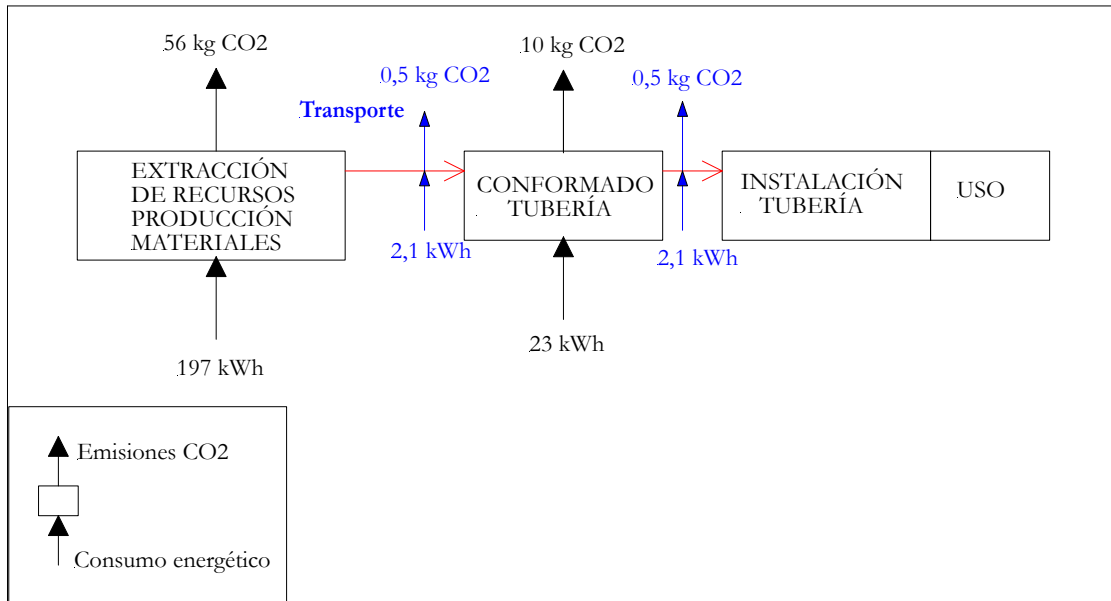


Figure 0.8. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD315 bioriented PVC sanitation pipe (without recycled material)**

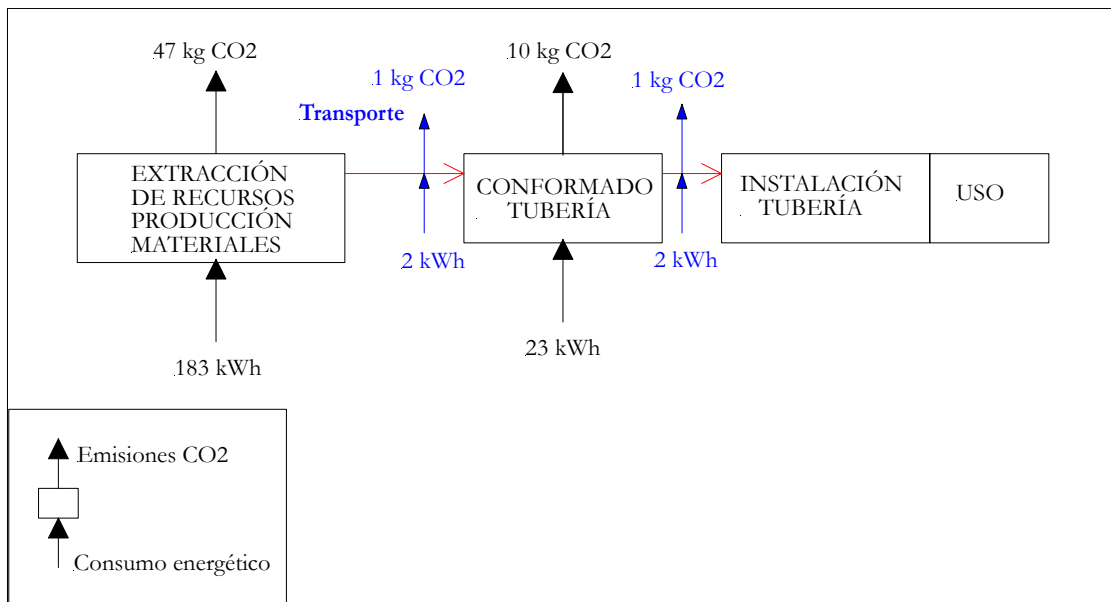


Figure 0.9. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD400 corrugated PE sanitation pipe (without using recycled material)**.

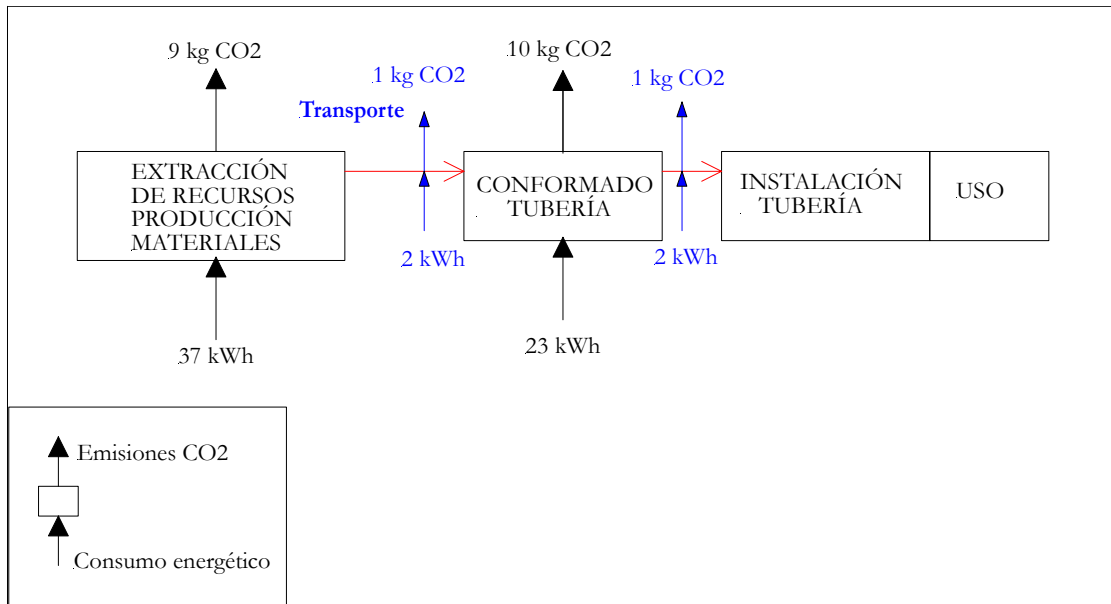


Figure 0.10. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD400 corrugated PE sanitation pipe (with 80% recycled material)**.

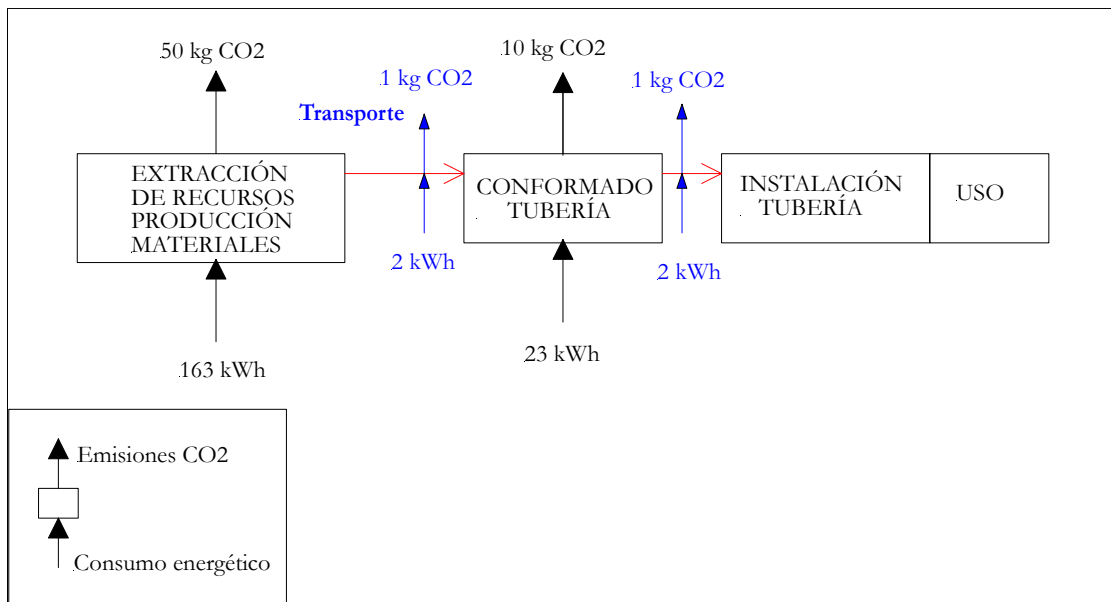


Figure 0.11. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD400 corrugated PP sanitation pipe (without using recycled material)**.

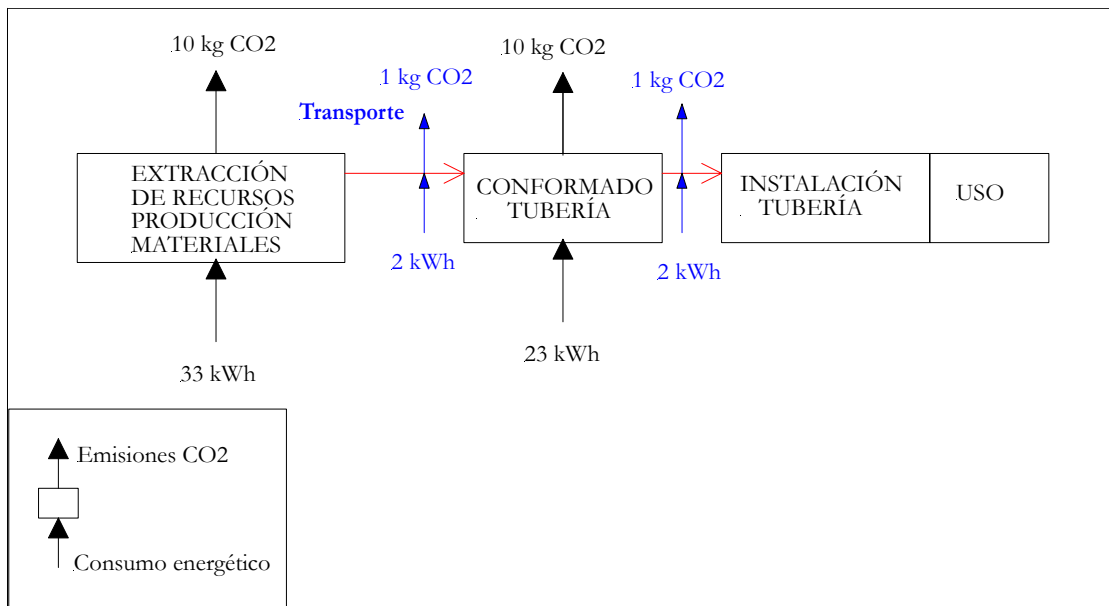


Figure 0.12. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD400 corrugated PP sanitation pipe (with 80% recycled material)**.

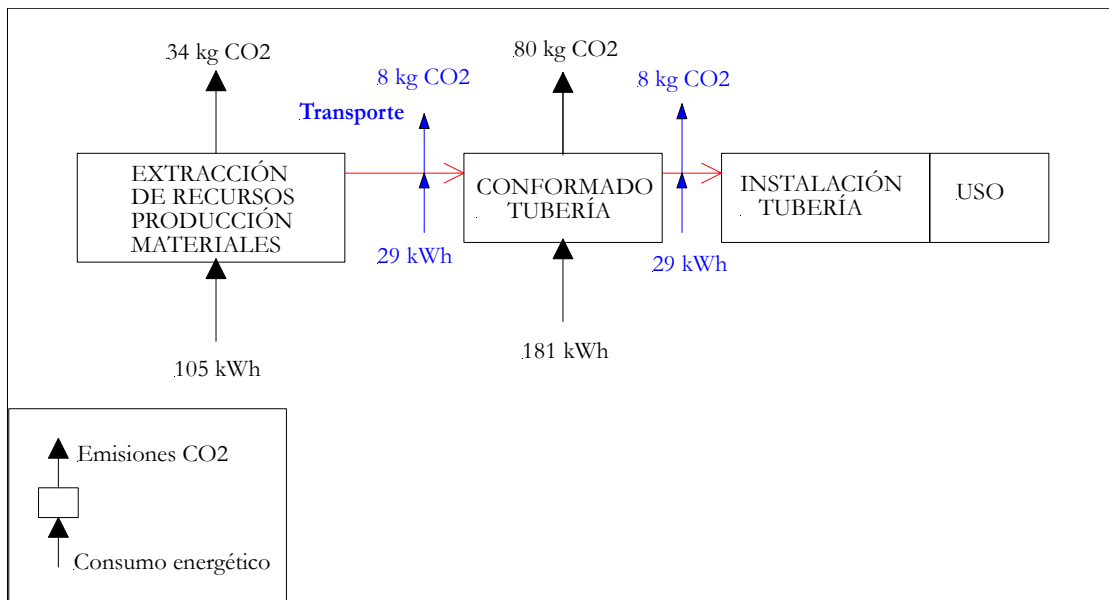


Figure 0.13. Estimate of energy consumption and CO₂ emissions consequent to the production and use of **3 m of RD400 concrete sanitation pipe**.

Tables 5.14 to 5.16 show a summary of the energy consumption and CO₂ emissions corresponding to each of the reference cases analysed.

Table 5.4. Estimated energy consumption for each of the life cycle stages of pipes made of different materials.

Calculation base: 3 m of pipe	Energy consumption (kWh)				
	Supply				
Material	PVC RD110	Bioriented PVC RD110	HDPE RD125	Ductile iron RD125	Ductile iron RD125 (80% recycled)
Extraction and supply of materials	56.7	23.9	71.5	390.6	86.3
Transport of materials to the production plant	0.6	0.2	0.8	4.7	4.7
Production of pipe	3.6	2.7	9.2	29.1	29.1
Transport of pipe for installation	0.6	0.2	0.8	4.7	4.7
Installation	negligible	negligible	0.2	negligible	negligible
Use of pipe (50 years)	979.8	800.9	972.6	1191.2	1191.2
TOTAL	1041.3	828.0	1055.2	1620.4	1316.1

Material	Sanitation							
	PVC RD315	PVC RD315 (80% recycled)	Bioriented PVC RD315	Concrete RD400	Corrugated PE RD400	Corrugated PE RD400 (80% recycled)	Corrugated PP RD 400	Corrugated PP RD400 (80% recycled)
Extraction and supply of materials	241.6	48.4	196.8	105.1	183.2	36.6	163.2	32.6
Transport of materials to the production plant	2.5	2.5	2.1	29.4	2.1	2.1	2.1	2.1
Production of pipe	15.6	15.6	22.5	181.1	23.5	23.5	23.5	23.5
Transport of pipe for installation	2.5	2.5	2.1	29.4	2.1	2.1	2.1	2.1
TOTAL	262.2	69.0	223.4	345.0	211.0	64.4	191.0	60.4

Table 5.5. Estimated CO₂ emissions for each of the life cycle stages of pipes made of different materials.

Calculation base: 3 m of pipe	CO ₂ emissions (kg of CO ₂)							
	Supply							
Material	PVC RD110	Bioriented PVC RD110	HDPE RD125	Ductile iron RD125	Ductile iron RD125 (80% recycled)			
Extraction and supply of materials	16.1	6.8	18.4	138.1	38.2			
Transport of materials to the production plant	0.2	0.1	0.2	1.3	1.3			
Production of pipe	1.6	1.2	4.1	12.9	12.9			
Transport of pipe for installation	0.2	0.1	0.2	1.3	1.3			
Installation	negligible	negligible	0.1	negligible	negligible			
Use of pipe (50 years)	433.9	354.7	430.7	527.5	527.5			
TOTAL	451.9	362.8	453.7	681.1	581.2			
Sanitation								
Material	PVC RD315	PVC RD315 (80% recycled)	Bioriented PVC RD315	Concrete RD400	Corrugated PE RD400	Corrugated PE RD400 (80% recycled)	Corrugated PP RD 400	Corrugated PP RD400 (80% recycled)
Extraction and supply of materials	68.7	13.8	55.9	33.6	47.0	9.4	50.0	10.0
Transport of materials to the production plant	0.7	0.7	0.5	7.8	0.6	0.6	0.6	0.6
Production of pipe	6.9	6.9	10.0	80.2	10.4	10.4	10.4	10.4
Transport of pipe for installation	0.7	0.7	0.5	7.8	0.6	0.6	0.6	0.6
TOTAL	76.9	22.0	67.0	129.4	58.6	21.0	61.5	21.6

Table 5.6. Energy consumption and CO₂ emissions attributable to the production and use (50 years) of pipes made of different materials. Summary.

Calculation base: 3 m of pipe without accessories (Recycled material % weight)	RD	Weight of pipe	s	Hazen Williams coeff.	Energy consumption	CO ₂ emissions	Variation energy consump. vs. ref. std.	Variation CO ₂ emissions vs. ref. std.
	mm	kg m ⁻¹	m s ⁻¹		kWh	kg CO ₂	%	%
SUPPLY PIPES								
Bioriented PVC	110	1.1	1.4	--(1)	828.0	362.8	-20.48	-19.73
PVC	110	2.7	1.5	150	1041.3	451.9	0.00	0.00
HDPE	125	3.8	1.4	140	1055.2	453.7	1.33	0.38
Ductile iron (80% recycled material)	125	21.6	0.9	100 (2)	1316.1	581.2	26.39	28.59
Ductile iron	125	21.6	0.9	100 (2)	1620.4	681.1	55.61	50.69
SANITATION PIPES								
Corrugated PP (80% recycled material)	400	9.8	3.8	-	60.4	21.6	-81.15	-74.23
Corrugated PE (80% recycled material)	400	9.8	3.8	-	64.4	21.0	-79.54	-75.02
PVC (80% recycled material)	315	11.5	5.0	-	69.0	22.0	-77.70	-73.63
Corrugated PP	400	9.8	3.8	-	191.0	61.5	-28.65	-20.62
Corrugated PE	400	9.8	3.8	-	211.0	58.6	-20.61	-24.56
Bioriented PVC	315	10.4	5.0	-	223.4	67.0	-17.4	-14.8
PVC	315	11.5	5.0	-	262.2	76.9	0.00	0.00
Concrete	400	134.1	2.8		345.0	129.4	33.26	70.43

(1). The load losses in the pipe over 50 years were estimated based on the Prandtl Colebrook White correlation (Pipelife, 2005).

(2) Value considered for new pipe.

6. Conclusions

This document presents the estimates of the energy consumption and CO₂ emissions associated with the production and use of pipes.

The basic references standards selected for the study were two widely used types of pipe: pipes for carrying drinking water and pipes for sanitation. The reference materials chosen were, in the first case, PVC, bioriented PVC, high-density polyethylene and ductile iron, and for the second case, PVC, bioriented PVC, corrugated polyethylene, corrugated polypropylene and bulk concrete.

The methodology used is based on a procedure of environmental accounting of energy consumption and CO₂ emission values, in which these indicators have been estimated in each of the stages of the life cycle of drinking water and sanitation pipes. The end results signify the sum of the energy consumption and CO₂ emission figures equivalent to each of these stages.

To make the estimates, sections of pipe 3 m in length and free from accessories were considered, in which, for the same hydraulic capacity, the fluid flow speed values would be kept within the usual ranges.

For the case of pipes for carrying drinking water, a PVC pipe with a rated diameter of 110 mm RP10 was taken as the reference standard. The comparative elements selected were: a bioriented PVC pipe with a rated diameter of 110 mm, an HDPE pipe with a rated diameter of 125 mm, and a ductile iron pipe with a rated diameter of 125 mm.

For the sanitation pipes, the standard pipe chosen was a PVC pipe with a diameter of 315 mm. The comparative elements chosen were: an RD315 bioriented PVC, an RD400 concrete pipe, an RD400 corrugated PP pipe and an RD400 corrugated PE pipe.

The selection was based on their hydraulic capacity so that, for a typical flow speed in the PVC pipe (1.5 m s^{-1} for supply and 5 m s^{-1} for sanitation), the flow-rate was estimated ($0.012 \text{ m}^3 \text{ s}^{-1}$ for the supply pipe and $0.35 \text{ m}^3 \text{ s}^{-1}$ for the sanitation pipe), and the pipes considered were commercially available with diameters allowing this flow to be conveyed at speeds equal to or less than the PVC pipe, bearing in mind that, for the specific case of the concrete, the typical flow speed is 3 m s^{-1} .

This report covers all the stages of a Life Cycle Assessment, although solely the 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 basic figures used in this document include the CO₂ emission factor of the Spanish electrical mix for the year 2002, and likewise the respective values for

energy consumption and CO₂ emissions associated with the production of PVC at the Hispavic-Vinilis plant in Martorell.

The results obtained for **supply pipes** indicate that the stage determining energy consumption and CO₂ emissions for all the pipes is the stage of use of the pipe, and this stage takes into account consumption figures for pumping during the mean lifetime allocated to all the pipes: 50 years. The stage with the next largest contribution is that of extraction and supply of materials.

The pipe presenting the best results in this case is the RD110 bioriented PVC pipe, followed by the RD110 conventional PVC pipe and the RD125 HDPE pipe, which signifies energy consumption and CO₂ emissions in the region of 1.4% and 0,4% higher than the basic reference (conventional PVC), respectively. The most unfavourable case corresponds to ductile iron pipes not using recycled material, with an energy consumption 56% higher and CO₂ emission 51% higher.

For **sanitation pipes**, the best results in terms of energy consumption and CO₂ emissions are noted for the pipe containing 80% recycled corrugated PP, 77 and 72% lower than for the reference case (the RD315 PVC pipe without recycled material). Next, we find the corrugated PE pipe with 80% recycled material, followed by the PVC pipe with 80% recycled material. However, the behaviour of the plastic pipes in respect of the environmental indicators considered is very similar.

The values for energy consumption and CO₂ emissions for the plastic pipes with recycled material are very close, and are between 72% and 77% lower than the values obtained for the PVC pipe not using recycled material. In increasing order of energy consumption and associated CO₂ emissions, we find the corrugated PP pipe without recycled material and the corrugated PE pipe without recycled material, the RD315 bioriented PVC pipe and the RD315 PVC pipe without recycled material and, in last place, the RD400 concrete pipes, which signify energy consumption 32% higher and CO₂ emissions 68% higher than for the PVC.

It should be born in mind that, although at present the use of recycled PVC in manufacture of bioriented PVC is not common, it is, however, a 100% recyclable material, and re-use of it seems likely in the future. Introducing recycled material in the manufacture of this type of pipes would bring about a reduction in energy consumption as regards extraction and supply of materials. In the case of sanitation pipes, it was noted that this stage is a determinant factor in terms of energy consumption and CO₂ emissions, whereby introducing recycled materials into their manufacture, together with the low specific gravity of the material, could bring about significant changes to the results.

7. References

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8. Schedule 1. Energy consumption and associated CO₂ emissions if considering processes of recycling and final disposal of pipes.

As has been mentioned several times in this document, it is not usual at present to dig up underground pipes for their subsequent deconstruction, recycling or final disposal.

Since such operations are, however, carried out on pipes installed above ground, and it is possible that the normal practice will change in the future and pipes will be dug up, we wished to complement this study assuming that the stages of deconstruction, recycling and final waste disposal do take place. (See Figure 3.1. Flowchart of the theoretical life cycle of a pipe)

8.1. Deconstruction

This activity, which is construed as dismantling the pipe with the aim of making best use of the materials through recycling, might require just labour and perhaps minor energy consumption. It is assumed that the energy consumption in this stage is irrelevant.

8.2. Recycling

It is assumed that 97% of the PVC, HDPE, corrugated PP, corrugated PE and of the ductile iron is recyclable. The remaining 3% forms waste which is deposited in a disposal site. In the case of concrete, it is considered that it would all be taken for waste disposal.

Recycling PVC, polyethylene and polypropylene uses electricity consumption of 0.25 kWh kg⁻¹. For recycling the ductile iron, the value for steel is taken for reference purposes, signifying electricity consumption of 5.03 kWh kg⁻¹ (EPA, 2004), corresponding to the energy consumption for steel casting, indicated by the European BREF.

8.3. Final disposal

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

8.4. Results and discussion.

Tables 8.1 to 8.13 and Figures 8.1 to 8.13 show the results obtained for each of the theoretical life cycle stages of pipes, in terms of energy consumption and CO₂ emissions. These results are shown in summary form in tables 8.14 to 8.18.

Table 8.1. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **PVC supply pipe**, with a rated diameter of **110 mm (without using recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials for PVC	56.7	5.4	16.1	3.6
Transport of materials to the production plant	0.6	0.1	0.2	0.0
Production of PVC pipe	3.6	0.3	1.6	0.4
Transport of pipe for installation	0.6	0.1	0.2	0.0
Use of pipe (50 years)	979.8	93.9	433.9	95.8
Transport of pipe for recycling	0.6	0.1	0.2	0.0
Recycling	1.9	0.2	0.9	0.2
Transport for final disposal in waste disposal site	0.03	0.0	0.01	0.0
Final disposal in waste disposal site	0.1	0.0	0.02	0.0
TOTAL	1043.9	100.0	453.0	100.0

Table 8.2 Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **bioriented PVC supply pipe**, with a rated diameter of **110 mm (without using recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials for PVC	23.9	2.9	6.8	1.9
Transport of materials to the production plant	0.2	0.0	0.1	0.0
Production of PVC pipe	2.7	0.3	1.2	0.3
Transport of pipe for installation	0.2	0.0	0.1	0.0
Use of pipe (50 years)	800.9	96.6	354.7	97.6
Transport of pipe for recycling	0.2	0.0	0.1	0.0
Recycling	0.8	0.1	0.4	0.1
Transport for final disposal in waste disposal site	0.01	0.0	0.00	0.0
Final disposal in waste disposal site	0.03	0.0	0.01	0.0
TOTAL	829.1	100.0	363.2	100.0

Table 8.3. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **ductile iron supply pipe**, with a rated diameter of **125 mm (without using recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	390.6	23.8	138.1	20.0
Transport of materials to the production plant	4.7	0.3	1.3	0.2
Production of ductile iron pipe	29.1	1.8	12.9	1.9
Transport of pipe for installation	4.7	0.3	1.3	0.2
Use of pipe (50 years)	1191.2	72.6	527.5	76.6
Transport of pipe for recycling	4.7	0.3	1.3	0.2
Recycling	13.8	0.8	6.1	0.9
Transport for final disposal in waste disposal site	0.7	0.0	0.2	0.0
Final disposal in waste disposal site	1.5	0.1	0.4	0.1
TOTAL	1641.1	100.0	689.0	100.0

Table 8.4. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **ductile iron supply pipe**, with a rated diameter of **125 mm (using 80% recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	86.3	6.5	38.2	6.5
Transport of materials to the production plant	4.7	0.4	1.3	0.2
Production of ductile iron pipe	29.1	2.2	12.9	2.2
Transport of pipe for installation	4.7	0.4	1.3	0.2
Use of pipe (50 years)	1191.2	89.1	527.5	89.5
Transport of pipe for recycling	4.7	0.4	1.3	0.2
Recycling	13.8	1.0	6.1	1.0
Transport for final disposal in waste disposal site	0.7	0.1	0.2	0.0
Final disposal in waste disposal site	1.5	0.1	0.4	0.1
TOTAL	1336.8	100.0	589.1	100.0

Table 8.5. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **HDPE supply pipe**, with a rated diameter of **125 mm (without using recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	71.5	6.8	18.4	4.0
Transport of materials to the production plant	0.8	0.1	0.2	0.0
Production of HDPE pipe	9.2	0.9	4.1	0.9
Transport of pipe for installation	0.8	0.1	0.2	0.0
Installation of pipe (thermo-welding HDPE)	0.2	0.0	0.1	0.0
Use of pipe (50 years)	972.6	91.9	430.7	94.6
Transport of pipe for recycling	0.8	0.1	0.2	0.0
Recycling	2.8	0.3	1.2	0.3
Transport for final disposal in waste disposal site	0.03	0.0	0.01	0.0
Final disposal in waste disposal site	0.05	0.0	0.01	0.0
TOTAL	1058.9	100.0	455.2	100.0

Table 8.6. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **PVC pipe for sanitation**, with a rated diameter of **315 mm (without using recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials for PVC	241.6	88.4	68.7	84.4
Transport of materials to the production plant	2.5	0.9	0.7	0.8
Production of PVC pipe	15.6	5.7	6.9	8.5
Transport of pipe for installation	2.5	0.9	0.7	0.8
Transport of pipe for recycling	2.5	0.9	0.7	0.8
Recycling	8.2	3.0	3.6	4.5
Transport for final disposal in waste disposal site	0.1	0.0	0.03	0.0
Final disposal in waste disposal site	0.3	0.1	0.1	0.1
TOTAL	273.4	100.0	81.3	100.0

Table 8.7. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **PVC pipe for sanitation, with a rated diameter of 315 mm (with 80% recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials for PVC	48.4	60.4	13.8	52.1
Transport of materials to the production plant	2.5	3.2	0.7	2.5
Production of PVC pipe	15.6	19.4	6.9	26.1
Transport of pipe for installation	2.5	3.2	0.7	2.5
Transport of pipe for recycling	2.5	3.2	0.7	2.5
Recycling	8.2	10.2	3.6	13.8
Transport for final disposal in waste disposal site	0.1	0.2	0.03	0.1
Final disposal in waste disposal site	0.3	0.3	0.1	0.3
TOTAL	80.1	100.0	26.4	100.0

Table 8.8. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **biooriented PVC pipe for sanitation, with a rated diameter of 315 mm (without recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials for PVC	196.8	84.6	55.9	79.2
Transport of materials to the production plant	2.1	0.9	0.5	0.8
Production of PVC pipe	22.5	9.7	10.0	14.1
Transport of pipe for installation	2.1	0.9	0.5	0.8
Transport of pipe for recycling	2.1	0.9	0.5	0.8
Recycling	6.7	2.9	3.0	4.2
Transport for final disposal in waste disposal site	0.1	0.0	0.03	0.0
Final disposal in waste disposal site	0.2	0.1	0.1	0.1
TOTAL	232.5	100.0	70.6	100.0

Table 8.9. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **corrugated PE pipe for sanitation**, with a rated diameter of **400 mm (without using recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	183.2	83.1	47.0	75.4
Transport of materials to the production plant	2.1	1.0	0.6	0.9
Production of corrugated PE pipe	23.5	10.7	10.4	16.7
Transport of pipe for installation	2.1	1.0	0.6	0.9
Transport of pipe for recycling	2.1	1.0	0.6	0.9
Recycling	7.1	3.2	3.2	5.1
Transport for final disposal in waste disposal site	0.1	0.0	0.02	0.0
Final disposal in waste disposal site	0.1	0.1	0.04	0.1
TOTAL	220.5	100.0	62.4	100.0

Table 8.10. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **corrugated PE pipe for sanitation**, with a rated diameter of **400 mm (with 80% recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	36.6	49.6	9.4	38.0
Transport of materials to the production plant	2.1	2.9	0.6	2.3
Production of corrugated PE pipe	23.5	31.8	10.4	42.1
Transport of pipe for installation	2.1	2.9	0.6	2.3
Transport of pipe for recycling	2.1	2.9	0.6	2.3
Recycling	7.1	9.6	3.2	12.8
Transport for final disposal in waste disposal site	0.1	0.1	0.02	0.1
Final disposal in waste disposal site	0.1	0.2	0.04	0.1
TOTAL	73.9	100.0	24.8	100.0

Table 8.11. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **corrugated PP pipe for sanitation**, with a rated diameter of **400 mm (without using recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	163.2	81.4	50.0	76.5
Transport of materials to the production plant	2.1	1.1	0.6	0.9
Production of corrugated PP pipe	23.5	11.7	10.4	15.9
Transport of pipe for installation	2.1	1.1	0.6	0.9
Transport of pipe for recycling	2.1	1.1	0.6	0.9
Recycling	7.1	3.6	3.2	4.8
Transport for final disposal in waste disposal site	0.1	0.0	0.02	0.0
Final disposal in waste disposal site	0.1	0.1	0.04	0.1
TOTAL	200.5	100.0	65.3	100.0

Table 8.12. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **corrugated PP pipe for sanitation**, with a rated diameter of **400 mm (with 80% recycled material)**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	32.6	46.7	10.0	39.4
Transport of materials to the production plant	2.1	3.1	0.6	2.3
Production of corrugated PP pipe	23.5	33.6	10.4	41.1
Transport of pipe for installation	2.1	3.1	0.6	2.3
Transport of pipe for recycling	2.1	3.1	0.6	2.3
Recycling	7.1	10.2	3.2	12.5
Transport for final disposal in waste disposal site	0.1	0.1	0.02	0.1
Final disposal in waste disposal site	0.1	0.2	0.0	0.1
TOTAL	69.9	100.0	25.3	100.0

Table 8.13. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of **concrete pipe for sanitation**, with a rated diameter of **400 mm**.

	Energy consumption		CO ₂ emission	
	kWh	%	kg	%
Extraction and supply of materials	105.1	24.1	33.6	21.8
Transport of materials to the production plant	29.4	6.7	7.8	5.1
Production of corrugated PP pipe	181.1	41.5	80.2	52.1
Transport of pipe for installation	29.4	6.7	7.8	5.1
Transport for final disposal in waste disposal site	29.4	6.7	7.8	5.1
Final disposal in waste disposal site	62.5	14.3	16.7	10.8
TOTAL	436.9	100.0	153.9	100.0

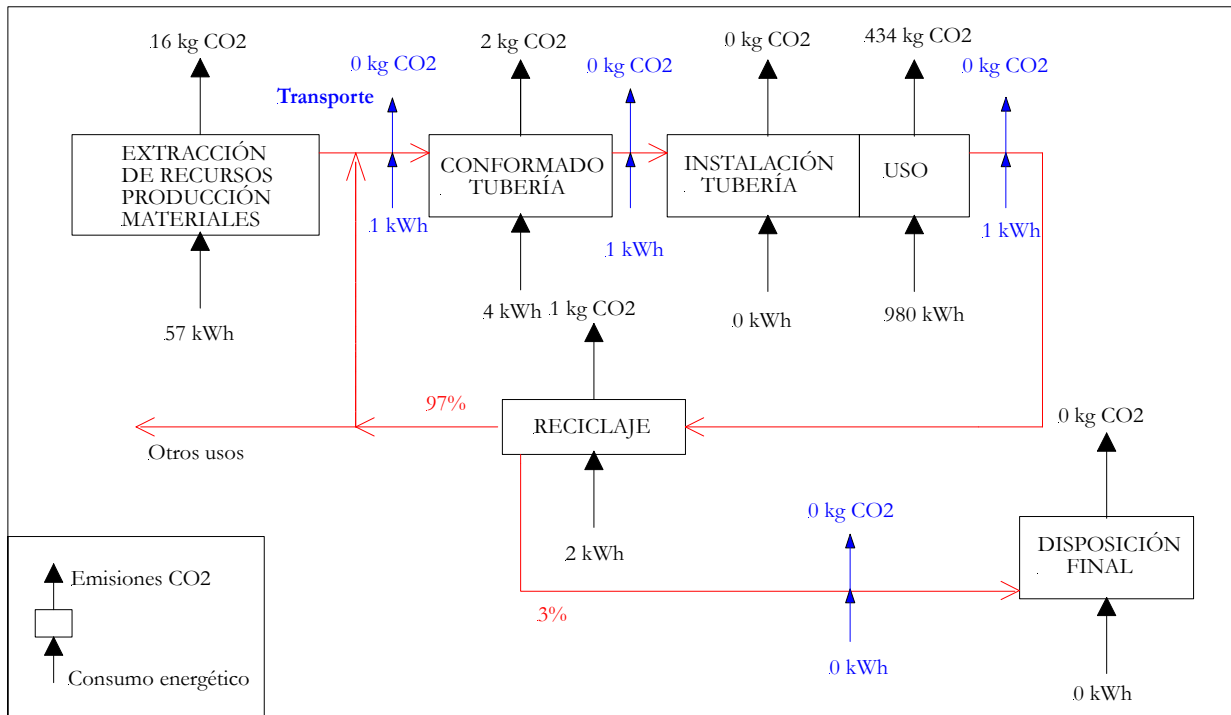


Figure 8.1. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of **3 m of RD110 PVC supply pipe (without using recycled PVC)**.

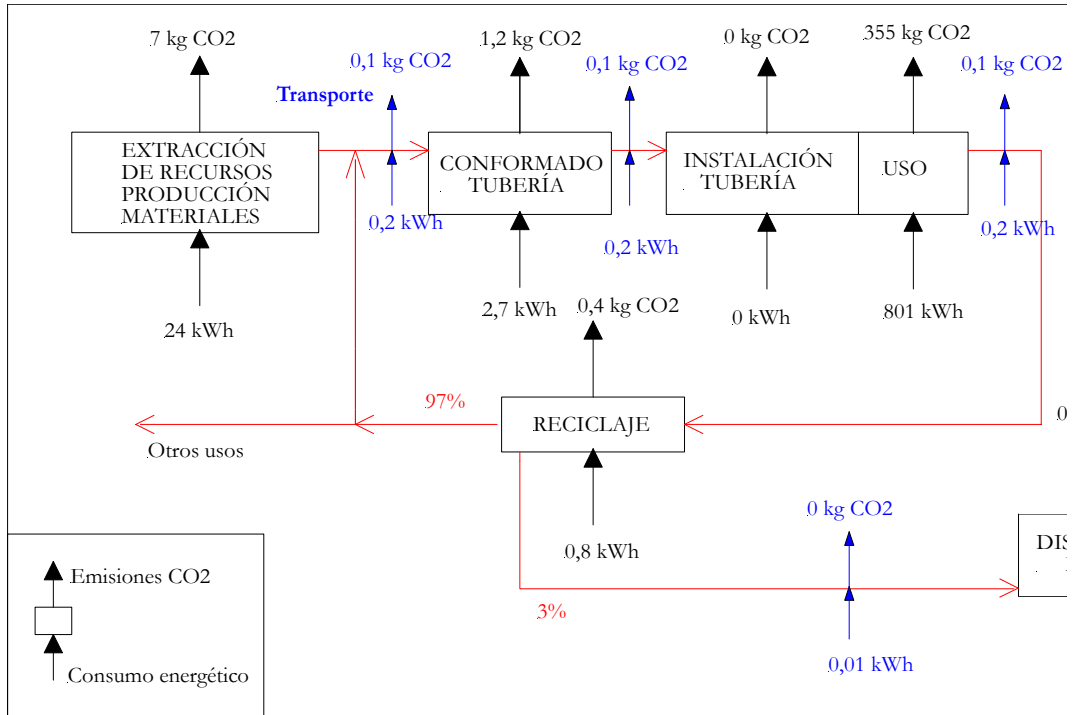


Figure 8.2. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of **3 m of RD110 bioriented PVC supply pipe (without using recycled PVC)**.

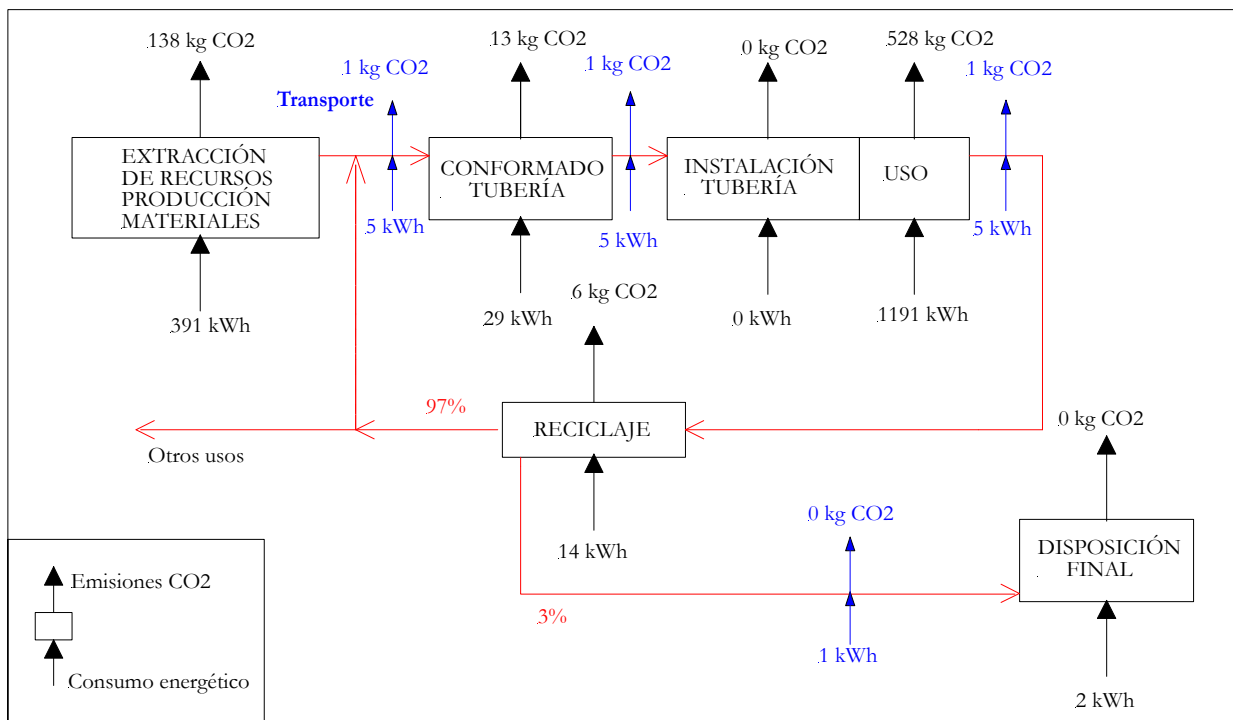


Figure 8.3. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of **3 m of RD125 ductile iron supply pipe**

(without using recycled iron).

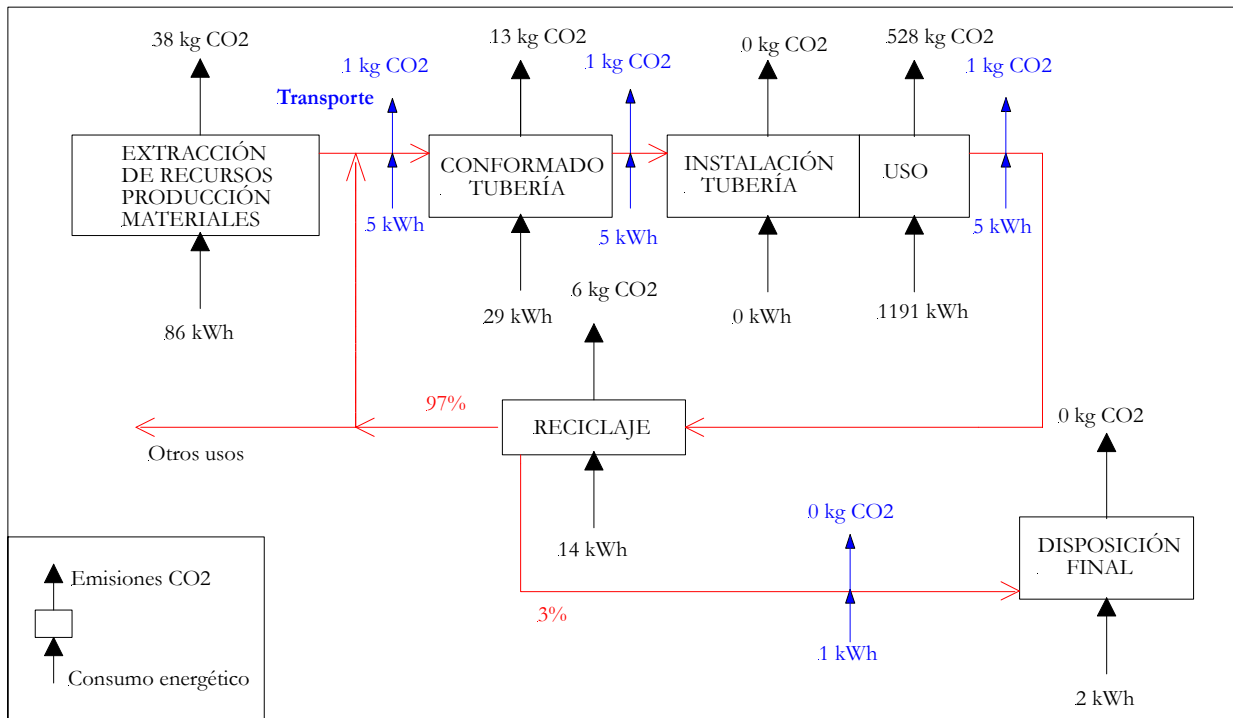


Figure 8.4. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of 3 m of RD125 ductile iron supply pipe (with 80% recycled iron).

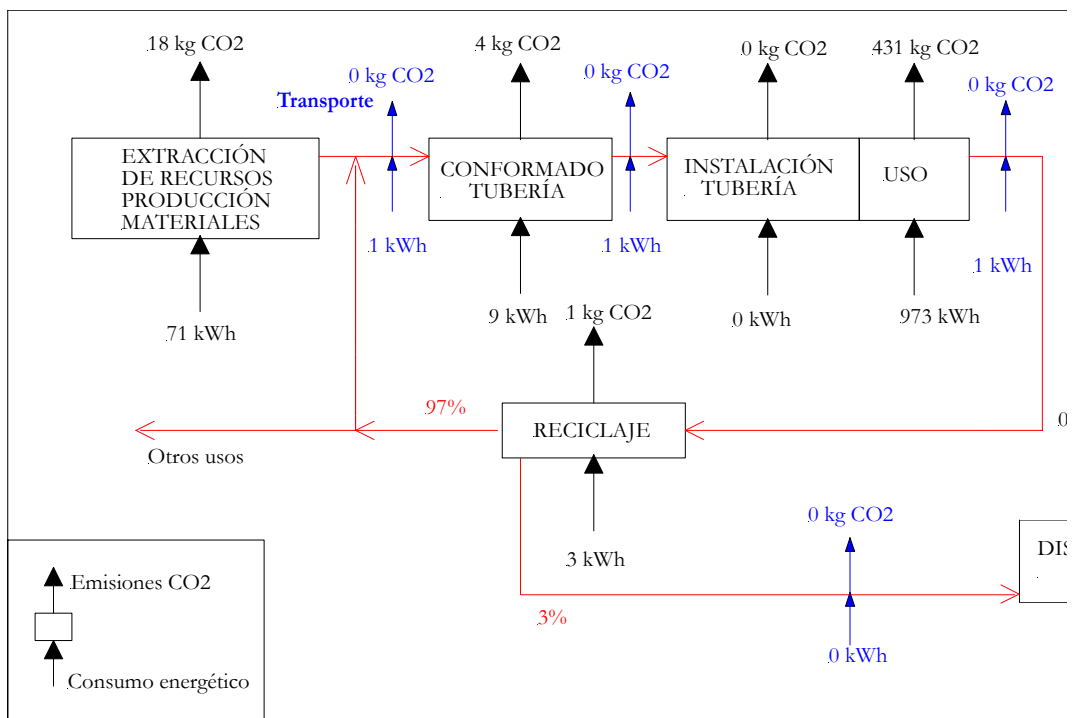


Figure 8.5. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of **3 m of RD125 HDPE supply pipe (without using recycled HDPE)**.

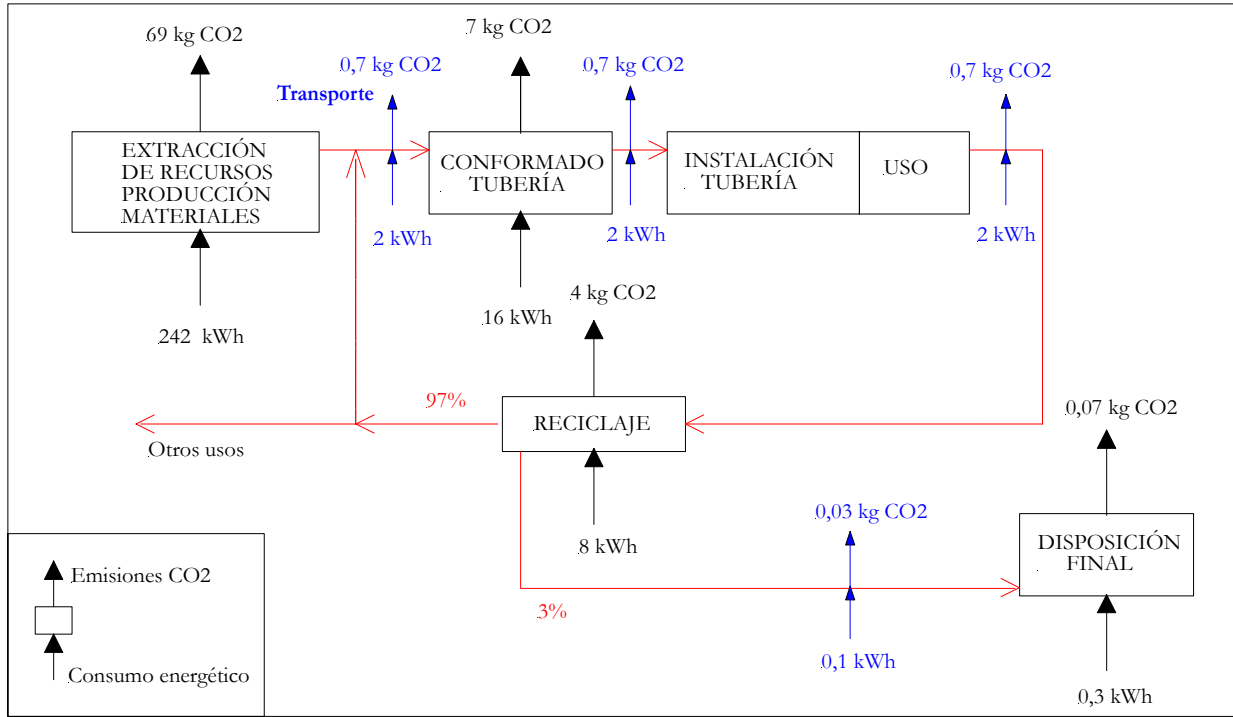


Figure 8.6. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of **3 m of RD315 PVC sanitation pipe (without using recycled PVC)**.

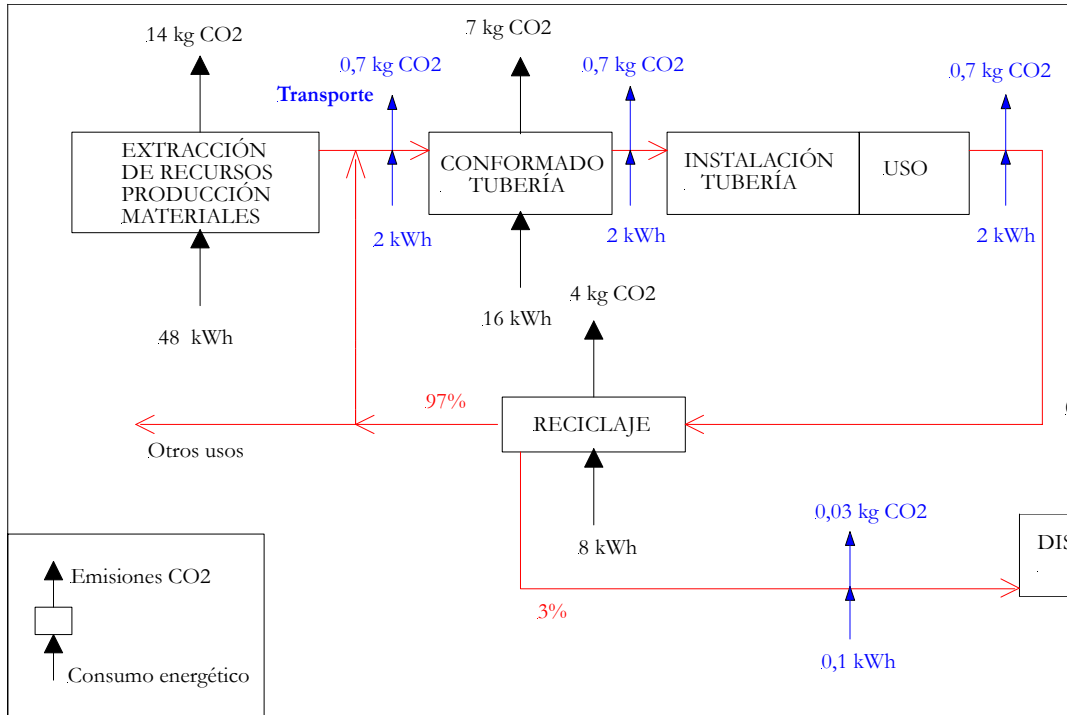


Figure 8.7. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of **3 m of RD315 PVC sanitation pipe (with 80% recycled PVC)**.

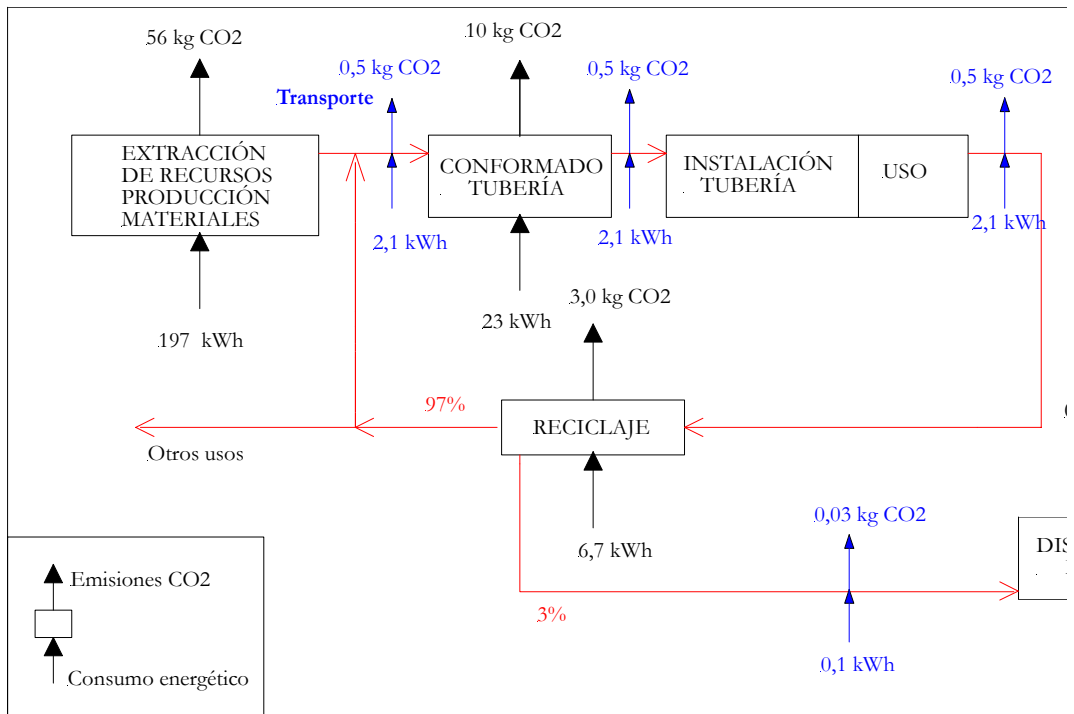


Figure 8.8. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of **3 m of RD315 bioriented PVC sanitation pipe (without using recycled PVC)**.

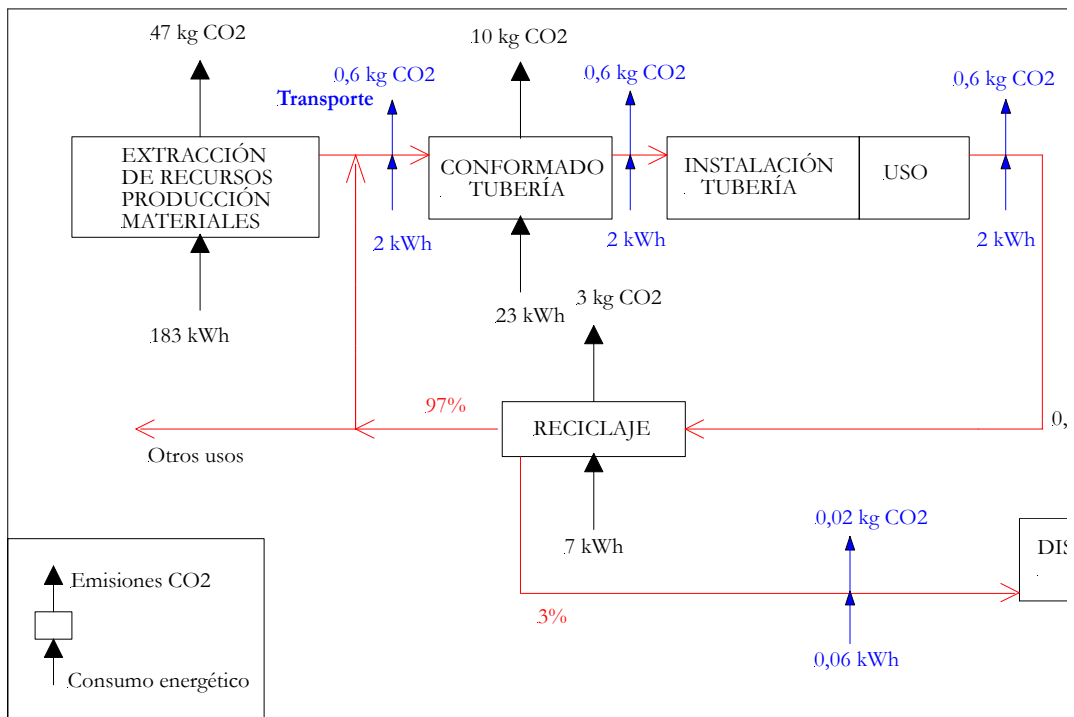


Figure 8.9. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of **3 m of RD400 corrugated PE sanitation pipe (without using recycled material)**.

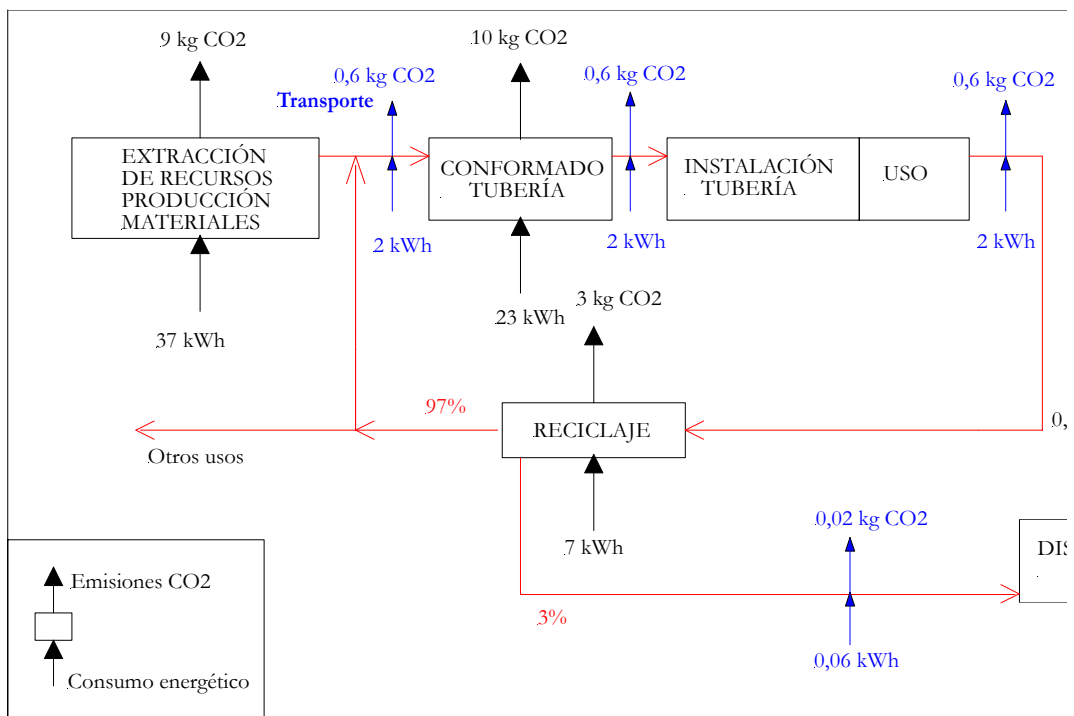


Figure 8.10. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of **3 m of RD400 corrugated PE sanitation pipe (with 80% recycled material.)**

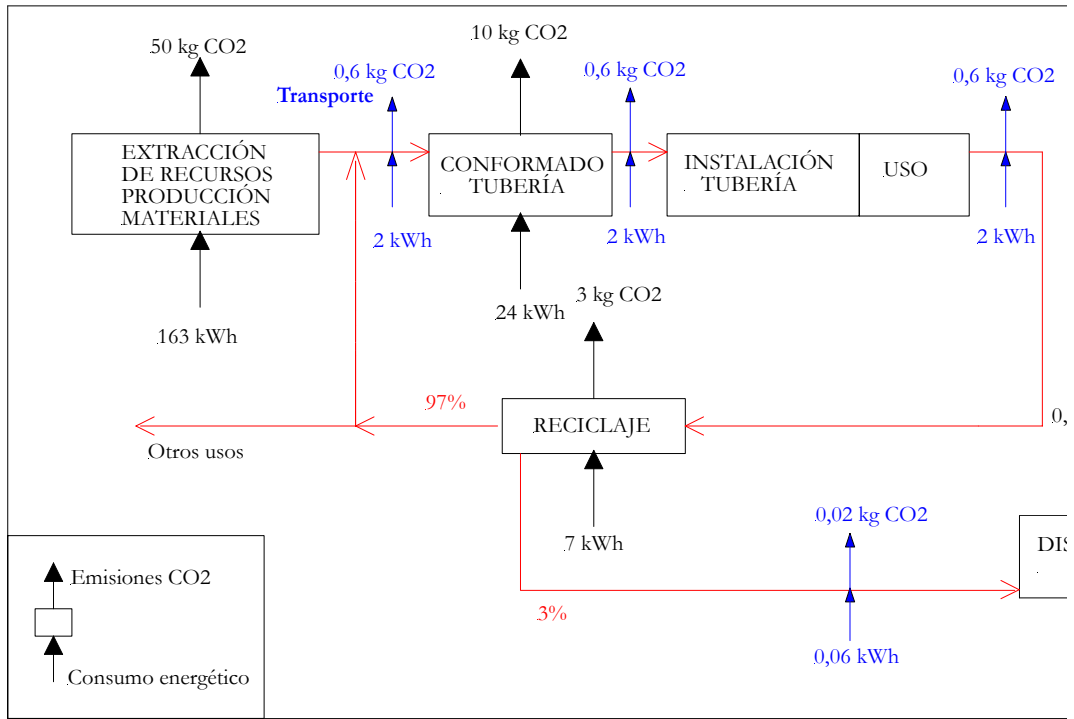


Figure 8.11. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of **3 m of RD400 corrugated PP sanitation pipe (without using recycled material.)**

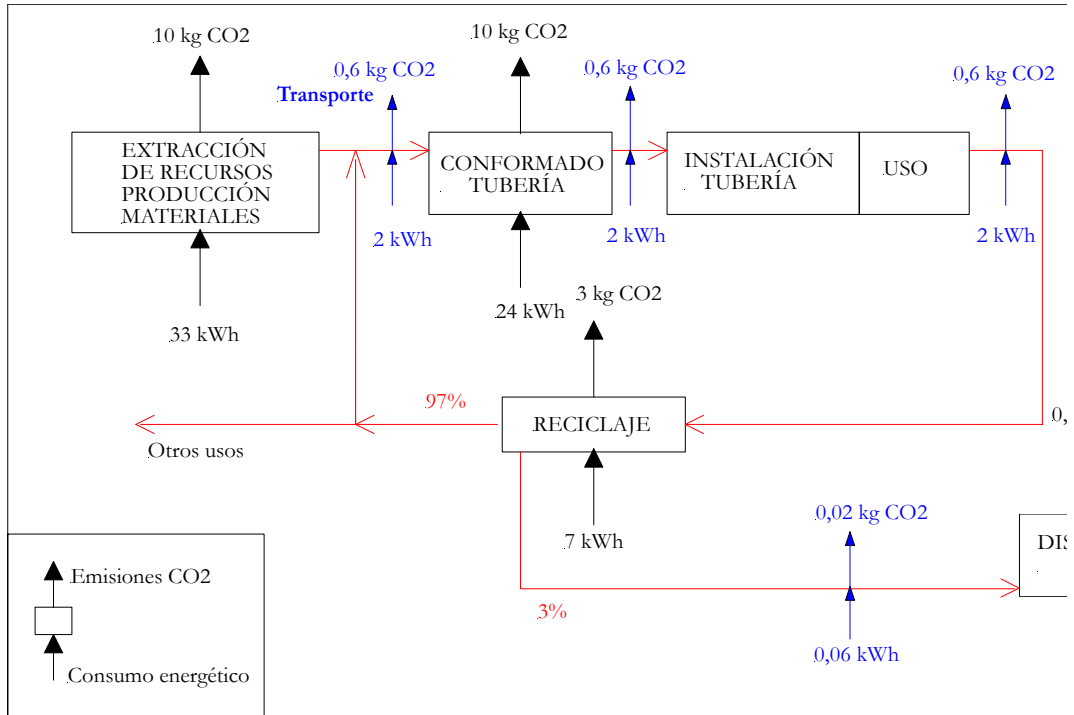


Figure 8.12. Estimate of energy consumption and CO₂ emissions consequent to the production, use, recycling and final waste disposal of **3 m of RD400 corrugated PP sanitation pipe (with 80% recycled material)**.

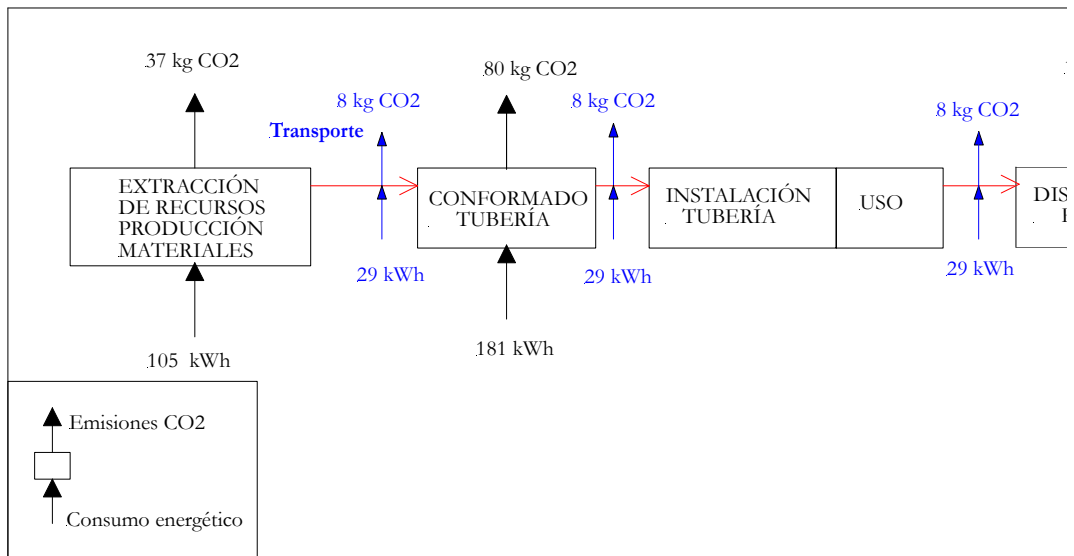


Figure 8.13. Estimate of energy consumption and CO₂ emissions consequent to the production, use and final waste disposal of **3 m of RD400 concrete sanitation pipe**.

Table 8.14. Energy consumption and CO₂ emissions attributable to the production and use (50 years) of pipes made of different materials considering processes of deconstruction, recycling and final disposal of materials. Summary.

Calculation base: 3 m of pipe without accessories (Recycled material % weight)	RD	Weight of pipe	s	Hazen Williams coeff.	Energy consumption	CO ₂ emissions	Variation energy consumption vs. ref. std.	Variation CO ₂ emissions vs. ref. std.
	mm	kg m ⁻¹	m s ⁻¹		kWh	kg CO ₂	%	%
SUPPLY PIPES								
Bioriented PVC	110	1.1	1.4	--(1)	829.1	363.2	-20.58	-19.81
PVC	110	2.7	1.5	150	1043.9	453.0	0.00	0.00
HDPE	125	3.8	1.4	140	1058.9	455.2	1.43	0.48
Ductile iron (80% recycled material)	125	21.6	0.9	100 (2)	1336.8	589.1	28.06	30.05
Ductile iron	125	21.6	0.9	100 (2)	1641.1	689.0	57.20	52.10
SANITATION PIPES								
Corrugated PP (80% recycled material)	400	9.8	3.8	-	69.9	25.3	-74.42	-68.84
Corrugated PE (80% recycled material)	400	9.8	3.8	-	73.9	24.8	-72.96	-69.57
PVC (80% recycled material)	315	11.5	5.0	-	80.1	26.4	-70.68	-67.51
Corrugated PP	400	9.8	3.8	-	200.5	65.3	-26.67	-19.68
Corrugated PE	400	9.8	3.8	-	220.5	62.4	-19.36	-23.30
Bioriented PVC	315	10.4	5.0	-	232.5	70.6	-14.96	-13.20
PVC	315	11.5	5.0	-	273.4	81.3	0.00	0.00
Concrete	400	134.1	2.8		436.9	153.9	59.81	89.28

(1). The load losses in the pipe over 50 years were estimated based on the Prandtl Colebrook White correlation (Pipelife, 2005).

(2) Value considered for new pipe.

Table 8.15. Estimated energy consumption for each of the life cycle stages of supply pipes made of different materials. Referring to 3 m sections of pipe.

3 m of supply pipe	Energy consumption (kWh)				
	PVC RD110	Bioriented PVC RD110	HDPE RD125	Ductile iron RD125	Ductile iron RD125 with 80% recycled material
Extraction and supply of materials	56.7	23.9	71.5	390.6	86.3
Transport of materials to the production plant	0.6	0.2	0.8	4.7	4.7
Production of pipe	3.6	2.7	9.2	29.1	29.1
Transport of pipe for installation	0.6	0.2	0.8	4.7	4.7
Installation	negligible	negligible	0.2	negligible	negligible
Use of pipe (50 years)	979.8	800.9	972.6	1191.2	1191.2
Transport of pipe for recycling	0.6	0.2	0.8	4.7	4.7
Recycling	1.9	0.8	2.8	13.8	13.8
Transport for final disposal in waste disposal site	0.0	0.01	0.0	0.7	0.7
Final disposal in waste disposal site	0.1	0.03	0.1	1.5	1.5
TOTAL	1043.9	829.1	1058.9	1641.1	1336.8

Table 8.16. Estimated energy consumption for each of the life cycle stages of sanitation pipes made of different materials. Referring to 3 m sections of pipe.

3 m of sanitation pipe	Energy consumption (kWh)							
	PVC RD315	PVC RD315 80% recycled material	Bioriented PVC RD315	Concrete RD400	HDPE RD400	HDPE RD400 80% recycled material	Corrugated PP RD 400	Corrugated PP RD400 80% recycled material
Extraction and supply of materials	241.6	48.4	196.8	105.1	183.2	36.6	163.2	32.6
Transport of materials to the production plant	2.5	2.5	2.1	29.4	2.1	2.1	2.1	2.1
Production of pipe	15.6	15.6	22.5	181.1	23.5	23.5	23.5	23.5
Transport of pipe for installation	2.5	2.5	2.1	29.4	2.1	2.1	2.1	2.1
Transport of pipe for recycling	2.5	2.5	2.1	--	2.1	2.1	2.1	2.1
Recycling	8.2	8.2	6.7	--	7.1	7.1	7.1	7.1
Transport for final disposal in waste disposal site	0.1	0.1	0.1	29.4	0.1	0.1	0.1	0.1
Final disposal in waste disposal site	0.3	0.3	0.2	62.5	0.1	0.1	0.1	0.1
TOTAL	273.4	80.1	232.5	436.9	220.5	73.9	200.5	69.9

Table 8.17. Estimated CO₂ emissions for each of the life cycle stages of supply pipes made of different materials. Referring to 3 m sections of pipe.

3 m of supply pipe	CO ₂ emissions (kg CO ₂)				
	PVC RD110	Bioriented PVC RD110	HDPE RD125	Ductile iron RD125	Ductile iron RD125 with 80% recycled material
Extraction and supply of materials	16.1	6.8	18.4	138.1	38.2
Transport of materials to the production plant	0.2	0.1	0.2	1.3	1.3
Production of pipe	1.6	1.2	4.1	12.9	12.9
Transport of pipe for installation	0.2	0.1	0.2	1.3	1.3
Installation	negligible	negligible	0.1	negligible	negligible
Use of pipe (50 years)	433.9	354.7	430.7	527.5	527.5
Transport of pipe for recycling	0.2	0.1	0.2	1.3	1.3
Recycling	0.9	0.4	1.2	6.1	6.1
Transport for final disposal in waste disposal site	0.0	0.00	0.0	0.2	0.2
Final disposal in waste disposal site	0.0	0.01	0.0	0.4	0.4
TOTAL	453.0	363.2	455.2	689.0	589.1

Table 8.18. Estimated CO₂ emissions for each of the life cycle stages of sanitation pipes made of different materials. Referring to 3 m sections of pipe.

3 m of sanitation pipe	CO ₂ emissions (kg CO ₂)							
	PVC RD315	PVC RD315 80% recycled material	Bioriented PVC RD315	Concrete RD400	HDPE RD400	HDPE RD400 80% recycled material	Corrugated PP RD 400	Corrugated PP RD400 80% recycled material
Extraction and supply of materials	68.7	13.8	55.9	33.6	47.0	9.4	50.0	10.0
Transport of materials to the production plant	0.7	0.7	0.5	7.8	0.6	0.6	0.6	0.6
Production of pipe	6.9	6.9	10.0	80.2	10.4	10.4	10.4	10.4
Transport of pipe for installation	0.7	0.7	0.5	7.8	0.6	0.6	0.6	0.6
Transport of pipe for recycling	0.7	0.7	0.5	--	0.6	0.6	0.6	0.6
Recycling	3.6	3.6	3.0	--	3.2	3.2	3.2	3.2
Transport for final disposal in waste disposal site	0.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0
Final disposal in waste disposal site	0.1	0.1	0.1	16.7	0.0	0.0	0.0	0.0
TOTAL	81.3	26.4	70.6	153.9	62.4	24.8	65.3	25.3

8.5. Conclusions

Consideration of the processes of digging up pipes, recycling in the cases where this is possible, and final disposal in waste disposal site, does not alter the order in terms of the importance of CO₂ emission and energy consumption figures for the pipes.

In other words, for supply pipes, the pipe giving the best results continues to be the RD110 bioriented PVC pipe, which presents energy consumption and CO₂ emissions 20% lower than the reference case (RD110 conventional PVC).

Next come the RD110 PVC pipe and the RD125 HDPE pipe; the second of these uses 1.4% more energy and emits 0.5% more CO₂ than the PVC reference standard pipe. The most unfavourable case is the RD125 ductile iron pipe, which has an energy consumption 57,2% higher.

In the case of sanitation pipes, once again the most favourable case is the corrugated PP pipe with 80% recycled material. In general, the plastics present better results than concrete, which has energy consumption and CO₂ emissions in the region of 60% and 90% higher, respectively, than for the RD315 PVC pipe taken as the reference standard.