THE ECOLOGICAL FOOTPRINT OF TRANSPORTING WASTE IN THE PROVINCE OF CASTELLON

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Abstract

One of the major problems of waste management in the province of Castellon is the shortage of treatment facilities and the unsuitable geographical distribution of existing facilities. This situation is contrary to the principles of self-sufficiency and proximity governing correct waste management and leads to excessive transport costs, in both economic and environmental terms.

An example of this situation can be seen in the facilities for treating municipal solid waste (MSW), most of which have been closed down in recent years. Yet, the construction of new facilities to replace them has suffered continual delays and, as a result, much of the MSW produced in the province of Castellon is transported to the province of Alicante.

In this study a Geographical Information System is used, together with indicators of the carbon footprint and the ecological footprint, to assess the environmental impact of transporting MSW in the province of Castellon. The footprint of transporting MSW is thus assessed in both the current scenario and the future scenario, that is, once the planned treatment facilities become operational. Results are then compared in order to determine the environmental impact caused by the delay in setting up new facilities in the province.

Keywords: *Ecological footprint; Carbon footprint; Waste transport; Municipal solid waste; Environmental impact; Geographic Information System*

1. Introduction

One of the most alarming aspects of waste management in the province of Castellon is the shortage of treatment plants and the inappropriate geographical distribution of the existing facilities (Vidal et al., 2009). This situation runs in completely the opposite direction to the principles of self-sufficiency and proximity that should govern correct waste management (MARM, 2008). Furthermore, it also leads to excessive transport costs, both in economic as well as environmental and social terms.

The clearest and most worrying example of this situation is that of municipal solid waste (MSW) treatment facilities. Currently, there is only one authorised MSW treatment facility operating in the whole province of Castellon, namely the composting plant in Onda and its adjoining sanitary landfill. This plant has to cater for 45 municipalities in the central districts, which are the only ones that process their refuse in compliance with the Law on Waste. The recent closure of the landfill in Villafranca del Cid, in the north of the province, has meant that a total of 27 municipalities in the northern districts now have to transport their rubbish to Jijona (Alicante), almost 300 kilometres away. Taking refuse to Alicante is not new to the province of Castellon. As a result of the closure of the sanitary landfills in Cortes de Arenoso and Tales, in 2007 and 2008 respectively, 41 municipalities in the southern districts of the province already decided to take their waste to Villena (Alicante). Moreover, there are a series of municipalities in the north of the province that do not have authorised facilities nearby and have been taking their waste to non-legal landfills.

The origin of this situation lies in the failure on the part of the municipal councils and, above all, the Generalitat Valenciana (Regional Government) to implement the Regional Waste Plans of the Community of Valencia (PZRCV), all of which have now been in force for more than five years (CMAAUV, 2001, 2002 and 2004). The PZRCV divide the province into five zones and establish the infrastructures that are needed in each of them to ensure proper management of the MSW (Figure 1).

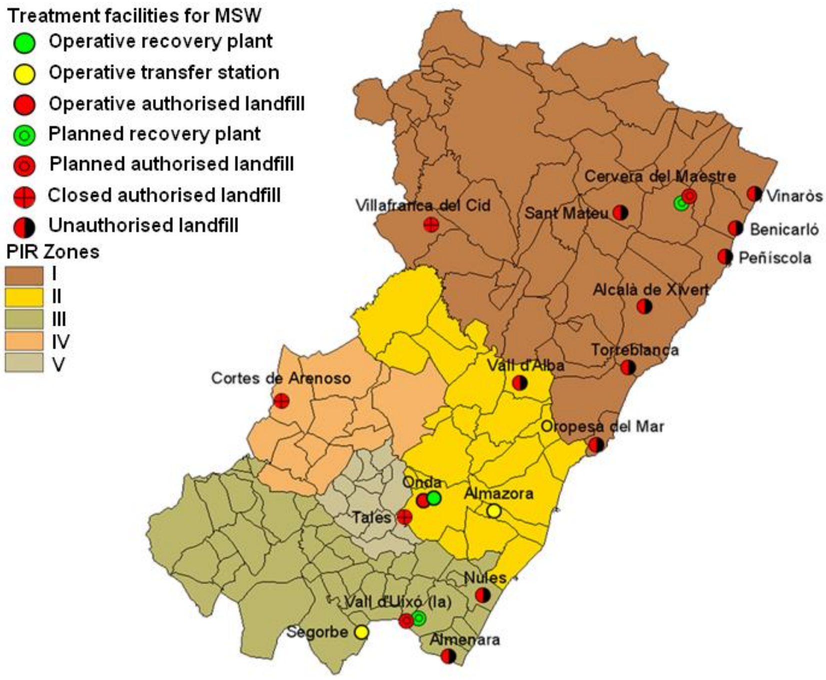
PIR Zone I covers the whole of the northern part of the province and should have an MSW treatment facility with its corresponding sanitary landfill. In the year 2002 it was decided that the treatment facility should be built in the municipal district of Cervera del Maestre. Since then, however, the choice of site has been changed several times due to the absence of reliable guarantees regarding the protection of the environment and to objections from local residents. Finally, construction of the facility in Cervera del Maestre now has environmental authorisation, although the same cannot be said of the sanitary landfill where rejected material from that facility is to be deposited.

PIR Zone II comprises most of the central part of the province, including the provincial capital, and is the only one that has implemented an MSW management service and has built the necessary infrastructures. The refuse from the most populated municipalities is compacted in the transfer station in Almazora and later taken to the treatment facility in Onda. The treatment facility and the landfill in Onda have been made larger so as to be able to cope with the waste generated in PIR Zones IV and V.

PIR Zone III covers the whole of the southern part of the province and should also have an MSW treatment facility and a landfill. In 2003, the decision was made to build these facilities in Vall d'Uixo, but a string of problems have meant that the infrastructures will not be finished for another two years.

The delay in building all these facilities has very important negative repercussions. Firstly, every year 70,000 tons of MSW (about 25% of the MSW of the province) are dumped in an uncontrolled manner, without any kind of previous treatment. And secondly, more than 50,000 tons of MSW (around 18% of the MSW of the province) are taken to the province of Alicante to be treated correctly, with the subsequent economic costs and environmental and social impact resulting from its transportation (Vidal et al., 2009).

Figure 1: PIR Zones and MSW treatment facilities



2. Aims

The purpose of this study is to assess the environmental impact of transporting the MSW produced in the province of Castellon. This environmental impact will be expressed by means of two indicators: the carbon footprint (annual emissions of CO2) and the ecological footprint (hectares of forest needed to absorb the CO2 emissions). On the one hand, the footprint resulting from the transportation of MSW in the current scenario will be assessed. On the other hand, the study will also assess the footprint caused by transporting MSW in the future scenario, that is to say, when the MSW treatment facilities envisaged in the PZRCV come into operation (CMAAUV, 2001, 2002 and 2004). Finally, the results obtained for the two scenarios will be compared. The purpose of this comparison is to determine the environmental impact caused by delaying the implementation of the new facilities that are to replace the plants that have been closed down in the province in recent years.

3. Methodology

In this study, the ecological footprint methodology was applied to the consumption of fossil fuels associated to the transportation of the MSW produced in the province of Castellon. The study was carried out with the aid of a Geographic Information System (GIS). The stages that were addressed in the study are outlined in the following subsections.

The ecological footprint of the consumption of fossil fuels

3.1. Creation of the scenarios

Before conducting this study, a previous step had to be carried out in which information was gathered so as to be able to determine the current and future configuration of waste management in the province of Castellon. This information about the production of MSW in the province of Castellon and where it goes is essential to the study.

Waste generation

The data on MSW generation used in this study were obtained from the “Waste Map of the province of Castellon” (Mapa de Residuos de la provincia de Castellón) (Vidal et al., 2009). This report provides an inventory of the waste produced in each municipality in the province of Castellon in the year 2008, divided into different categories, one of which is MSW. The data on annual generation of MSW from the “waste Map of the province of Castellon” are used to model both the current and the future scenarios. Although there is a growing tendency to increase consumption, it is assumed that the generation of waste will remain constant over the period 2005-2020, as a consequence of the application of policies to reduce waste generation and to implement sorted waste collection (CMAAUV, 2010). In any case, since the aim of the study is to compare the impacts of transporting MSW in the current scenario and in the future scenario, it makes no sense to assume that the generation of MSW is different in each scenario.

Waste treatment facilities

The “Waste Map of the province of Castellon” (Vidal et al., 2009) also provides information about the environmental management –consisting in collection, transport and treatment– currently applied to the MSW produced in the province of Castellon. Moreover, the PZRCV (CMAAUV, 2001, 2002 and 2004) and the Integrated Waste Plan of the Community of Valencia 2010 (PIR10, CMAAUV, 2010) describe the MSW treatment facilities that are planned for the future. These sources are used to determine the MSW treatment facilities (including transfer stations, recovery plants and authorised sanitary landfills) that are currently in operation and those that will operate in the future. Thus, the geographic location of these facilities is determined and it can be seen which municipalities in the province of Castellon use them today and/or will use each of them in the future.

Waste transportation logistics

For the purposes of this study, MSW is assumed to be collected daily in all the municipalities in the province of Castellon. Furthermore, it is supposed that two reference vehicles are used to transport the MSW: a compactor refuse collection vehicle, which collects waste inside the town and carries it to the transfer station or treatment facility, depending on the case; and another larger capacity vehicle, which transports waste from the transfer station to the treatment facility (Table 1).

The payload of these vehicles is then taken as the basis on which to assign the number of waste collection lorries (vehicle 1) required by each municipality, according to their mean daily generation of MSW. In municipalities where the daily generation of MSW does not reach the capacity of one lorry, collection will be carried out working jointly with neighbouring municipalities. That is to say, one lorry will collect the MSW from several nearby municipalities and, finally, carry it all to the corresponding treatment facility. In this case, the relative proportion of a lorry (vehicle 1) corresponding to each municipality will be assigned.

On the other hand, transportation of the MSW between transfer stations and treatment facilities is performed as the articulated lorries (vehicle 2) are filled in the transfer stations. That is to say, one lorry will load the MSW from several municipalities and, once it has reached the limit of its capacity, it will carry the waste to the treatment facility. In this case, the number of articulated lorries (vehicle 2) required by each municipality will be assigned depending on their annual generation of MSW and the capacity of these vehicles.

Table 1: Characteristics of the vehicles used to collect and transport MSW

	Vehicle 1	Vehicle 2
Operations	Collection inside the municipality and transport to transfer station or treatment facility	Transport from transfer station to treatment facility
Type of vehicle	Rigid compactor lorry	Articulated lorry
Type of fuel	Diesel	Diesel
Container capacity (m^3)	12.6	39
Unladen weight (kg)	8,880	19,865
Payload (kg)	5,500	20,135
Gross weight (kg)	14,380	40,000

3.2. Calculation of the distances travelled by the vehicles

Once the (intermediate and/or final) destination of the MSW produced in each municipality has been determined, the routes to be taken by the vehicles that will pick up and transport the waste are established. This is performed with the aid of a GIS, which is a system that makes it easier to obtain, manage, handle, analyse, model, represent and output spatially referenced data in order to solve complex planning and management problems (NCGIA, 1990).

In this case the free software application gvSIG and its extension, Redes, were used to calculate the optimal routes that allow the vehicles to go from a starting point to a destination (and back) in the shortest time possible. Thus, the GIS is used to solve a graph problem in which the following elements have been assigned: a starting point (municipality), several intermediate stops (other municipalities in the case of collection service shared by several municipalities), a destination (treatment facility) and a whole network of possible paths (roads) with an associated cost (speed). To perform these calculations, a digital map of the municipalities in the province of Castellon and the current and future MSW treatment facilities is introduced into the GIS. Likewise, a digital roadmap showing three types of road is introduced and a mean speed is assigned to each one (Burón et al., 2004): motorways and dual carriageways (70 km/h), rural roads (50 km/h) and urban roadways (14 km/h).

The Redes extension was used to identify the optimal routes for the collection lorries (vehicle 1), whether it is a direct route between a municipality and a treatment facility or a shared route passing through several municipalities before finally reaching the treatment facility. In the same way, the optimal routes taken by the articulated lorries (vehicle 2) between the transfer stations and the treatment facilities are also identified. In the two cases, the outgoing route to the treatment facility and the return route back to the starting point are determined and taken into account, for both the current and the future scenarios. In contrast, neither the route travelled within the municipality to collect waste from the containers nor the trips made to take the waste from the recovery facilities to the adjoining landfills are taken into account. In any case, there is very little difference between these routes and the environmental impacts associated to them in the two scenarios, so they do not interfere with the comparison.

3.3. Calculation of the carbon footprint and the ecological footprint

The previous stages provide the following data: number of lorries used to collect and transport the MSW (vehicle 1) by each municipality annually; number of articulated lorries used to transport MSW (vehicle 2) by each municipality annually; and the distances travelled by these vehicles in going from their starting point to their destination and back. From these data it is possible to calculate the total number of kilometres travelled by each type of vehicle in order to handle the MSW generated in each municipality in the province of Castellon. At this point, it is also possible to calculate the fuel consumption, CO2 emissions and the ecological footprint resulting from the transportation of the MSW produced in the province of Castellon.

Fuel consumption

To calculate the total fuel consumption associated to each municipality, the following mean diesel consumption ratios were considered: 0.249 litres per kilometre for type 1 vehicles and 0.331 litres per kilometre for type 2 (Léonardi & Baumgartner, 2004).

CO2 emissions

In order to calculate the carbon footprint of each municipality, a CO2 emission ratio per litre of fuel consumed was applied to the results concerning fuel consumption for each municipality. According to the Intergovernmental Panel on Climate Change (IPCC), this ratio is around 74,100 kilograms per terajoule of diesel (IPCC, 2006), which is approximately equal to 2.65 kilograms of CO2 per litre of diesel consumed.

Ecological footprint

The ecological footprint, developed by Wackernagel and Rees, is a tool that assesses the ecological impact of human action on the environment in terms of the surface area of land needed to absorb such an impact or to sustain the production or consumption of goods by an individual or a community (Wackernagel & Rees, 1995). The ecological footprint of the consumption of fossil fuels is represented by the area of forestland needed to absorb the CO2 emissions generated by that consumption.

Therefore, to calculate the ecological footprint of each municipality, the starting point is taken as the results of the CO2 emissions associated to each municipality and then a ratio of the amount of carbon absorbed by the forestland is applied. In general, this ratio is estimated at 5.21 tons of CO2 absorbed annually by each hectare of forest (IPCC, 2001). Nevertheless, in this study a specific ratio, with a value of 3.7 tons of CO2 absorbed annually by each hectare of Mediterranean forestland, was used (Tello, 2002).

Lastly, the numbers of hectares of forestland required to absorb the CO2 associated to the transportation of the MSW produced by each municipality are compared with the hectares of forestland available in the municipalities. The surface areas of forestland are determined using the CORINE Land Cover Project (CLC), carried out by the European Environment Agency (EEA), which provides a database on land use for the year 2000.

3.4. Assessment of the scenarios

Once the environmental impacts derived from transporting the MSW produced in the province of Castellon in the current and the future scenarios have been obtained, the results are then assessed. The main aim of the study is to perform a comparative analysis of the environmental impacts of the current and the future scenarios. The purpose of this analysis is to determine the environmental impact caused by delaying the implementation of the new facilities that must replace the plants that have been closed down in the province in recent years.

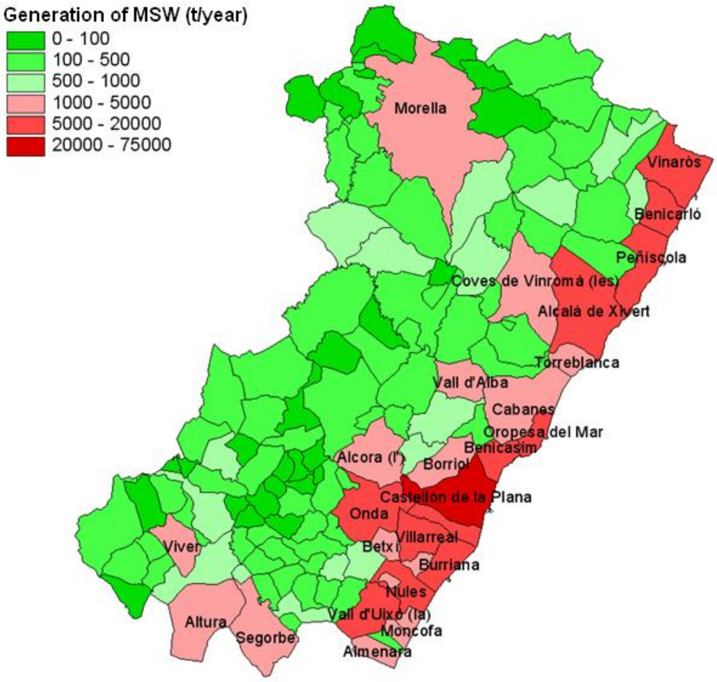
4. Results

The subsections that follow present the results from the study concerning the carbon footprint and the ecological footprint of transporting the MSW of the province of Castellon for the current and future scenarios. Finally, the comparison of the results obtained for both scenarios will be presented.

4.1. Current scenario

Figure 2 shows the geographical distribution of the annual generation of MSW in the province of Castellon. It can be seen how the production of MSW is concentrated mainly along the coastal area, which is where the most populated municipalities are situated.

Figure 2: Annual generation of MSW in the province of Castellon (Source: Vidal et al., 2009)



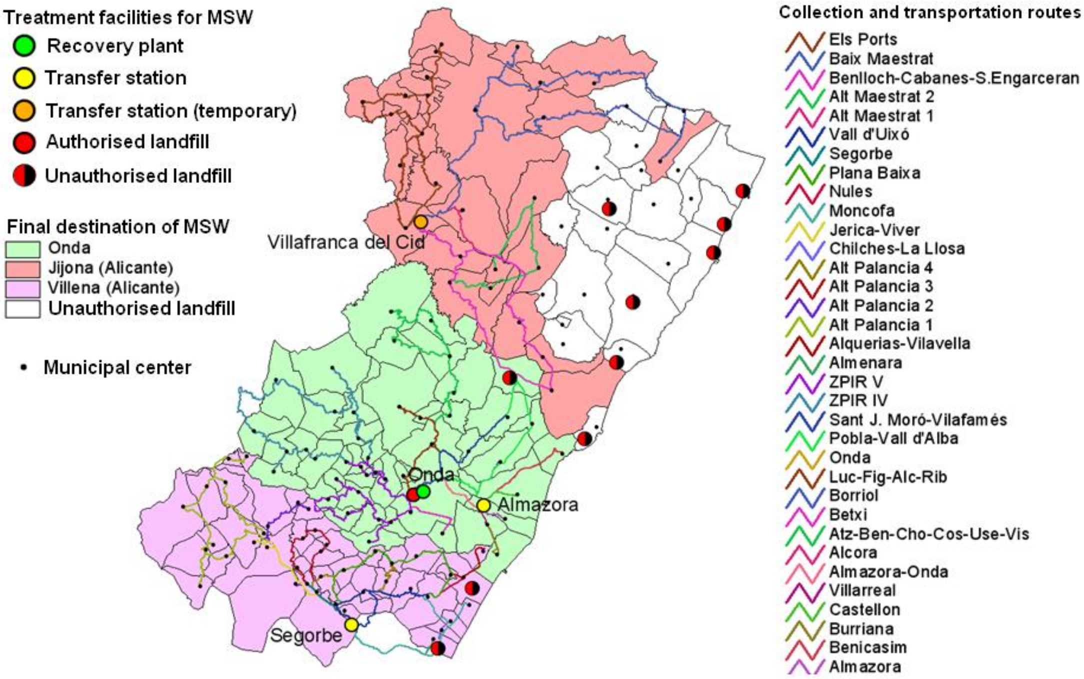
At present, the MSW of the province of Castellon is taken to different destinations depending on which PIR Zone the municipalities that produce it belong to (Figure 1):

- Following the closure of the authorised sanitary landfill in Villafranca del Cid, the municipalities in PIR Zone I that used to send their MSW to this facility (27 municipalities) now take it to the authorised landfill in Jijona (Alicante). The collection vehicles take the waste to the old landfill in Villafranca del Cid (which has temporarily been turned into a transfer station) and from there it is transported by higher-capacity articulated lorries to Jijona.
- The municipalities in PIR Zone II (21 municipalities) send their MSW to the recovery facility in Onda. The towns that generate the most waste (Almazora, Benicasim, Burriana, Castellon de la Plana and Vila-real) use the transfer station in Almazora.
- Following the closure of the authorised sanitary landfill in Tales, the municipalities in PIR Zone III (41 municipalities) now take their MSW to the authorised landfill in Villena (Alicante). The collection vehicles take the waste to the transfer station in Segorbe and from there it is transported by higher-capacity articulated lorries to Villena.
- Following the closure of the sanitary landfills in Cortes de Arenoso and Tales, the municipalities in PIR Zone IV (11 municipalities) and in PIR Zone V (13 municipalities) now send their MSW to the recovery facility in Onda.

Figure 3 shows a map representing the current scenario of MSW collection and transportation in the province of Castellon. This map includes the final destination of the MSW generated in each municipality and the optimal routes travelled by the lorries used for collecting and transporting MSW. Both the routes running directly between municipalities and treatment facilities and the shared routes that go through several municipalities before they eventually reach the treatment facilities have been included.

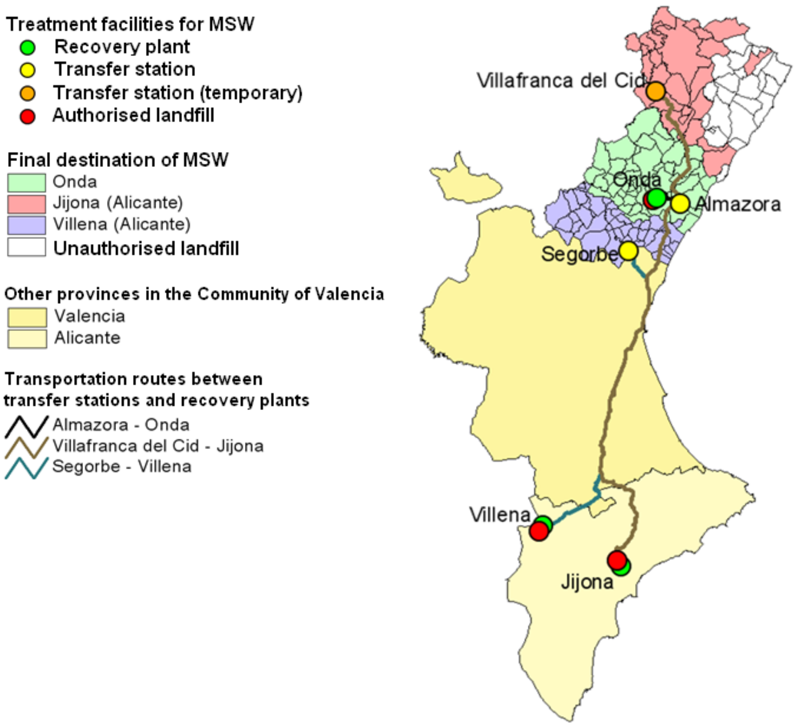
As Figure 3 shows, there are municipalities in PIR Zone I that still send their MSW to non-legal sanitary landfills (22 municipalities altogether). This means that close to 70,000 tons of MSW a year fail to undergo any kind of previous recovery treatment and are disposed of in an uncontrolled manner. The environmental impact of the transportation in these cases is not really an important cause for concern, since the municipalities that carry out uncontrolled dumping do so in nearby non-legal landfills. Yet, there are a number of environmental risks associated to uncontrolled dumping, including: pollution of land, water and atmosphere; impact on biodiversity and ecosystems; impact on the landscape; depletion of natural resources; and harm to the population (Strange, 2002). These municipalities have not been included in the assessment of the ecological footprint of transporting MSW because the actual destination of the waste is unknown.

Figure 3: Current MSW collection and transportation scenario between municipalities and transfer stations or recovery facilities



The current scenario of MSW transportation is completed with Figure 4, which shows the optimal routes travelled by the articulated lorries between the transfer stations and the recovery facilities.

Figure 4: Current scenario of MSW transportation between transfer stations and recovery facilities



In Figure 4 it can be seen that the transportation of MSW in the current situation is especially critical for the municipalities in PIR Zones I and III. On the one hand, more than 8,600 tons of MSW generated in PIR Zone I are carried annually from the temporary transfer station in Villafranca del Cid to the sanitary landfill in Jijona, which involves a journey of 583.5 kilometres for each lorry (there and back). On the other hand, more than 43,800 tons of MSW generated in PIR Zone III are transported annually from the transfer station in Segorbe to the sanitary landfill in Villena. In this case, each lorry travels a total distance of 329.1 kilometres (there and back). These interprovincial MSW transportation routes, together with the uncontrolled dumping carried out in some municipalities, are the most challenging aspects of the current management of MSW in the province of Castellon.

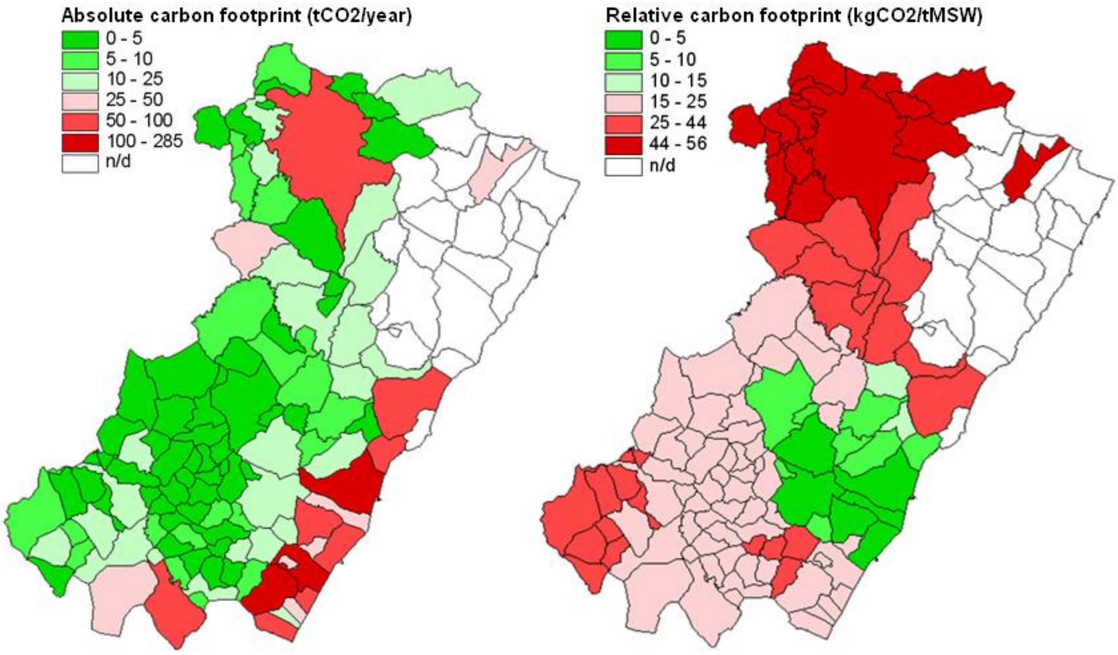
To determine the environmental impact of transporting MSW associated with each municipality in the province of Castellon, the ecological footprint methodology is applied. Table 2 shows the application of the methodology to the town of Castellon de la Plana, which is the provincial capital and is where the largest amounts of MSW are produced. The calculations shown in Table 2 are also carried out for the rest of the municipalities in the province of Castellon. In order to simplify this task, the Data Base Management System (DBMS) of the GIS software application (gvSIG) was used, since it allows the data to be handled in a way that is similar to working with a spreadsheet.

Table 2: Application of the ecological footprint methodology to the transportation of MSW and results for the town of Castellon de la Plana

Parameter	Calculation	Result
Annual generation of MSW: MSW_a [t/year]	Obtained from Vidal et al. 2009	72,066.46
Daily generation of MSW: MSW_d [t/day]	—	197.44
Transfer stations: TS	-	Almazora
Treatment facility: TF	-	Onda
Type 1 vehicles per day to transport between municipalities and TS or TF: $NV1_d$ [veh./day]	For towns with their own route: —; rounding up to the next whole figure For a municipality *j* with a route shared among *n* municipalities: —	36
Type 1 vehicles annually to transport between municipalities and TS or TF: $NV1_a$ [veh./year]		13,140
Type 2 vehicles annually to transport between TS and TF: $NV2_a$ [veh./year]	—	3,603.323
Distance covered by one type 1 vehicle in one trip (there and back): $DV1_u$ [km/veh.]	Obtained by means of GIS software application (gvSIG and its extension, Redes)	17.628
Distance covered annually by all the type 1 vehicles: $DV1_a$ [km/year]		231,631.920
Distance covered by one type 2 vehicle in one trip (there and back): $DV2_u$ [km/veh.]	Obtained by means of GIS software application (gvSIG and its extension, Redes)	33.128
Distance covered annually by all the type 2 vehicles: $DV2_a$ [km/year]		119,370.884
Annual fuel consumption: FC [l/year]		97,188.111
Annual carbon footprint: CF [$kgCO_2$/year]		257,548.494
Annual ecological footprint: EF [ha/year]	—	69.608
Forestland with trees: FWT [ha/year]	Obtained from the CORINE Land Cover Project	1,036.32
Percentage of forest cover consumed: FCC [%]	—	4.77
Carbon Footprint per ton of MSW transported: CF_u [$kgCO_2$/t]	—	3.574
Ecological Footprint per ton of MSW transported: EF_u [ha/t]	—	0.686e-04

Figure 5 shows the results for the carbon footprint in the municipalities in the province of Castellon in the current scenario, both in absolute and in relative terms (with respect to the amounts of MSW transported). An analysis of these results reveals that the municipalities that generate the most MSW (Figure 2) are the ones that produce the greatest environmental impact in absolute terms as a result of transporting the waste. Nevertheless, if the CO2 emissions are assessed in relative terms, it can be seen that the municipalities with the highest environmental impact per ton of MSW transported belong to PIR Zone I, followed by the municipalities in PIR Zone III.

Figure 5: Absolute and relative carbon footprint in the current MSW transportation scenario



As expected, the municipalities that transport the waste from one province to another have a higher relative environmental impact. Yet, a comparison of the municipalities of Castellon de la Plana and Vall d'Uixo, which belong to PIR Zones II and III respectively, will give an idea of just how serious the situation is. Castellon de la Plana is the municipality with the highest generation of MSW, with 72,066 tons of MSW per year. Vall d'Uixo, on the other hand, generates 13,550 tons of MSW per year (less than 19% of the amount generated by Castellon de la Plana). Yet, Vall d'Uixo tops the list in terms of CO2 emissions from transporting MSW, with 281.2 tons a year (20.75 kgCO2/tMSW) versus 257.5 tons per year for Castellon de la Plana (3.57 kgCO2/tMSW). These figures, together with other results from the study, show that there is an urgent need to make more treatment facilities available in the province of Castellon, starting with PIR Zones I and III, since they are the ones that are most severely affected.

Finally, Table 3 offers the results from the study concerning the current scenario aggregated by PIR Zones. From the results that were obtained, it can be concluded that the emissions deriving from current transport of the MSW produced in the province of Castellon amount to 2,111.362 tons of CO2 per year. Absorbing such an amount would require a total of 570.63 hectares of Mediterranean woodland.

Table 3: Carbon footprint and ecological footprint in the current MSW transportation scenario (aggregated by PIR Zones)

PIR Zone	Municipalities	MSW [t/year]	Carbon Footprint		Ecological Footprint	
			Absolute [kgCO_2/year]	Relative [kgCO_2/tMSW]	Absolute [ha/year]	Relative [ha/tMSW]
I	27	8,686.52	379,045	43.64	102.44	1.18e-02
I*	22	69,952.67	n/a	n/a	n/a	n/a
II	21	158,027.15	665,357	4.21	179.83	1.14e-03
III	41	43,840.80	985,215	22.47	266.27	6.07e-03
IV	11	2,522.34	46,947	18.61	12.69	5.03e-03
V	13	1,702.45	34,798	20.44	9.40	5.52e-03
Total	113	214,779.26	2,111,362	9.83	570.63	2.66e-03

* Municipalities that carry out uncontrolled dumping; these municipalities have not been taken into account in the current scenario and do not appear in the overall results

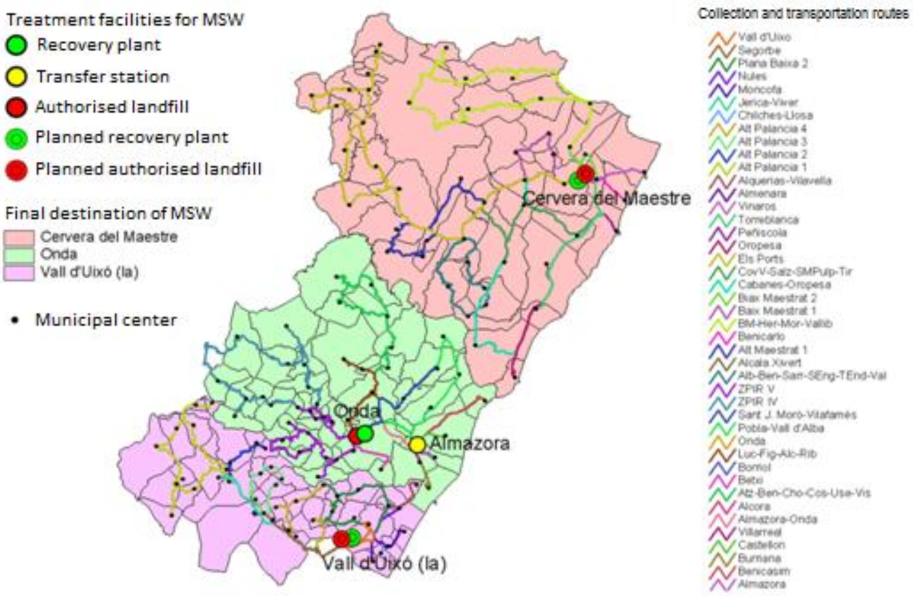
4.2. Future scenario

The generation of MSW in the future scenario is considered to be identical to that of the current scenario (Figure 2), so that the two scenarios can be compared under the same conditions. In contrast, there are important differences in the destination of the MSW in the future and the current scenarios. In accordance with the plans set out in the Integrated Waste Plan of the Community of Valencia 2010 (PIR10, CMAAUV, 2010), the MSW from the province of Castellon will be sent to the following destinations:

- All the municipalities in PIR Zone I (49 municipalities, including those that currently carry out uncontrolled dumping) will send their MSW to the recovery facility to be built in Cervera del Maestre. In addition, this plant will have an adjoining authorised landfill where reject material will be sent. PIR10 does not include a transfer station in this zone.
- The municipalities in PIR Zones II, IV and V (45 municipalities altogether) will send their MSW to the recovery facility in Onda, as they do at present. Likewise, the transfer station in Almazora will continue to cater for the towns that generate the most waste (Almazora, Benicasim, Burriana, Castellon de la Plana and Vila-real).
- The municipalities in PIR Zone III (41 municipalities) will send their MSW to the recovery facility to be built in Vall d'Uixo. This plant will have an adjoining authorised landfill where reject material will be sent. PIR10 does not include a transfer station in this zone, and so the transfer station in Segorbe will stop operating.

Figure 6 shows a map representing the future scenario of MSW collection and transportation in the municipalities of the province of Castellon. This map includes the final destination of the MSW generated in each municipality and all the optimal routes travelled by the lorries used for MSW collection and transportation.

Figure 6: Future scenario of MSW collection and transportation



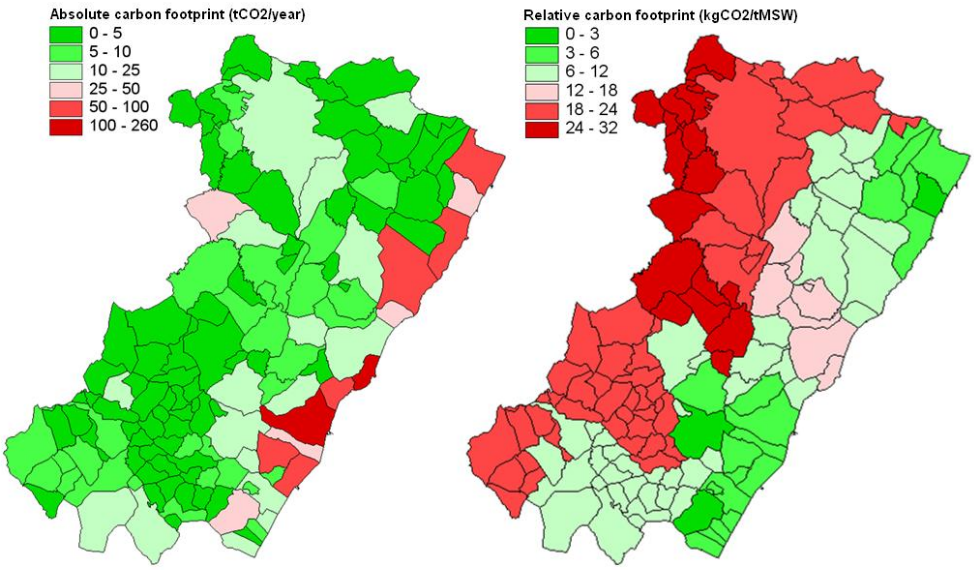
When the new treatment facilities eventually start operating, there will no longer be any need to transport MSW from one province to another. Moreover, the municipalities that to date have disposed of their waste in an uncontrolled manner will have an authorised treatment facility nearby. Therefore, the future scenario of treatment facilities will also have favourable effects as far as reducing the activity of non-legal sanitary landfills is concerned.

The ecological footprint methodology is applied again to determine the environmental impact of transporting MSW in the future scenario. Figure 7 shows the results for the carbon footprint in the municipalities in the province of Castellon in the future scenario, both in absolute and in relative terms (with respect to the amounts of MSW transported). The municipalities that generate the most MSW (Figure 2) are still the ones that produce the greatest environmental impact in absolute terms as a result of transporting the MSW. Moreover, the carbon footprint of the municipalities in PIR Zones I and III is considerably reduced with respect to the current scenario, both in absolute and relative terms.

If the towns of Castellon de la Plana and Vall d'Uixo are compared again, it can be observed how the relative impact of both of them is now more equally balanced: Castellon de la Plana generates 72,066 tons of MSW a year, which gives rise to 257.5 tons of CO2 (3.574 kgCO2/tMSW), whereas Vall d'Uixo generates 13,550 tons of MSW per year and transporting it produces 39.5 tons of CO2 per year (2.92 kgCO2/tMSW).

Therefore, on analysing the CO2 emissions per ton of MSW transported, it can be seen quite clearly that the municipalities with the highest relative impact are those situated further inland, away from the coast. And they are the municipalities that are also furthest from the planned treatment facilities. To reduce the environmental impact and the costs of transporting MSW in the inland municipalities, the implementation of transfer stations in those areas is a possibility that should be considered.

Figure 7: Absolute and relative carbon footprint in the future MSW transportation scenario



Finally, Table 4 offers the results from the study concerning the future scenario aggregated by PIR Zones. According to the future scenario, the emissions due to MSW transportation in the whole of the province of Castellon are estimated to be 1,684.869 tons of CO2 annually. A total of 455.37 hectares of Mediterranean woodland would be needed to absorb such an amount.

Table 4: Carbon footprint and ecological footprint in the future MSW transport scenario (aggregated by PIR Zones)

PIR Zone	Municipalities	MSW [t/year]	Carbon Footprint		Ecological Footprint	
			Absolute [$kgCO_2$/year]	Relative [$kgCO_2$/tMSW]	Absolute [ha/year]	Relative [ha/tMSW]
I	27	8,686.52	174,688	20.11	47.21	5.44e-03
I*	22	69,952.67	486,113	6.95	131.38	1.88e-03
II	21	158,027.15	665,357	4.21	179.83	1.14e-03
III	41	43,840.80	276,966	6.32	74.86	1.71e-03
IV	11	2,522.34	46,947	18.61	12.69	5.03e-03
V	13	1,702.45	34,798	20.44	9.40	5.52e-03
Total without I*	113	214,779.26	1,198,756	5.58	323.99	1.51e-03
Total	135	284,731.93	1,684,869	5.92	455.37	1.60e-03

* Corresponds to municipalities that currently carry out uncontrolled dumping; these municipalities have been taken into account separately in order to make it easier to compare the results with the current scenario (where these municipalities were not taken into account).

4.3. Comparison of the scenarios

The emissions derived from transporting the MSW produced in the province of Castellon in the current scenario are estimated to be 2,111.362 tons of CO2 annually. To absorb such an amount requires a total of 570.63 hectares of Mediterranean woodland. The greatest producers of emissions are the municipalities in PIR Zones I, II and III (18.0%, 31.5% and 46.7% of the emissions in the province, respectively). The environmental impact of transporting MSW in PIR Zone II is mainly due to the large amounts of waste that are transported, since the rate of CO2 emissions per ton of MSW transported is only 4.21 kgCO2/tMSW. In contrast, the environmental impact of transporting MSW in PIR Zones I and III is largely due to the long distances that the waste has to travel to reach Alicante. As a result of these trips between provinces, PIR Zones I and III present much higher rates of CO2 emission per ton of MSW transported, with estimated values of 43.64 and 22.47 kgCO2/tMSW, respectively (Table 3).

In the future scenario, the MSW from PIR Zones I and III will no longer be taken to Alicante, since recovery facilities and authorised MSW landfills will be implemented in the same province. Thus, according to the estimations, the rates of CO2 emissions per ton of MSW transported in PIR Zones I and III will be reduced by approximately 54% and 72% respectively. As a result, the absolute emissions of CO2 in PIR Zones I and III will be reduced by these same proportions. The emissions derived from transporting the MSW produced in the province of Castellon in the future scenario are estimated to be 1,198.756 tons of CO2 annually. To absorb such an amount requires a total of 323.99 hectares of Mediterranean woodland (Table 4). Hence, the implementation of the treatment facilities that are planned for the coming years will make it possible to reduce the emissions of CO2 from transporting MSW by a little over 43%, thus avoiding the production of 912.606 tons of CO2 annually, as well as freeing up 246.64 hectares of Mediterranean woodland.

5. Conclusions

Most of the authorised MSW landfills operating in the province of Castellon have been closed down in recent years. Nevertheless, disputes between municipalities and the incompetence of provincial and autonomic authorities have led to delays in the implementation of the treatment facilities envisaged in the PZRCV (CMAAUV, 2001, 2002 and 2004). In consequence, more than 50,000 tons of MSW per year (around 18% of the MSW of the province) are taken to the province of Alicante to be treated properly. This not only leads to a considerable increase in the cost of transporting the waste, but also has a series of environmental and social repercussions.

In this study, the ecological footprint methodology was applied to determine the environmental impact associated to the transport of the MSW produced in the province of Castellon, taking into account two different scenarios: the current scenario, with an important percentage of the MSW being taken to Alicante, and the future scenario (once the MSW treatment plants envisaged in the PZRCV become operative), in which it will no longer be necessary to transport MSW beyond the provincial borders. On comparing the results obtained for both scenarios, it can be deduced that for each year the implementation of the new facilities is delayed, an additional emission of approximately 912 tons of CO2 will be produced. Therefore, it can be concluded that these facilities need to be implemented as soon as possible, with a view to reducing the environmental impact of transporting MSW.

In addition to reducing the environmental impact of the transport, the treatment facilities foreseen for the future will also put a stop to uncontrolled dumping in the province, which currently amounts to almost 70,000 tons of MSW per year. The municipalities that at present dispose of their MSW in non-legal sanitary landfills will, in the future, have an authorised treatment facility nearby.

Once the new treatment facilities become operative, only the municipalities in the inner part of the province away from the coast might still have some difficulties to transport their waste to treatment facilities, which will be situated along the coastal area. Although it is true to say that the generation of MSW in the inland municipalities is low, the implementation of transfer stations in those areas in order to reduce the environmental impact and transport costs is a possibility that should be taken into consideration.

Finally, it should be noted that in this study only the CO2 emissions derived from transporting the waste have been assessed. If the other externalities from transportation (atmospheric pollution, noise, impact of land use, accident rates and traffic congestion) are added to the environmental impact of CO2 emissions, the need to speed up the implementation of the envisaged treatment facilities becomes even more apparent. In future work the idea is to incorporate other environmental impacts of transportation that have received less attention from researchers, such as noise or land use, in order to complement the results obtained in this study.

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