Resource extraction, trade and waste management: a regional approach to the Spanish socioeconomic metabolism

PhD Thesis

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Glossary of terms and acronyms

AC: (Spanish) Autonomous Communities. In order to ease the readability of the text, tables and figures, a working denomination and an acronym has been created for each of the Autonomous Communities. This working denomination is based on the EU Nomenclature of Territorial units for Statistics (NUTS, see below).

Official denomination	Working denomination	Acronym
Andalucía	Andalucía	AN
Aragón	Aragón	AR
Principado de Asturias	Asturias	AS
Illes Balears	Baleares	BI
Canarias	Canarias	CA
Cantabria	Cantabria	CB
Castilla y León	Castilla y León	CL
Castilla-La Mancha	Castilla-La Mancha	CM
Cataluña	Cataluña	CT
Extremadura	Extremadura	EX
Galicia	Galicia	GL
Comunidad de Madrid	Madrid	MD
Región de Murcia	Murcia	MR
Comunidad Foral de Navarra	Navarra	NV
País Vasco	País Vasco	PV
La Rioja	Rioja	RJ
Comunidad Valenciana	Valencia	VL

- BA: waste batteries and accumulators..
- BAT: Best available techniques.
- BK: bulky waste (furniture and others).
- DE: Domestic extraction (indicator).
- DEpc: Domestic extraction per capita (indicator).
- DMC: Domestic material consumption (indicator).
- DPSIR: “driver, pressure, state, impact, response” referring to the model for environmental assessment proposed by the OECD (OECD 1993) and the EEA (EEA 1995) in the 90’s.
- EBS: Environmental burden shifting.
- EU: European Union.
- EW-MFA: Economy-wide material flow analysis.
- FGW: food and garden waste.
- FGWp: composting and/or anaerobic digestion plants (for the treatment of separately collected biowaste).

- G: non-packaging glass.
- GP: glass packaging.
- INE: (Spanish) national statistics institute.
- InT: international trade.
- IPAT: IPAT is the name and acronym for the formula describing environmental impact (I) which is represented as a function of population size (P), affluence (A), and technology (T).
- IrT: interregional trade.
- LP: light packaging.
- LPp: light packaging treatment plants.
- MBADp: mechanical-biological treatment plants, biostabilisation is carried out through anaerobic digestions plus composting.
- MBp: mechanical-biological treatment plants, biostabilisation is carried out through composting.
- M-BT: mechanical biological treatment.
- MET: non-packaging metals.
- MFA: material flow analysis.
- MITECO: (Spanish) Ministry for the Ecological Transition and for the Demographic Challenge. This Ministry holds the competences on environmental issues at national level.
- Mp: mechanical sorting plants.
- MS: (EU) member states.
- MSW: municipal solid waste.
- NST/R: (commodity classification) the "Nomenclature uniforme des marchandises pour les Statistiques de Transport, Révisée" is used to publish detailed trade in goods data by mode of transport. This classification is used since 1 January 1989. It comprises 99 chapter headings and 10 sections.
- NUTS: nomenclature of territorial units for statistics. It refers to the geocode standard for referencing the subdivision of European Union members for statistical purposes (similarly to the Combined Statistical Areas of the United States). NUTS are hierarchically organized into 3 nested levels (NUTS1, NUTS2, NUTS3). Spain is divided into 19 NUTS2 regions known as Autonomous Communities.
- PC: paper and cardboard.
- PEMAR: spanish acronym for "National Waste Management Framework Plan".
- PLA: non-packaging plastics.

- PTB: physical trade balance (indicator).
- Regional: for the purpose of this thesis, “regional” refers to a geographical and administrative scale below the national level and above the municipal level. In the case of Spain, region is used as a synonym for “Autonomous Community”.
- RMFA: regional material flow analysis.
- RWMP: regional waste management plans.
- SC: separate collection.
- TEX: textiles.
- USW: residual unsorted waste.
- WD: wood.
- WEEE: waste electric and electronic equipment.
- WFD: waste framework directive.

Chapter 1

Introduction

1.1 Introduction

The intellectual race to reinsert homo sapiens, and particularly the richer ones, within the limits of the biosphere can be claimed to be almost two centuries old now (Naredo 1987, Martinez-Alier and Schlüpmann 1994). This race continues in 2021 and yet a fast development of narratives and tools feeding the debate persists, since the issue keeps being relevant, if not urgent (Turner 2008, Lewis and Maslin 2015). Ecological economics could be acknowledged as one of the cornerstones and main sources of these contributions (Røpke 2004, 2005, Haberl et al. 2019, Pirgmaier and Steinberger 2019, Wironen and Erickson 2020).

Within ecological economics, the notion of social metabolism (Fischer-Kowalski 1998, Fischer-Kowalski and Huttler 1999) has resulted in a successful metaphor to convey the idea of "limits to (economic) growth" (Pauliuk and Hertwich 2015). This metaphor consists of nesting the socioeconomic activities within the broader context of the biosphere, as an open system in thermodynamic terms that exchanges matter and energy with ecosystems and other socioeconomic systems. Under this metaphor, socioeconomic systems extract resources from their own administrative borders and from other socioeconomic systems. These resources are transformed to provide a certain level of goods and services consumed either locally or abroad. Following the laws of thermodynamics, these resources eventually become waste and emissions, which are sent back to the biosphere.

Socioeconomic systems should maintain an overarching resource consumption pattern that allows for renewable resources to recover, while conserving the biosphere capacity to provide non-renewable resources and absorb wastes and emissions at a level where human life is feasible (and hopefully, enjoyable).

Quantitative tools derived from this rationale, notably Economy-Wide Material Flow Accounting (EW-MFA), have been refined in the last 20 years to the point that they have been mainstreamed into official statistical systems (Eurostat 2001, OECD 2008). EW-MFA indicators are currently available for most countries around the globe, whereas its analytical scope has expanded covering a vast range of issues (Eisenmenger and Giljum 2006, Krausmann *et al.* 2008, Martinez-Alier 2013, Haas ***et al.*** 2015).

1.1.1 Why this thesis?

Despite these remarkable advances, the fact that the data required for building up EW-MFA is more easily available at national scale has resulted in a bias towards the study of the socioeconomic metabolism of nations and groups of these. Also, the fact that Eurostat has been one of the main driving forces for the harmonisation of EW-MFA accounts led the interest of EW-MFA studies towards EU Member States (i.e. national level). This trait has been exacerbated along with the increase of MFA studies using input-output tables (Kovanda and Weinzettel 2013), traditionally available at national level only.

As a consequence, EW-MFA has largely forgotten the subnational scale (Hammer et al. 2003) and even considering the remarkable efforts of a small group of authors (see below), in 2021 the focus of EW-MFA studies remains at the national and international level. The lack of data in turn impeding the development of standardised guidelines for the application of EW-MFA at subnational level remains a significant methodological pitfall. This challenge expands when all the regions of a country are to be addressed, as it is the case of this work.

This thesis addresses the existing subnational gap regarding EW-MFA studies, focusing on the case of Spain. Covering this gap entails multiple challenges, from data compilation to methodological decisions where general EW-MFA methodological standards cannot be directly applied to the subnational scale or require further elaboration. Also, the analytical issues arising in the interpretation of results and indicators have points in common with national/international analyses but there are some issues inherent to the subnational scale, e.g. trade occurring between the regions of a country and the regions and the rest of the world.

The choice of Spain for this purpose is not by chance and forms part of the motivations of this thesis. First, because of the relevance of the subnational scale in Spain in administrative terms, given that relevant competences (including environmental-related competences) rely on the Autonomous Community (AC) level. Therefore each of the Spanish subnational units has the capacity to design and implement their own policies, which anticipates significant deviations from average values for aggregated indicators, either economic, environmental social, etc.

Also, the poor data availability for key sectors in Spain is relevant since EW-MFA is highly demanding in terms of data and by developing the regional EW-MFA, data gaps and inconsistencies can be revealed.

Finally, the exceptional character of the period studied (1997-2010) which comprised of an intense economic growth preceding 2007's crash and the subsequent economic crisis. These events, of global extent, had quite specific features in Spain, notably a housing bubble that rocketed housing and infrastructure construction. The environmental burdens from construction minerals extraction are often assumed to happen at a domestic level but, as we present later, these are also shifted between regions through interregional trade. Applying EW-MFA at a subnational level to identify and quantify this phenomenon constitutes an original contribution of this thesis.

1.1.2 Background

The formal interest in regional[1] and urban approaches to material flow accounts has existed since the sixties, initiated with the seminal work by Wolman (Wolman 1965). Table 1 includes a compilation of works in the specific field of regional EW-MFA.

[1] For the purpose of this thesis, "regional" refers to a geographical and administrative scale below the national level and above the municipal level.

Table 1.1 Studies addressing material flows at regional and urban scale

Author/s	City/region, country
(Naredo and Frías 1988)	**Madrid, Spain**
(Brunner *et al.* 1990)	**Untere Bünztal, Switzerland**
(Brunner *et al.* 1994)	**Bünz Valley region, Switzerland**
(Bringezu and Schütz 1996)	**Ruhr Area, Germany**
(Baccini 1997)	**Swiss Lowlands**
(Almenar Asensio *et al.* 2000)	**Valencia, Spain**
(Singh *et al.* 2001)	**Trinket Island, Nicobar, Pacific Ocean**
(McEvoy *et al.* 2001)	**North West Region, UK**
(Amann *et al.* 2002)	**3 Amazonian communities**
(Arto 2002)	**Basque Country, Spain**
(Grünbühel *et al.* 2003)	**SangSaeng, Thailand**
(Doldán 2003)	**Galicia, Spain**
(Arto 2003)	**Basque Country, Spain**
(Naredo and Frías 2003)	**Madrid, Spain**
(Huang and Hsu 2003)	**Taipei, Taiwan**
(Hercowitz 2004)	**Lanzarote, Spain**
(Sendra Sala *et al.* 2006)	**Catalonia, Spain**
(Kovanda *et al.* 2009)	**All regions, Czech Republic**
(Barles 2009)	**Paris (city and region)**
(Arto 2009)	**Basque Country, Spain**
(Murray 2012)	**Baleares, Spain**
(Carpintero, Sastre, Lomas, Arto, Delgado, *et al.* 2014, Sastre *et al.* 2015)	**All regions, Spain**
(Senthilnayagam 2017)	**Waterloo, Canada**
(Christis *et al.* 2017)	**Flanders, the Netherlands**
(Ma *et al.* 2018)	**Liaoning Province, China**
(Wang *et al.* 2019)	**All regions, China**
(Silva *et al.* 2020)	**Alentejo, Portugal**
(Piñero *et al.* 2020)	**Galicia, Spain**

Source: own elaboration.

The development of regional material flow accounts had an early development in parallel with nation-wide approaches, prior to the harmonisation made by Eurostat in 2001 (Eurostat 2001) , which can be considered a turning point from which literature on EW-MFA at national scale bloomed. Although regional approaches still captured the attention of researchers for its methodological harmonisation until 2003 (Hammer *et al.* 2003, Hinterberger et al. 2003), these efforts were left behind and only scattered examples of regional EW-MFA were produced in the following years. Regional studies after 2001 incorporated Eurostat's main methodological guidelines to a great extent, but also included a certain degree of discretion for those aspects requiring further methodological work, particularly the normalisation of subnational trade. Besides Eurostat-based approaches, the most recent methodological innovations in the field of regional EW-MFA have arisen from the use of subnational input-output tables (Christis et al. 2017, Piñero *et al.* 2020) and statistical techniques (Bianchi *et al.* 2020).

It is worth noting that within the relatively small universe of regional EW-MFA studies, the cases focused on Spanish regions are surprisingly numerous. This is related to the interest and relevance of the subnational scale both in environmental and administrative terms in Spain. Plus, the influence of domestic researchers devoted to ecological economics from the early 80's (i.e. Joan Martínez Alier and José Manuel Naredo) has motivated the development of regional EW-MFA in Spain. In turn, it is striking that the same did not happen in other countries where the subnational scale does have a prominent role, such as Germany, the United States or the Netherlands.

All in all, as pointed out by Niza *et al* (Niza *et al.* 2009) *"studies focusing on the regional or local level have still been very limited, and a standardized method equivalent to that presented by Eurostat (2001) for the national level does not yet exist"* and this is still true in 2021. If we narrow the scope and target all the regions of a country, to the author's knowledge only three per-reviewed references can be found: the study from Kovanda *et al.* on the Czech Republic (Kovanda *et al.* 2009), the study from Wang and colleagues (Wang *et al.* 2019) on China and the works related to thesis (Carpintero, Sastre, Lomas, Arto, Delgado, *et al.* 2014, Sastre *et al.* 2015), focused on Spain.

1.1.3 Objectives and structure

The overarching objective of this thesis is to shed light on material flows at subnational level covering three main areas: extraction, trade, and wastes/emissions. Derived from this overall objective, more specific goals are:

1. Identifying the available data sources and identifying gaps for the compilation of the EW-MFA at subnational level in Spain.

2. Identifying the main methodological challenges when applying Eurostat's methodological guidelines at subnational level and proposing solutions to these challenges.

3. Calculating the main EW-MFA indicators for the whole of the Spanish regions.

4. Identifying and addressing those analytical issues specific to subnational EW-MFA, particularly interregional trade.

5. Analysing the regional patterns of regional output flows.

To these ends, the case of Spain is addressed in three chapters following this introduction plus a final chapter summarising the main conclusions. I have intentionally adopted a synthetic approach regarding the style and the information explicitly included in this thesis. The reason behind this decision is improving the readability of the text and making the contents more focused, in the vein of contemporaneous scientific literature. In this sense, this thesis includes the information required to illustrate the specific analytical points developed in the text.

This approach has the advantage of making the thesis more appealing to the reader. However, unless the reader is familiar with this type of research, this approach does not reflect the efforts required in the compilation of data and the calculation of indicators, particularly regarding chapters 2 and 3. Compiling the extraction, interregional and international trade flows of the 17 regional units of Spain for a series of 15 years (including pre-internet times) has entailed a great amount of time and dedication which might add several hundreds of pages to this thesis if the whole database (7.38 Gb) was displayed. In any case, a detailed (1,112 pages)[2] report on the regional metabolism of Spain including in-depth case studies, the methodological details and calculations and a selection of relevant tables was made available online under Creative Commons license (Carpintero, Sastre, Lomas, Arto, Delgado, *et al.* 2014).

Taking these points into account, each chapter has been conceived to be methodologically self-contained, focusing on the specific methodological aspects relevant to the purpose of each chapter. The structure of the thesis is the following:

- The second chapter compiles all the necessary data for the calculation of input EW-MFA indicators for the whole of the Spanish AC and identifies the main challenges in this process. The main indicators are displayed and analysed in the light of the Spanish housing bubble and anticipates that interregional trade (i.e. trade between subnational units of a country) is even more intense than trade between regions and the rest of the world.

- The third chapter explores trade at regional level in detail, focusing on the commercial exchanges between the Spanish regions, and between the Spanish regions and the rest of the world, addressing each material category separately. First, a methodological exercise of the normalisation of trade categories for international and interregional trade is proposed. Next, a profiling method is designed to deal with the uncertainty related to the use of direct flows of trade, enclosing both raw and manufactured materials together. The AC are profiled according to this method and both practical and conceptual limitations of the approach are exposed. Also, a methodological reflection on the environmental significance of EW-MFA is provided.

- Derived from the works for chapter two, the significant data gaps identified for the calculation of output EW-MFA indicators made a comprehensive calculation of such indicators impossible. Instead, and given that emissions are well covered in the literature, chapter four is devoted to municipal solid waste management, which is the only output flow (i.e. besides greenhouse gases) for which data availability makes regional analysis possible. Municipal solid waste is a qualitatively relevant flow since most of this waste is disposed of in landfills which entails significant environmental issues (e.g. lixiviates, methane emissions, etc.). Furthermore, municipal solid waste is subject to specific normative targets at national and regional level. Chapter four focuses on modelling municipal solid waste management across AC and evaluating their degree of compliance with the EU recycling targets.

- Finally, chapter five sums up the conclusions of the previous chapters and provides points stemming from an integrated view of the thesis.

[2] https://www.fuhem.es/2016/06/15/el-metabolismo-economico-regional-espanol/

Chapter 2

Regional Material Flow Accounting and Environmental Pressures: The Spanish Case

The content of this chapter was published in *Environmental Science & Technology* (Sastre *et al.* 2015). Data has been updated where new information was available. References have been revised and updated. Tables and figures have been revised and updated to fit within the format. Minor changes have been introduced to the main text.

2.1 Abstract

This chapter explores patterns of material extraction, trade, consumption and productivity for the Spanish Autonomous Communities (AC) within the 1996-2010 period. The main methodological variation as compared to whole-country based approaches is the inclusion of interregional trade, which can be separately assessed from the international exchanges. Thus, besides extraction and international trade, each AC was additionally profiled regarding its commercial exchanges with the rest of the Spanish AC, which in turn gives an indication of the related environmental pressures. Given its magnitude, interregional trade is confirmed to be a significant source of environmental pressure since most of the physical exchanges occur between regions. The interregional trade of construction materials is particularly striking, which in Spain represents the largest share of extracted and consumed materials. However, construction materials do not cover long distances, so their impact remain at the regional level. During the housing bubble, ending by 2007, economic growth did not improve material productivity.

2.2 Introduction

Consumption of materials and energy exerts a general environmental pressure. Materials are extracted to produce goods and services throughout the socioeconomic system (conceived as an open subsystem of the biosphere). Some of them are recycled and others are finally released back into the environment in the form of waste. Economy-wide material flow analysis (EW-MFA) has been acknowledged as a key assessment tool for examining the material exchanges between human activity and the environment through a set of consistent and comparable indicators. Several of the current environmental challenges related to resource depletion or sinks exhaustion can be framed, quantified and analysed from an EW-MFA perspective, complementing the understanding of the environmental dimension associated with economic development (Fischer-Kowalski *et al.* 2011). The potential of this type of analysis for environmental policy has been revealed through the international initiatives entailing resource use efficiency, in turn supported by EW-MFA indicators (Eurostat 2001, OECD 2004, 2011, European Comission 2011, Fischer-Kowalski *et al.* 2011, UNEP 2012, United Nations 2015, Haberl *et al.* 2019, Helander *et al.* 2019, Mayer *et al.* 2019, Saidani *et al.* 2019).

EW-MFA has been widely applied at global scale (Krausmann *et al.* 2018), to entire countries (Carpintero 2005, Kovanda and Hak 2011, Schandl and West 2012, West and Schandl 2013, Magalhães *et al.* 2019), global regions (Krausmann *et al.* 2009, Giljum *et al.* 2014, Shah *et al.* 2020), and cities (Rosado *et al.* 2014). However, most case studies have been carried out at the national scale, for which the first standardized methodological guidelines were originally devised and for which data are often readily available.

The application of EW-MFA at the regional level involves several methodological drawbacks, of which lack of data is the most important (Hammer *et al.* 2003). Additionally, environmental pressures tend to be related to enterprises and households located in specific urban and rural environments, which are not regularly distributed across territories. Hence zooming in on the material flows at the regional scale is crucial in order to identify current and future environmental pressures and provide decision-makers with more precise information.

The number of studies on Regional Material Flow Analysis (RMFA) has grown steadily during the last 20 years, particularly those focused on single regions (Arto 2003, Barles 2009, Senthilnayagam 2017). Furthermore, comprehensive reviews of studies in this field have already been made (Hammer *et al.* 2003, Kennedy *et al.* 2007, Rosado *et al.* 2014). In early attempts to carry out RMFA, Frias and Naredo (Frías and Naredo 1987) reported the monetary, material, energy, water and waste flows for the region of Madrid. As in the other publications in the field prior to the publication of the first standardized MFA guidelines (Brunner *et al.* 1990, Bringezu and Schütz 1996, Baccini 1997), these early attempts followed non-harmonized methodological procedures. In 2001, the first standardized methodological framework was published (Eurostat 2001) but the regional application of such guidelines is still subject to difficulties (Almenar Asensio *et al.* 2000, Hammer *et al.* 2003, Rosado *et al.* 2014).

However, the approaches focused on calculating the indicators for the whole of the regions of a country are yet uncommon. To the author's knowledge, the RMFA of entire countries has been carried out for the Czech Republic[3] (Kovanda *et al.* 2009) and China[4] (Li and Zhang 2013, Wang *et al.* 2019).

This chapter presents the RMFA of Spain covering the period 1996-2010 for the whole of its Autonomous Communities with the aim of exploring:

1. the similarity of the structure of domestic material extraction and consumption across regions within the same country;
2. the role and structure of interregional and international trade in domestic material consumption; and
3. the regional performance in terms of resource use efficiency (and associated environmental pressures) during the last period of economic growth in Spain.

[3] In this case, trade between the regions and foreign countries could not be compiled; therefore, results do not include DMI or DMC.
[4] In the article by Wang and colleagues, only domestic extraction is calculated. In the case of Wang and colleagues the whole of the indicators are estimated, using monetary input output data instead of internationally harmonised EW-MFA procedures (e.g. Eurostat, OECD).

2.3 Methods

2.3.1 Methodological approach and general issues

General issues of compiling an EW-MFA database at the regional scale have been addressed elsewhere (Hammer *et al.* 2003, FUHEM 2014). A regional database covering the main material flows was compiled (FUHEM 2014) following the most recent Eurostat's guidelines (Eurostat 2018). Based on this framework, a set of standard EW-MFA indicators can be calculated, namely domestic extraction (DE), physical trade balance (PTB) and domestic material consumption (DMC). Extraction comprises biomass, fossil fuels, metals, industrial minerals and construction minerals. Trade is split into interregional (IrT) and international (InT) exchanges.

Due to data availability, the focus of this work is on direct flows which means that, in spite of its relevance (Schoer *et al.* 2012), the upstream requirements of imports and the share of non-used DE is not included herein. Nevertheless, the main structural features and trends can be still analysed and the dataset may serve for future calculation of the material footprint of consumption (Wiedmann *et al.* 2015).

System boundaries were set by balancing both statistical availability and analytical relevance. NUTS 2 regions accomplished both because statistics are reported directly at this scale (except in the case of trade by pipeline, which was modelled), and these boundaries coincide with the main Spanish regional administrative borders: the AC.

IrT is addressed separately from InT in order to broaden the analytical depth. To the author's knowledge, this is the first work including such data for a whole country following EW-MFA harmonised standards. Splitting trade into these two categories offers a gain in resolution and a better understanding of the allocation of environmental loads through commercial exchanges (Kovanda *et al.* 2009, Bruckner *et al.* 2012, Giljum *et al.* 2014, Piñero *et al.* 2020).

The details on data compilation and estimates have been made available online elsewhere (FUHEM 2014). Given their extension, they are not reproduced in this work. However, the most relevant methodological aspects are summarised below.

2.3.2 Specific issues regarding data and estimates on fishing

Although the residence principle is preferred instead of the territory principle (Eurostat 2001) in order to define the system boundaries of the economic system, it is not always possible to apply this criterion in practice. The effects of such cases have been acknowledged in the different versions of Eurostat's guidelines. One of these cases at the regional scale concerns fishing because fishing vessels work not only within jurisdictional waters. A large share of the captures made by Spanish vessels—particularly those belonging to the northern regions of Spain (the Basque Country, Asturias, Cantabria and Galicia) are made in non-jurisdictional waters (the open sea). These captures are recorded by fishing statistics as "national production" rather than imports, following the residence principle. However, these captures are not necessarily landed at the same port where the vessels are resident at the regional scale (some harbours attract landings from vessels registered in other Spanish regions because fishing products are more easily marketed at ports such as Vigo in Galicia, whose fishing products are typically perceived as high quality). This phenomenon affects mainly frozen fish.

Fresh fish are captured within regional waters and sold the following day at the ports where they belong as economic units. Though fishing represents a small share of total DE, a conservative criterion was applied in order not to overestimate fishing flows. We decided to record fresh fish separately from frozen fish. Fresh fish captures were used to calculate domestic extraction, whereas extraction made in non-jurisdictional waters was registered as a memorandum item. Consequently, the territory principle applies in this case.

2.3.3 Specific issues regarding data and estimates on metal ores

Coupled production of metal ores has been a source of methodological debate in the context of EW-MFA (Eurostat 2001, 2018). In order to prioritise transparency, the classification of metal ores was designed so that their origin can be traced back in the case of coupled production processes (e.g. copper is registered as a by-product of sulphur complex extraction, as copper from copper ores, and as copper as a by-product of iron ore extraction).

2.3.4 Specific issues regarding data and estimates on interregional trade

Interregional trade includes freight transport by road, domestic coastwise traffic, pipelines, railway trade and cargo planes. Our database accounts for the first three categories, which include more than 90% of total interregional trade following the reports of the Spanish National Statistics Institute (INE). Data on trade by railway and cargo planes was not included for reporting because the data sources did not meet the quality criteria regarding time spans and commodity disaggregation for normalisation. Normalisation of interregional trade commodity classifications into aggregated material flow categories is provided in Table 2.1. Both freight transport by road and domestic coastwise traffic are recorded following NST/R[5] codes which has a direct correspondence with the Combined Nomenclature, used for international trade purposes. The Combined Nomenclature has a direct correspondence with the MFA codes (Eurostat 2018), so NST/R codes can be converted into MFA codes as well.

[5] The 'Nomenclature uniforme des marchandises pour les Statistiques de Transport, Révisée' (NST/R) is used to publish detailed trade in goods data by mode of transport. This classification is used since 1 January 1989. It comprises 99 chapter headings and 10 sections.

Table 2.1 Correspondence between NST/R commodity codes and Eurostat's MFA codes

Material flow category	MFA code	NST/R code
Biomass products		
Agricultural biomass	A.1.1; A.1.2	11, 12, 13, 14, 15, 16, 19, 20, 31, 35, 39, 60, 92, 135, 164, 165, 167, 171, 179, 181.
Livestock biomass	-	1, 141, 143, 146, 147.
Forestry biomass	A.1.3; A.1.4.3	57.
Fish biomass	A.1.4.1; A.1.4.2	142.
Abiotic products		
Metallic	A.2	410, 451, 452, 453, 455, 459.
Non-metallic	A.3	611, 612, 613, 614, 621, 622, 623, 631, 632, 633, 634, 639, 650, 713.
Fossil fuels	A.4	211, 213, 221, 223, 224, 310, 330, 343.
Semimanufactured products		
Biomass products	-	41, 42, 45, 49, 51, 52, 55, 56, 144, 145, 148, 161, 162, 163, 166, 172, 182, 895.
Metallic	-	453, 463, 465, 466, 467, 512, 513, 515, 522, 523, 561, 562, 563, 564, 565, 615.
Non-metallic	-	691, 692, 711, 712, 719, 721, 722, 723, 724, 729.
Energy carriers	-	321, 323, 325, 327, 341, 349, 831, 839.
Manufactured products		
Manufactured products	-	43, 91, 111, 112, 113, 121, 122, 125, 128, 131, 132, 133, 134, 136, 139, 532, 533, 535, 536, 537, 542, 543, 545, 545, 551, 552, 568, 811, 812, 813, 814, 819, 841, 842, 891, 892, 893, 894, 896, 910, 920, 931, 939, 941, 949, 951, 952, 961, 962, 963, 971, 972, 973, 974, 975, 991, 992, 994, 995, 996, 997, 999.

Source: own elaboration.

For its part, data on regional and interregional trade by pipeline were not directly available. A model was built in order to estimate the overall interregional physical exchanges of energy carriers, namely fuels and gas. It was assumed that 1) regions owning refineries (AN, AS, GL, CT, BC, MR, CM) are the only possible net interregional exporters; 2) these regions fulfill their requirements with their own refined products; and 3) regions which do not own refineries are net importers of fossil fuels.

Hence, regions owning a refinery should show a negative interregional trade balance for those energy carriers traded by pipelines (i.e. they were net interregional exporters), calculated by deducting their consumption and international exports from their production and international imports of these products. The rest of the regions were assumed to have a positive trade balance (i.e. they were net interregional importers), calculated by equalling their annual imports (i.e. interregional plus international, of which international imports are known) to their annual consumption of these products.

Consequently, interregional exchanges of semi-manufactured energy carriers were deducted from the freight transport by road and coastwise domestic traffic databases.

Refineries are located in coastal regions, with the exception of Castilla-La Mancha, an inland region owning a refinery that receives crude oil from Murcia by pipeline. In order to consider this flow, Castilla-La Mancha's production was added both as an interregional import of crude oil by pipeline to Castilla-La Mancha accounts and as an interregional export of crude oil by pipeline from Murcia.

This working assumption very likely underestimates both Castilla-La Mancha's imports and Murcia's exports since refineries use crude oil not only for energy carrier production but also for chemicals and other related products.

Through this model, net interregional balances of individual categories of the main fossil fuels can be estimated. The results of these interregional trade balances were assimilated to interregional imports and exports under the pragmatic assumption that regions owning refineries do not import a significant quantity of processed fossil fuels from other AC by pipeline. This assumption was accurate in the case of freight transport by road and coastwise domestic transport. Likewise, the rest of the regions were assumed not to export significant amounts of processed fossil fuels by pipe to the rest of AC. By using this assumption, interregional exchanges of fossil fuels can be treated as flows instead of balances, allowing the calculation of indicators such as domestic material input (DMI).

The weakest point of this model was the uncertainty about the balance of imports and exports, which must equal imports and exports plus net changes in stock. The imbalances found were similar to the storage capacity available in Spain.

2.3.5 Specific issues regarding data and estimates on solid waste

Data series for agricultural, industrial and urban solid waste showed noteworthy irregularities for the period 1996-2010. A crosscheck with regional statistics revealed significant inconsistencies, which prevented the authors from calculating output indicators.

2.4 Results

2.4.1 Spain: Autonomous Communities and their basic indicators

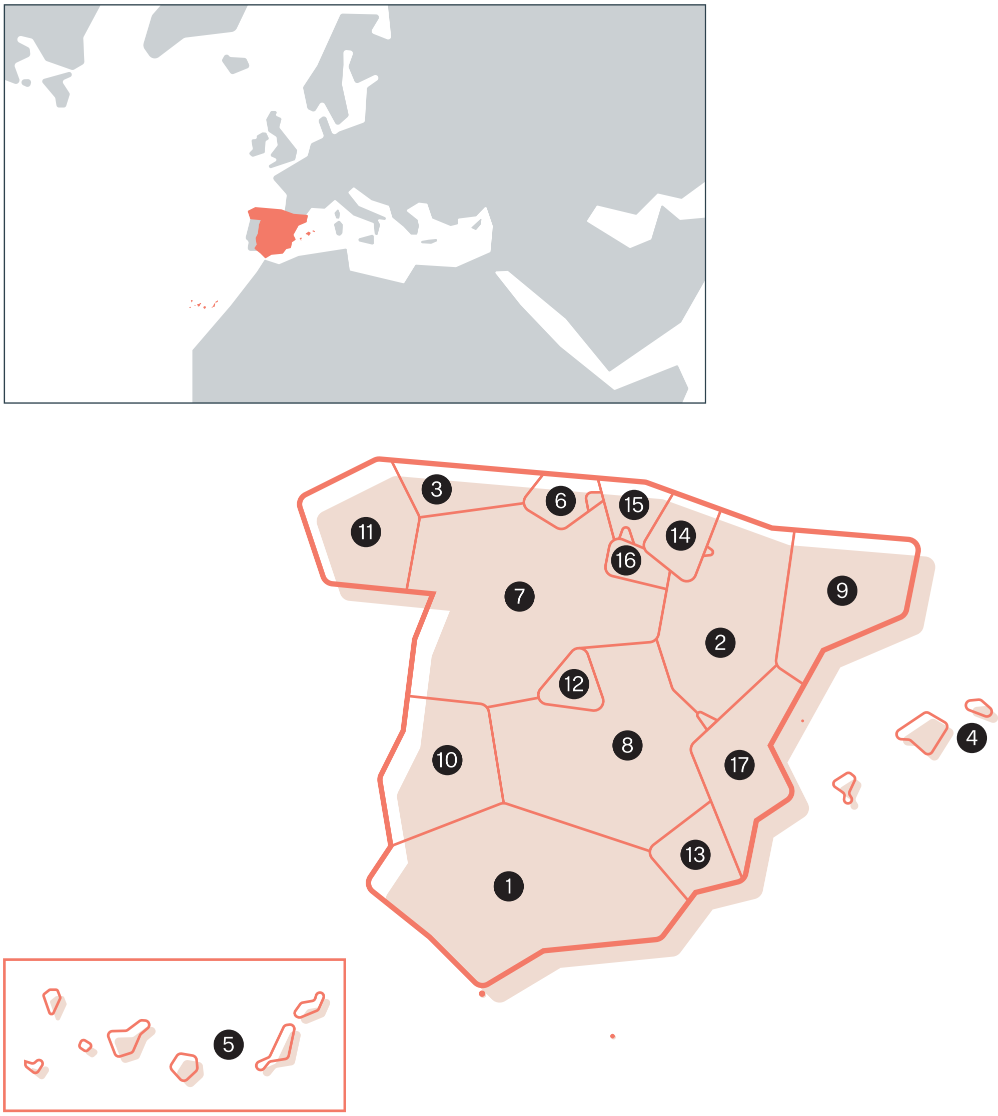
Spain is a medium-sized country (506,000 km^2) located in the Iberian Peninsula on the northwest side of the Mediterranean Sea and in the southwest of the European continent (Figure 2.1). It is made up of 17 AC, 15 of which are located within the Iberian Peninsula plus two archipelagos (Baleares are located in the northwestern Mediterranean Sea and Canarias are located off the northwest coast of Morocco and the Western Sahara). Furthermore, there are two Autonomous Cities, Ceuta and Melilla, located on the north and northeast coast of Morocco, respectively.

Both the 17 AC and two autonomous cities are considered for calculation purposes (namely interregional trade). The results for the Autonomous Cities are not included in the paper, though. Their specific geographical and political context makes comparison unnecessarily intricate because they represent an exception for all of the indicators (e.g. domestic extraction is non-existent).

Table 2.2 shows the name, acronym, area, population and GDP per capita for the 17 AC. Regarding their denomination, a working name plus an acronym has been created based on the official denomination of the EU regions, called NUTS. These working names and acronyms will be used in the text, figures and tables for easier readability.

In order to contextualize the economic performance of Spain between 1996 and 2010, it should be borne in mind that it was affected by both the onset of the global financial crisis and the bursting of the "housing bubble" in 2007-2008 (Naredo *et al.* 2008, Montalvo 2011).

Figure 2.1 **Spanish Regions at the NUTS 2 scale (Autonomous Communities and Autonomous Cities)**



Region

1. Andalucía
2. Aragón
3. Asturias
4. Baleares
5. Canarias
6. Cantabria
7. Castilla y León
8. Castilla-La Mancha
9. Cataluña
10. Extremadura
11. Galicia
12. Madrid
13. Murcia
14. Navarra
15. País Vasco
16. Rioja
17. Valencia

Table 2.2 Name, acronym and basic features of the Spanish Autonomous Communities

EU NUTS 2 denomination	Working denomination	Acronym	Area (km²)	Population in 2010 (thousands)	GDP per capita in 2010 (thousand €)
Andalucía	Andalucía	AN	87,598	8,371	12.4
Aragón	Aragón	AR	47,721	1,347	17.7
Principado de Asturias	Asturias	AS	10,602	1,084	15.4
Illes Balears	Baleares	BI	4,992	1,106	16.8
Canarias	Canarias	CA	7,447	2,119	14.3
Cantabria	Cantabria	CB	5,321	592	16.3
Castilla y León	Castilla y León	CL	94,227	2,56	16.8
Castilla-La Mancha	Castilla-La Mancha	CM	79,462	2,098	12.7
Cataluña	Cataluña	CT	32,113	7,512	19
Extremadura	Extremadura	EX	41,634	1,107	12.3
Galicia	Galicia	GL	29,575	2,798	14.4
Comunidad de Madrid	Madrid	MD	8,028	6,459	21.5
Región de Murcia	Murcia	MR	11,313	1,462	13.4
Comunidad Foral de Navarra	Navarra	NV	10,39	637	21.7
País Vasco	País Vasco	PV	7,23	2,178	22.3
La Rioja	Rioja	RJ	5,045	322	18.2
Comunidad Valenciana	Valencia	VL	23,255	5,112	14.4

Source: EU NUTS denomination is published in Regulation 1059/2003 of the European Parliament and of the Council (European Parliament and European Council 2003). Data has been retrieved from the Spanish National Statistics Institute (INE). Acronyms are own elaboration.

2.4.2 Domestic extraction (used): common trends for differing metabolic profiles

The magnitude of DE in Spain rose from 446.4 Mt in 1996 (equivalent to 11.3 t/cap and 882 t/km²) to 482.5 Mt in 2010 (10.3 t/cap and 954 t/km²), peaking at 770.5 Mt in 2007 (17 t/cap and 1,523 t/km²) (Table 2.3).

Table 2.3 **Domestic extraction. Absolute, per capita and per surface area values and biomass share**

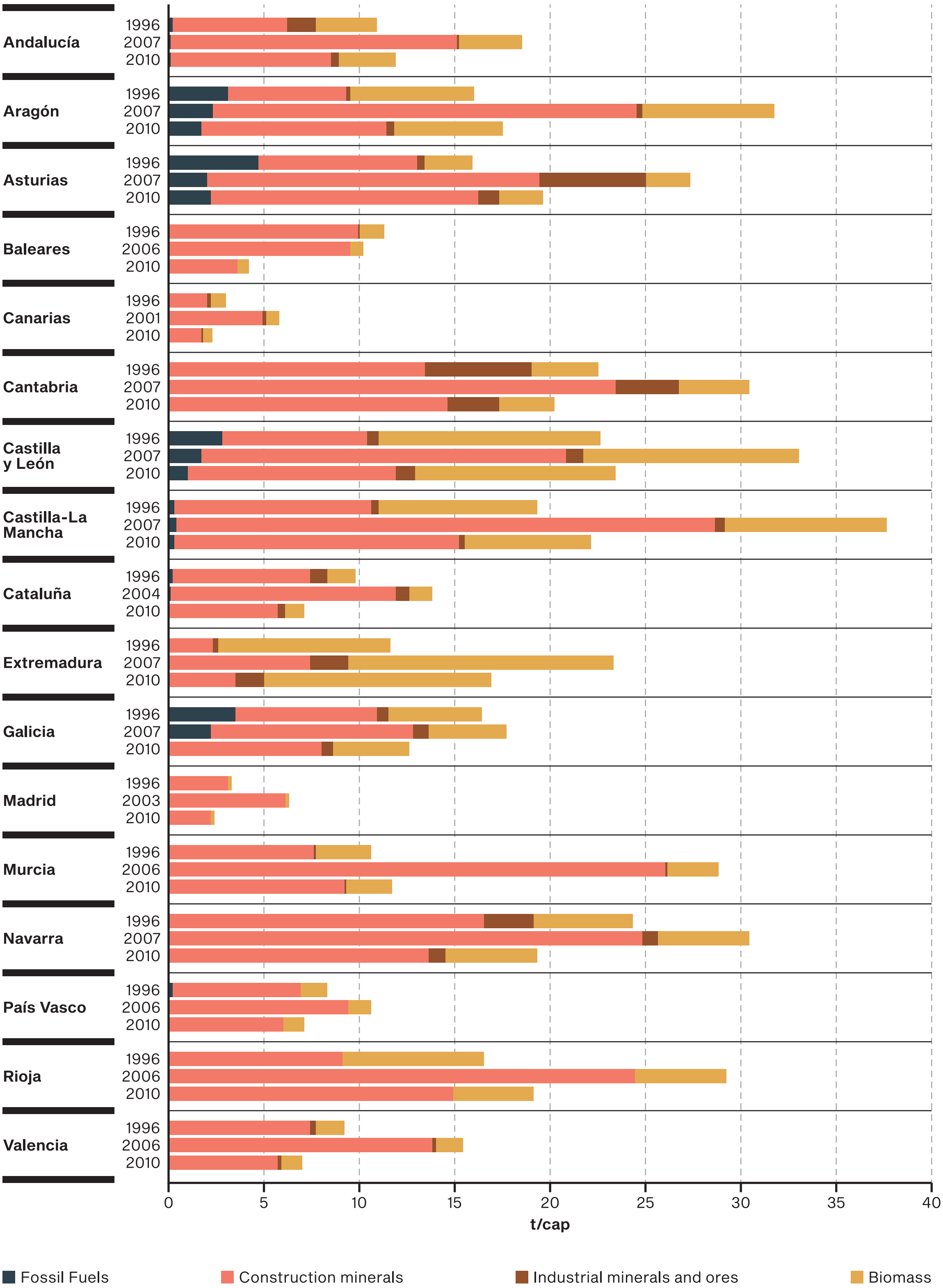
	DE (Mt)				% Biomass			DE (t/cap)				DE (t/km²)		
Region	**1996**	**Max**	**2010**	**PY**	**1996**	**PY**	**2010**	**1996**	**Max**	**2010**	**PY**	**1996**	**Max**	**2010**
AN	78.9	149	99.6	2007	29.4	18	25.5	10.9	18.5	11.9	2007	901	1,7	1,14
AR	18.9	41.1	23.6	2007	40.9	22	32.4	15.9	31.7	17.5	2007	396	861	495
AS	17.2	29.4	21.2	2007	15.7	8.6	11.8	15.8	27.3	19.6	2007	1,62	2,77	2
BI	8.6	10.3	4.7	2007	11.5	7.7	14.1	11.3	10.2	4.3	2006	1,72	2,07	949
CA	4.8	10.4	4.8	2001	27.6	12	24	3	5.8	2.3	2001	641	1,4	644
CB	11.9	17.4	12	2007	15.6	12	14.5	22.5	30.4	20.2	2007	2,23	3,28	2,25
CL	56.4	83.8	59.9	2007	51.4	34	44.8	22.5	33.1	23.4	2007	599	2,87	636
CM	33.2	74.3	46.3	2007	42.9	23	29.9	19.4	37.6	22.1	2007	418	935	583
CT	59.2	93.7	54.1	2004	15.7	8.7	14.3	9.7	13.7	7.2	2004	1,84	2,92	1,69
EX	12.4	25.4	18.7	2007	77.8	60	70.5	11.6	23.3	16.9	2007	298	610	450
GL	45.1	49.1	35.3	2007	29.8	23	31.4	16.5	17.7	12.6	2007	1,53	1,66	1,2
MD	16.7	36.4	15.3	2003	6.8	3.9	7.3	3.3	6.4	2.4	2003	2,07	4,53	1,9
MR	11.7	39.6	17.2	2007	27.7	9.1	20.5	10.6	28.4	11.7	2006	1,03	3,5	1,52
NV	12.6	18.4	12.3	2007	21.4	16	25	24.2	30.4	19.2	2007	1,22	1,77	1,18
PV	17.4	22.7	15.5	2006	17.1	11	15.4	8.3	10.7	7.1	2006	2,4	3,14	2,14
RJ	4.4	9	6.2	2006	44.8	16	21.8	16.5	29.2	19.1	2006	867	1,77	1,22
VL	37.2	74	35.8	2006	16.6	9.1	15.7	9.3	15.4	7	2006	1,6	3,18	1,54
Spain	**446.4**	**770.5**	**482.5**	**2007**	**29.5**	**16.7**	**26.7**	**11.3**	**17.0**	**10.3**	**2007**	**882**	**1,52**	**954**

Source: compiled by the authors from sources shown in (Sastre et al. 2015).

The two main features of the period were the strong influence of the construction sector and the coexistence of different extractive profiles across AC. The construction sector influenced DE in two manners. Firstly, it drove DE to a maximum in absolute and per capita terms in almost all regions around 2007. This point coincides with the onset of the global financial crisis, the end of the housing bubble in Spain and the beginning of the recession on the national and regional level.

Secondly, the share of biomass extraction in all the regions until 2007 decreased independently of the starting values. This decrease was particularly sharp (over 20%) in the case of Cantabria, Galicia, Castilla y León and Extremadura, typically agricultural regions in gross value added terms. Construction minerals drove the changes in the structure and level of extraction during the period (Figure 2.2). The dominance of construction minerals in DE per capita (DEpc) is a common feature in the physical structure within developing and industrialized countries, particularly in the EU (Weisz et al. 2006). However, the values obtained in some AC exceeded the maximum values found until now in the EU (17.8 t/cap in the case of Finland in 2000) or China, where DEpc was below 10 t/cap. Castilla-La Mancha extracted a maximum of 28.2 t/cap of construction minerals, and six other regions (Aragón, Cantabria, Murcia, Navarra and Rioja) reached values over 20 t/cap.

Figure 2.2 Level and composition of regional domestic extraction per capita



Source: compiled by the authors from sources shown in (Sastre et al. 2015).

A second significant feature is the coexistence of different extractive profiles between regions of Spain with high and low population densities. Madrid, a small and densely populated region in which the capital city is located, has the lowest share of biomass extraction (3.9%-7.3%) whereas other regions with lower population densities have shares of biomass extraction close to preindustrial metabolic regimes (Krausmann *et al*. 2008). This is the case of Castilla y León with almost 45% and Extremadura with 70% share of biomass extraction as per 2010.

DEpc reached its maximum value at some point near 2007, followed by a sharp descent, which in 2010 led to lower values than those registered in 1996 in nine regions. Madrid and Canarias showed the lowest values (2.4-6.4 and 2.3-5.8 t/cap, respectively), 60% lower than the average for Spain. The figures for Madrid match particularly well with the general profile of global industrialized metropolitan areas such as Paris (Barles 2009) and Prague (Kovanda *et al*. 2009), where per capita domestic extraction is significantly lower than in other regions. A different pattern seems to appear in the islands, although there is as yet little literature for comparisons on the metabolism and particularities of the islands (Murray 2012).

Regions with a low population density, such as Castilla La-Mancha, Castilla y León and Aragon, where agriculture has traditionally played a more important role in terms of gross value added and employment, showed the highest DEpc values. Castilla y Leon (34.2-51.4 t/cap) had double the average values for Spain and five and almost ten times the values for Madrid and Canarias, respectively. These regions (i.e. low population density regions) have particularly high per capita values of biomass extraction due to livestock feeding products. Over 10 t of biomass per capita are extracted in Extremadura, Castilla y León and Castilla-La Mancha. In Extremadura, approximately 70% of the biomass extraction was devoted to livestock feeding. By the end of the period, the differences in DEpc among regions rose from a factor of 8 to a factor of 10.

In terms of environmental pressure of extraction, Madrid led with 1,903 to 4,530 t/km2, followed by Murcia, Pais Vasco and Cantabria. In contrast, the larger regions with low population density, namely Extremadura, Aragon, Castilla-La Mancha and Castilla y León, showed the lowest values. However, it multiplied by a factor of 4.8 in Castilla y León and 3.4 in Murcia when the maximum was reached in 2007, whereas the average value for Spain had barely doubled. Madrid showed a DE of 4,300 t/km^2 of construction materials in 2003, which is over the maximum value across the EU countries. This is a very high value in comparison with those of other European urban regions such as Prague (Kovanda et al. 2009), Paris (Barles 2009) and Manchester (McEvoy et al. 2001) none of which exceeded 3,000 t/km^2. It is also remarkable in comparison with Asia and the Pacific countries, where only Singapore showed higher values according to the "Material Flow Analysis Portal" database (Lutter *et al*. n.d.).

Investigating further into structural features, almost 70% of Spain's biomass extraction was concentrated in five regions representing 65% of the Spanish territory: Castilla y León, Andalucía, Castilla-La Mancha, Extremadura and Galicia. Andalucía, Castilla y León and Extremadura extracted half of the total agricultural biomass and Galicia more than 40% of the forest and fishing products.

With regard to fossil fuels, Spain has low fossil fuel reserves in comparison with its apparent consumption. The extraction of fossil fuels, mostly coal, fell from 28 Mt in 1996 to 5 Mt in 2010. The main coal reserves were located in Galicia, Castilla y León, Asturias, Aragon and Castilla-La Mancha. Galicia led extraction of coal (lignite) until 2008, when it completely stopped due to reserve depletion and Kyoto Protocol–related legislation on sulphured coals. The remaining regions extracted other types of coal and anthracite. Extraction of crude oil and gas on the coasts of Cataluña and País Vasco is quantitatively insignificant.

Metal ores are found in Andalucía (sulphur complexes, copper, zinc, lead and gold), Extremadura (nickel, zinc), Cantabria (gold) and Asturias (gold, copper). However, only Andalucía extracted significant quantities. Metal ore extraction in Spain collapsed by 2004 although the following price rise led to the reopening of the most profitable mines in Andalucía. Cataluña led industrial mineral extraction for the fertilizer industry (i.e. potash), followed by Cantabria and Valencia, which also extracted salts.

2.4.3 Physical trade balances: the role of international and interregional trade in regional metabolism

The largest share of physical commercial trade of the Spanish regions was in interregional exchanges (70% of total exports, 60% of total imports). The most prominent importers at the regional level (Table 2.4) were Madrid, Valencia, Cataluña, Castilla y León and Castilla-La Mancha, which together accounted for 54% of regional imports. Madrid's imports were ten times those of the islands and Rioja, and more than doubled the average. Cataluña, the main interregional exporter, and Castilla-La Mancha, Valencia, Andalucía and Madrid together accounted for 52% of regional exports. Cataluña's exports were one hundred times those of Baleares, ten times those of Canarias and Extremadura, and double the average.

Table 2.4 **Accumulated interregional (Ir) and international (In) imports, exports, physical trade balance (PTB) and accumulated electricity balances (AEB)**

	Imports (Mt)			Exports (Mt)			PTB (Mt)			AEB
Region	Ir	In	% Ir	Ir	In	% Ir	Ir	In	Total	(Gwh)
AN	331	657	34	453	285	61	-122	372	250	66
AR	303	64	83	269	40	87	34	24	57	-47
AS	128	262	33	146	55	73	-18	208	190	-84
BI	52	30	64	5	6	44	48	23	71	-
CA	49	130	27	19	35	35	30	95	125	-
CB	110	42	72	109	26	81	1	16	17	36
CL	423	58	88	405	52	89	18	6	24	-206
CM	397	18	96	499	24	95	-103	-6	-109	-102
CT	427	709	38	508	292	64	-81	418	337	50
EX	128	16	89	66	24	73	62	-8	54	-175
GL	174	314	36	179	115	61	-5	199	194	-109
MD	650	266	71	419	106	80	231	160	391	344
MR	205	244	46	324	56	85	-119	188	69	3
NV	165	31	84	169	31	85	-4	0	-4	-6
PV	328	343	49	384	144	73	-55	198	143	133
RJ	90	6	93	87	5	94	3	1	4	-11
VL	536	296	64	476	222	68	60	74	134	120

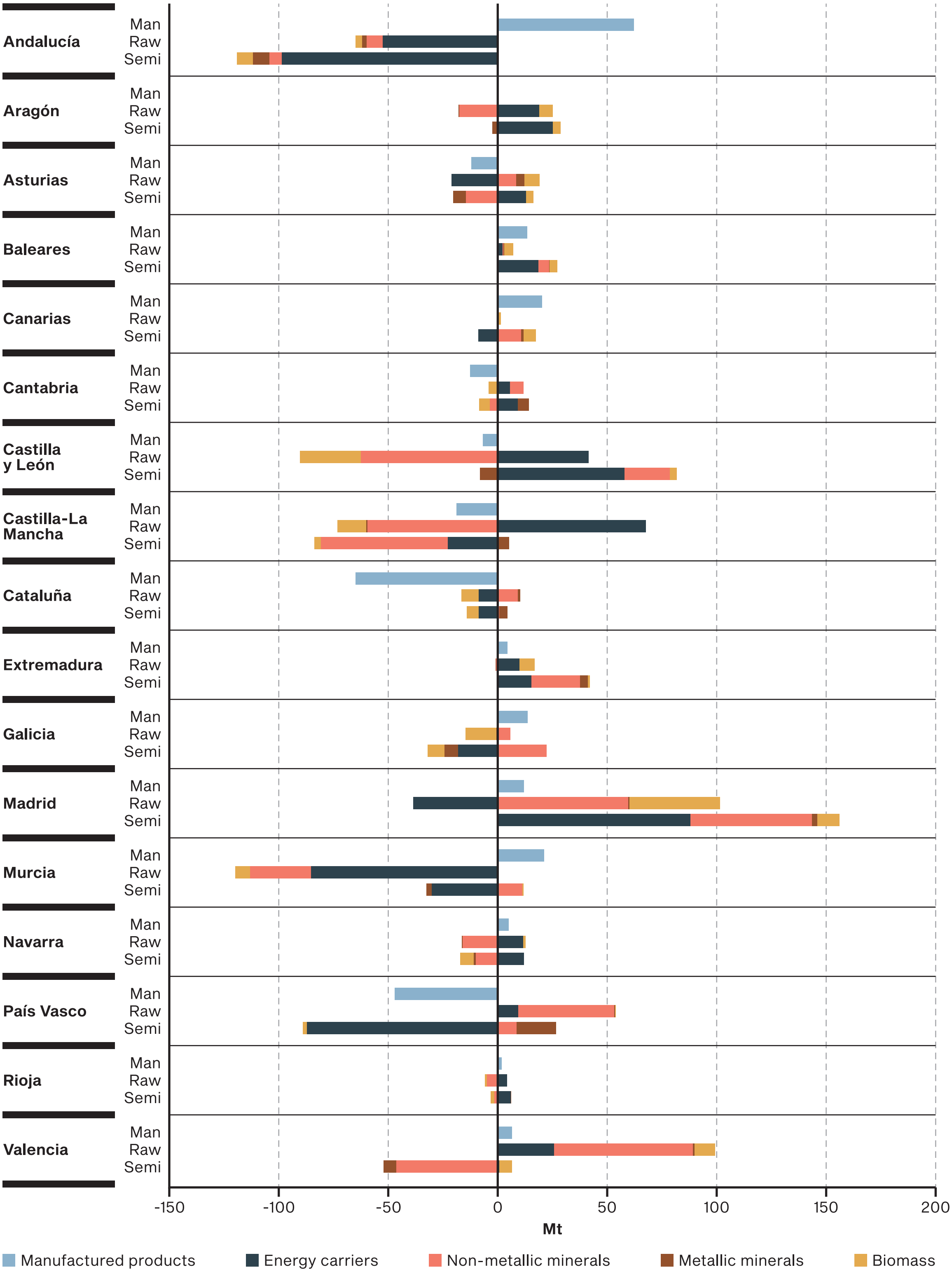
Source: compiled by the authors from sources shown in (Sastre et al. 2015).

The main importers of international products, Cataluña, Andalucía and País Vasco, accounted for 49% of international imports. Cataluña imported three times the average value. One of the reasons for this accumulation of imports is related to the imports of fossil fuels, since most refineries are located in coastal regions.

International exports were concentrated in Cataluña, Andalucía and Valencia, which together accounted for 52% of international exports, and their individual exports were one hundred times greater than those of Rioja and Baleares. Cataluña and Andalucía both tripled the average value and Valencia more than doubled it.

Based on interregional and international trade, a variety of profiles can be observed. Some regions traded mainly with other Spanish regions. Castilla-La Mancha and Rioja were the most extreme cases, with over 90% of their trade made at the regional level. Castilla y León, Aragón, Extremadura, Cantabria, Navarre, Rioja, Cantabria and Madrid showed a diversity of trading structures (Figure 2.3). Castilla-La Mancha was a net regional exporter of raw and semi-manufactured products, particularly biomass and non-metallic minerals, as was Castilla y León, which included a larger share of biomass among its exports. Madrid played precisely the opposite role as a net importer of non-metallic minerals and energy carriers.

Figure 2.3 **Level and composition of the accumulated interregional physical trade balances (1996-2010)**



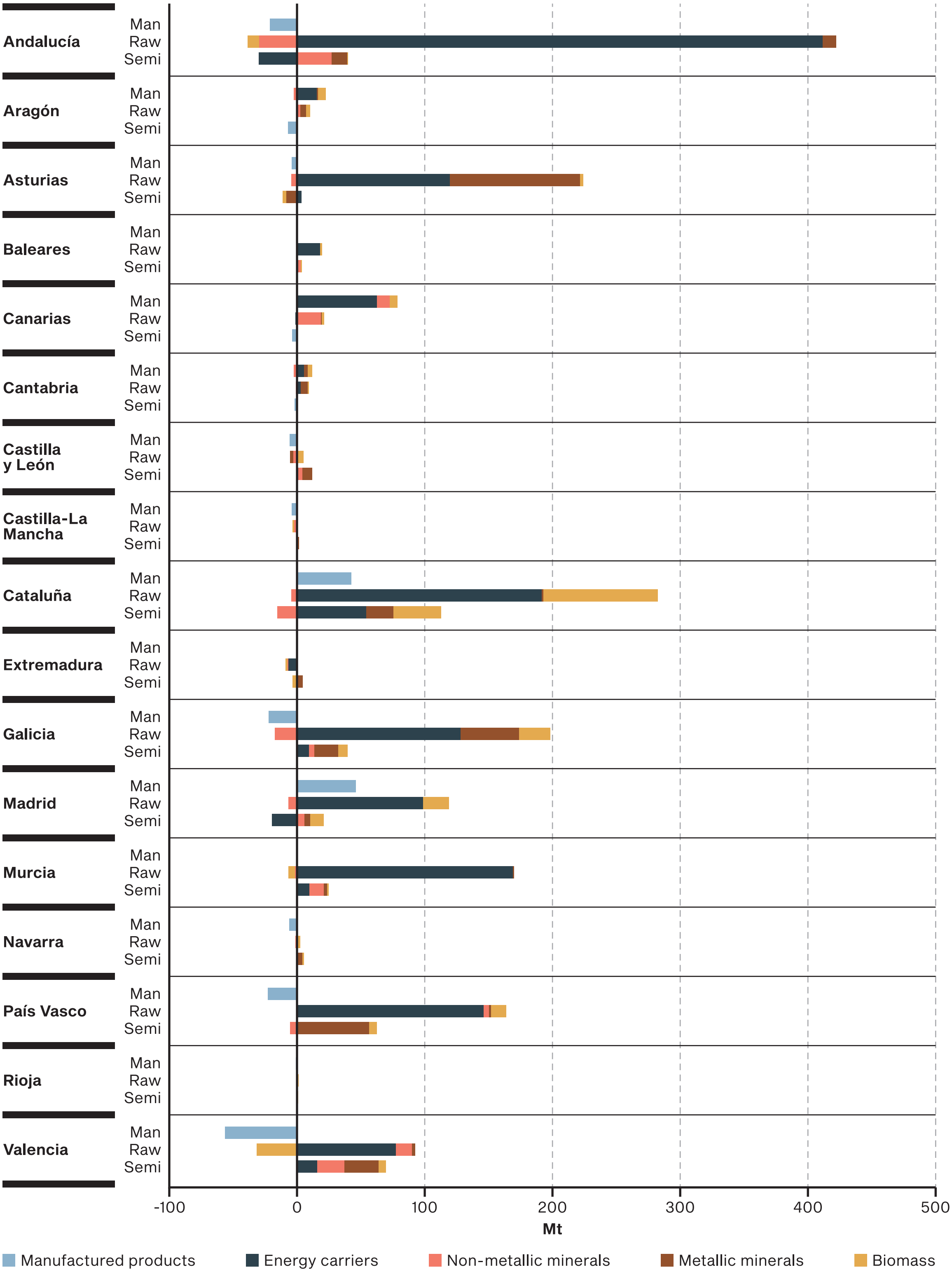
Source: compiled by the authors from sources shown in (Sastre et al. 2015).
Note: "Raw" means raw materials; "Semi" means semimanufactured materials; "Man" means manufactured products.

Canarias was more closely connected to the rest of the world than to Spanish regions in both imports and exports, which makes sense considering their distant location. Its trade structure was determined by the absence of profitable fossil fuels in the area and therefore an inherent dependence on raw and semi-manufactured energy carriers imported from abroad (Figure 2.4). This situation was similar for the rest of the products except for biomass, for which the situation is more balanced.

Other regions showed a mixed profile in terms of origin of their imports and destination of their exports determined by the absence of fossil fuels in the Spanish territory and consequently by the location of infrastructures for crude oil and gas storage and refinement. Andalucía, Cataluña, Galicia and Asturias imported mostly fossil fuels from other countries, whereas around 60% of their exports were delivered to the rest of the Spanish regions. Their structural features, particularly regarding exports, are diverse. Andalucía was a net exporter of raw and semi-manufactured energy carriers on the regional level, balanced by the large share of fossil fuels imported from abroad. Imports of fossil fuels were also important in Galicia, as were metals and biomass, while exports to other Spanish regions were mainly in the form of animal products and semi-manufactured energy carriers. On the other hand, most of the international imports of Cataluña were energy carriers and exports were mainly manufactured products. In Asturias, international imports of metals and energy carriers were related to its heavy industry, while exports were more diversified.

Pais Vasco and Murcia also had a profile highly influenced by the presence of refineries, the largest share of their imports being fossil fuels from the rest of the world and semi-manufactured metallic products in the case of Pais Vasco. In contrast, Pais Vasco's exports in both the international and interregional context were largely composed of manufactured goods and semi-manufactured forms of energy carriers. In turn, Murcia was a net interregional exporter of raw and semi-manufactured products and a net importer of manufactured products from the rest of Spain.

Figure 2.4 Level and composition of the accumulated international physical trade balance (1996-2010)



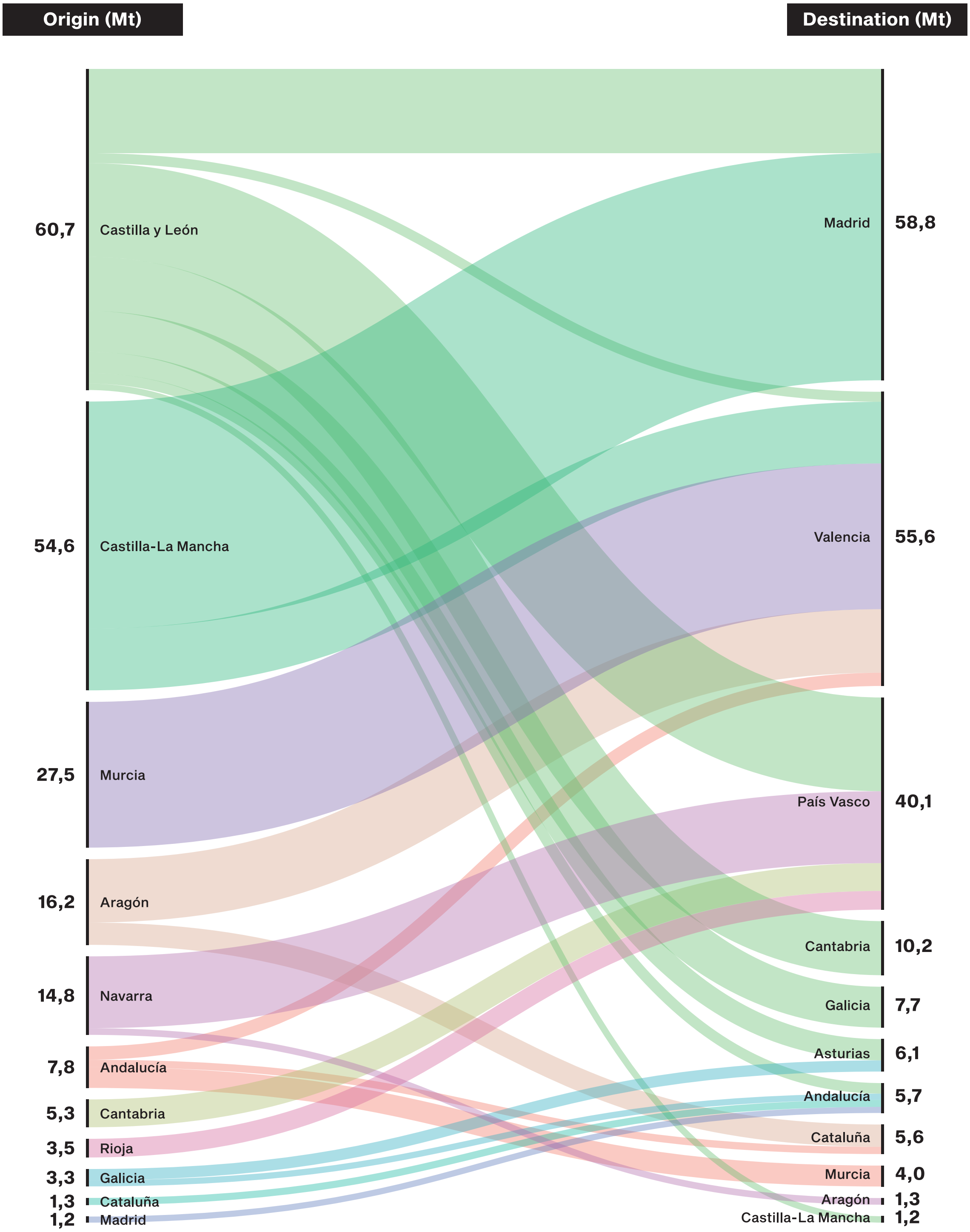
Source: compiled by the authors from sources shown in (Sastre et al. 2015).
Note: "Raw" means raw materials; "Semi" means semimanufactured materials; "Man" means manufactured products.

International and interregional trade are highly influenced by fossil fuels. Hence, regions where refineries are located have overall negative values for the IrPTB (i.e. they are net exporters). The remaining regions are net importers. However, as we look more closely at their structural features, the picture becomes more diverse. Castilla y León, Castilla-La Mancha, Galicia, Murcia and Andalucía are net interregional providers of biomass. Moreover, Andalucía and Castilla y León are the main interregional suppliers of metals.

Given the economic performance of Spain regarding the housing bubble, interregional trade of non-metallic minerals is particularly interesting. Figure 2.5 shows net cross-regional flows of non-metallic minerals (indicating environmental load displacement related to the housing bubble). These flows follow the typical pattern of non-metallic minerals, showing limited mobility because they are cheap and relatively abundant (Weisz *et al*. 2006, Kovanda *et al*. 2009). In consequence, adjacent territories supported the material requirements of regions where the construction sector was more dynamic.

This fact makes RMFA particularly useful if pressures derived from construction activities (the largest flows in volume) are to be revealed: the limited mobility of construction minerals might make their pressures invisible on the national level. In the case of Spain, Castilla-La Mancha and Castilla y León were among the main providers of Madrid, Valencia and Pais Vasco. Castilla-La Mancha and Castilla y León largely covered Madrid's demand. Murcia, Aragón, and Castilla-La Mancha covered Valencia's demand. Finally, Castilla y León, Aragón, Navarra, Cantabria and Rioja covered País Vasco's demand.

Figure 2.5	Cross-regional accumulated physical trade balances of non-metallic minerals (1996-2010). Units: thousand tons



Source: compiled by the authors from sources shown in Table S1.
Notes: the figure covers 90% of the overall flows between AC in the period 1996-2010. The remaining 10% was not included in order to optimise visualisation.

In aggregated terms, Madrid was a net importer, with the highest values of IrPTB, while Andalucía and Murcia were the main net exporters, with negative values. In terms of environmental pressures, this means that Madrid exported the greatest pressure to the remaining regions of Spain, in addition to the high pressure placed on its own territories, as stated above. The Spanish economy as a whole has been supported by a physical trade deficit with the rest of the world during the last few decades (Carpintero 2005). The same occurs at the regional level. Extremadura and Castilla-La Mancha are the only net exporters in the international context. Extremadura sold gas to Portugal on a few occasions and Castilla-La Mancha exports mainly non-metallic minerals, cereals, legumes and animal products.

Given the importance of the energy carriers for both interregional and international trade, net flows of electricity comprehensively enrich the analysis of several regions. The electricity balance complements the international imports of energy carriers to Galicia and Asturias and the interregional imports of energy carriers to Castilla y León, Aragon and Extremadura. Madrid is again the largest net importer, along with País Vasco and Valencia. This is important considering that CO_2 emissions are not measured where electricity is consumed but where it is produced (Roca Jusmet *et al.* 2013).

2.4.4 Domestic Material Consumption

The magnitude of DMC ranged from 12.6 to 20.9 t/cap at the national level. However, a significant variability was observed beneath the aggregated values: DMCpc varied by a factor of 4 in 1996 and 6 in 2010 across the Spanish regions, so the last period of economic growth in Spain resulted in an increased difference in DMCpc and in DEpc (Table 2.5). This variability is larger and the trend was the opposite of those found across European countries (Weisz *et al.* 2006) where DMC per capita has varied by a factor of 3 in a converging pattern since 1970. Globally, differences have also grown during the last few decades (Giljum *et al*. 2014, Krausmann *et al.* 2018).

Table 2.5 **Domestic material consumption. Absolute, per capita and per surface area values and biomass share**

Region	DMC (Mt)				% Biomass			DMC (t/cap)				DMC (t/km²)			DE/DMC (Average in %)			
	1996	Max	2010	PY	1996	PY	2010	1996	Max	2010	PY	1996	Max	2010	B	M	NM	EC
AN	91	174	110	2007	25.2	15	21.9	12.6	21.5	13.1	2007	1,041	1,981	1,251	105	59	102	6
AR	22	48	26	2007	34.8	25	28.9	18.6	36.8	19.2	2007	462	1	542	86	0	107	44
AS	27	45	33	2006	11.5	8	11.3	25.1	41.6	30	2007	2,58	4,22	3,07	81	3	106	30
BI	11	17	10	2007	14.7	11	16.4	14.8	16.8	8.7	2006	2,249	3,417	1,929	55	0	94	0
CA	11	21	11	2001	18.6	12	20.4	7.1	12	5.1	2001	1,522	2,872	1,446	56	0	71	0
CB	12	19	13	2008	13.9	9.3	12.8	22	34.4	22.8	2008	2,185	3,649	2,533	165	28	101	0
CL	60	86	59	2007	45.7	31	40.6	24	33.9	23.1	2007	639	911	628	105	11	108	43
CM	27	63	40	2007	47.2	24	30.1	16.1	29.5	17.2	2007	346	789	503	108	4	128	18
CT	66	124	76	2007	21.9	14	19.9	10.8	17.7	10.1	2004	2,044	3,853	2,354	52	0	101	4
EX	15	30	23	2007	64.8	53	60.7	14.3	27.4	20.3	2007	367	716	541	98	28	81	0
GL	54	65	46	2007	25.9	18	22.7	19.8	23.3	16.6	2007	1,835	2,187	1,572	94	0	96	41
MD	34	71	38	2006	18.5	15	16.5	6.7	11.9	5.9	2006	4,21	8,906	4,743	18	0	79	0
MR	13	49	19	2006	17.1	9.5	14.6	11.8	39.1	15.6	2006	1,148	4,326	1,657	130	0	102	0
NV	14	20	11	2008	22	13	19.7	27.1	32.2	17.7	2008	1,359	1,921	1,083	104	0	117	0
PV	20	36	26	2007	15.2	8	12.4	9.6	16.8	12.1	2007	2,774	4,972	3,647	71	0	83	3
RJ	4	9	6	2003	39.6	17	8.1	14.3	32.5	18.4	2007	737	1,83	1,174	118	0	115	0
VL	39	89	42	2006	14.4	4.6	10.9	9.7	18.4	8.3	2006	1,68	3,807	1,816	116	0	95	0
Spain	**528**	**943**	**592**	**2007**	**26.7**	**15.3**	**23.4**	**13.3**	**20.9**	**12.6**	**2007**	**1.04**	**1.86**	**1.17**	**93**	**46**	**102**	**29**

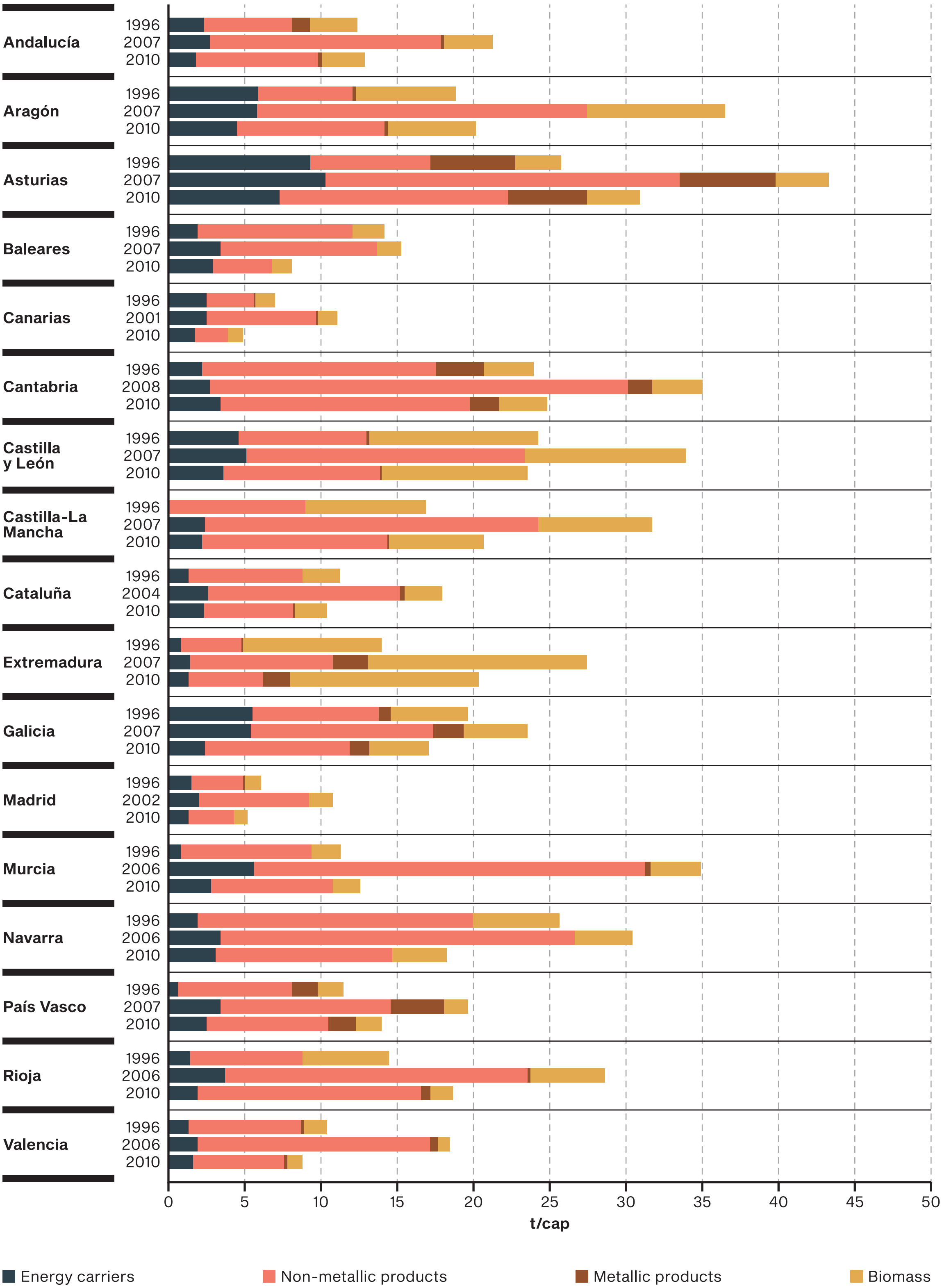
Source: compiled by the authors from sources shown in (Sastre et al. 2015).
Notes: PY means peak year as the year when the maximum value was reached. Biomass percentage refers to the peak year in absolute terms. DE, domestic extraction; DMC, domestic material consumption. In the DE/DMC column, B, biomass; M, metals; NM, non-metallic minerals; EC, energy carriers.

The trends are similar to those of DE: general growth until 2007, followed by a sharp decrease to values close to and even below those of 1996. Asturias reached the highest value (41.6 t/cap), whereas Canarias and Madrid had low values, both peaking at around 12 t/cap and decreasing below 6 t/cap in 2010.

Low DE/DMC ratios highlight the dependency of the Spanish regions on international imports of fossil fuels and metals. The situation is balanced for biomass and non-metallic minerals, with the exception of Madrid and the islands, where 18% and 50% of the biomass consumed is extracted domestically. Non-metallic products are extracted in the region where they are consumed and in nearby territories, as stated above. Only País Vasco, Canarias and Madrid domestically extracted less than 90% of the non-metallic minerals consumed. Furthermore, as the housing bubble progressed and the exacerbated use of non-metallic minerals increased, so did the overall material dependency of the Spanish regions.

The structure of DMCpc varies greatly across regions (Figure 2.6). Aragón, Castilla-La Mancha, Castilla y León and Extremadura showed a significantly larger share of biomass: over 20% during the whole period. Other regions such as Andalucía and Galicia started and finished the period with values over 20% of biomass. However, as the housing bubble evolved the share of biomass dropped, which is the general trend. All the regions experienced an increase in the share of non-metallic minerals, with the exception of Murcia, País Vasco and Baleares, where the share of energy carriers attenuated this trend. Extreme values of the share of non-metallic minerals were found in Murcia (73%), Cantabria (78%) and Valencia (83%).

Figure 2.6 Level and structure of domestic material consumption per capita of the Spanish regions



Source: compiled by the authors from sources shown in (Sastre et al. 2015).

2.4.5 Material intensity, dematerialization and environmental Kuznets curves

The direct material requirements (and associated environmental pressures) of the regional economies in order to produce €1000 of GDP followed the same path as DE and DMC (Table 2.6). First, they grew to a maximum (the most extreme case was Murcia, where direct material requirements doubled in 2007, whereas the value for Spain multiplied by a factor 1.2) and then they fell to values lower than those of 1996, with the sole exception of La Rioja. This means that, as GDP grew, so did resource inefficiency. No evidence of absolute dematerialization (Cleveland and Ruth 1998) was found. Relative dematerialization was observed in the case of Galicia, Navarra and Canarias, where GDP grew faster than DMC between 1996 and 2008.

Table 2.6 **Material intensity and Pearson coefficient of domestic material consumption and CO_2 related to GDP (1996-2008)**

Region	DMC/GDP (t/1000€)				P Cf (DMC)	P Cf (CO_2)
	1996	Max	2010	Peak Year	1996-2008	1996-2008
AN	1.3	1.6	1.1	2007	0.94	0.89
AR	1.3	2	1.1	2007	0.92	0.71
AS	2.2	2.6	2	2007	0.95	0.4
BI	0.8	0.9	0.5	2007	0.3	0.24
CA	0.5	0.8	0.4	2001	0.31	0.88
CB	1.8	2.4	1.4	2000	0.49	0.95
CL	1.9	2	1.4	2007	0.87	0.43
CM	1.5	2.3	1.5	2007	0.94	0.73
CT	0.6	0.9	0.5	2004	0.91	0.06
EX	1.7	2.4	1.7	2004	0.93	0.98
GL	1.9	1.8	1.2	1998	0.58	0.32
MD	0.4	0.5	0.3	2005	0.82	0.72
MR	1.1	2.4	1	2007	0.86	0.8
NV	1.6	1.6	0.8	1996	0.74	0.86
PV	0.6	0.8	0.5	2002	0.82	0.94
RJ	0.9	1.6	1	2003	0.85	0.8
VL	0.8	1.2	0.6	2006	0.91	0.94
Spain	**1**	**1.2**	**0.8**	**2004**	**0.93**	**0.79**

Source: compiled by the authors from sources shown in (Sastre et al. 2015).
Notes: DMC: domestic material consumption; P Cf: Pearson coefficient.

The performance of the regional indicators did not generally met the environmental Kuznets curve hypothesis, following an inverted-U shape (Dinda 2004). However, a strong positive linear relationship between DMC and GDP and between CO_2 emissions and GDP was found in most of the regions. A Pearson coefficient above 0.8 was obtained in 12 of the 17 AC for DMC. Regarding CO_2 emissions, 9 of the 17 AC had a Pearson coefficient over 0.8 for a linear positive adjustment. Asturias, Madrid and Galicia showed a particularly good fit for a second-degree polynomial function ($r^2 > 0.7$), which can be explained by the substitution of coal for electricity generation in the case of Galicia and Asturias. In the case of Madrid it is related to the methodological approach, since electricity generation related emissions are registered in other AC (Roca Jusmet *et al.* 2013).

2.5 Discussion

This chapter includes the results of the RMFA of Spain based on a new dataset. This is one of the first cases studies in which data series of the entire set of the direct indicators for a whole country at the regional level were compiled.

The results for the RMFA of Spain must be placed in the context of an economic growth and subsequent recession linked to global financial trends and the strong performance of the national construction sector (Table 2.7). Evidence has been found for a strong influence of construction sector dynamics (the housing bubble) on the regional metabolic trends and profiles. The most important consequence is that economic growth driven by these dynamics worsened material productivity, thus increasing augmenting the pressure exerted on the environment in order to produce one unit of GDP. Conversely to what has previously been observed in developing countries (Steinberger *et al.* 2013) neither material efficiency nor CO_2 emissions were clearly reduced during the economic growth period (1996-2008). On the contrary, a generalized "rematerialization" of the regional economies occurred as GDP grew in both absolute and relative terms. Future research in other countries and regions must test whether the decrease in resource productivity and increased environmental pressure is a general feature of housing bubbles.

Table 2.7 **Gross value added (%) by the construction sector in the Spanish regions, Spain and selected countries of the European Union**

Region	1996	2000	2006	2010
AN	8.7	9.4	11.4	9.3
AR	7.7	7.9	9.5	9
AS	9.3	10.3	11.9	10.6
BI	7.3	8.8	9.2	8
CA	7.6	9.1	9.9	8.1
CB	7.1	10.1	11.1	9.6
CL	8.1	8.8	10.2	9
CM	9.8	9.7	11.4	9.9
CT	7.2	7.1	8.3	7.2
EX	12.1	11.1	13	11.9
GL	9.2	10.3	11	10.1
MD	7.7	7.3	8.3	7.2
MR	8.7	8.4	9.8	8.1
NV	7.4	8.3	9.5	8.4
PV	6.4	7.2	8.1	7.8
RJ	6.2	7.7	9.4	9
VL	7.4	9	10.1	8.9
Spain	**7.9**	**8.3**	**9.6**	**8.4**
EU27	**-**	**6**	**6.7**	**6**
Ireland	**6.1**	**7.3**	**11.1**	**1.9**
Italy	**5.4**	**5.1**	**6.3**	**6**
France	**5.1**	**5**	**5.9**	**6.1**
Germany	**6.5**	**5.3**	**4.1**	**4.6**
Portugal	**7**	**8.2**	**7.3**	**6.3**

Source: Spanish National Statistics Institute for the Autonomous Communities and Spain and Eurostat for the EU countries.

Another effect of these dynamics is the reduction in the share of renewable materials for domestic extraction and consumption across regions, including those with a pronounced agricultural profile. This is a common feature in developing and developed countries, but its effect is greater at the regional level, reaching very high values in Madrid and Asturias. Moreover, extraction and consumption trends reached their historical maximum levels in aggregate terms in at least the last fifty years (Carpintero 2005). In addition to the geographic distribution of natural resources such as metals, and suitability for agriculture linked to soil fertility and climatic conditions, construction minerals played a leading role in the quantitative and qualitative extractive profile across regions. The last period of economic growth in Spain caused changes in the structure of the DE and DMC of regions through a massive increase in the use of non-renewable materials. In addition, differences across regions in DEpc, DMCpc and resource efficiency were more pronounced in 2010 than in 1996, so this particular period of economic growth entailed an increase in the regional differences in material extraction and consumption.

This work can serve as a first illustration of the regional environmental consequences of economic growth driven by a housing bubble. The most obvious outcome of the Spanish housing bubble is soil sealing as a result of the spread of artificial surfaces (i.e. urban areas). Following the results obtained by the Corine Land Cover Project (CLC)[6], artificial surfaces grew by 52% from 1987 to 2006. Between 2000 and 2005, conversion into artificial surfaces progressed at a rate of 3.4 ha/hour, doubling the transformation ratio reached from 1986 to 2000 (Prieto *et al.* 2010). Most of the surfaces transformed were fertile agricultural areas (73%). A case study focusing on Madrid (Naredo and García Zaldívar 2008) revealed that given the limited capacity of CLC for capturing artificial surfaces due to its spatial resolution, this transformation might have occurred faster and the total area of artificial surface could actually be larger (CLC identified 13% of the surface as artificial, whereas the case study based on detailed planimetry photo interpretation obtained 20%). Therefore, apart from causing a loss of material efficiency, the Spanish housing bubble amplified existing land artificialization trends.

The physical sizes of IrT and InT are for the first time compared with each other and between regions. IrT is a crucial factor for identifying environmental pressures given that the largest share of physical commercial exchanges occur across regions. This fact is important regarding displacement of environmental loads through trade. Production and consumption processes in the global economy can be disconnected in space, as has been claimed in the international context (Schoer *et al.* 2012, Giljum et al. 2014, Tian *et al.* 2017).

The results showed in this chapter suggest that these processes might be quantitatively more important across regions. Seemingly, regions are able to play different physical commercial roles (e.g. act as raw material suppliers) in the regional and the international context similar to the roles played by countries (West and Schandl 2013, Wang *et al*. 2019, Piñero *et al*. 2020). Patterns of extractive and commercial specialization are also likely to appear at the regional level. Consequently, the implications of IrT for climate change and material productivity policies emerge as a relevant issue (Meng *et al.* 2018, Banerjee 2020, Wu *et al.* 2020).

Finally, applying material flow accounting to the regional scale opens a new space for understanding and interpreting indicators. Madrid stood out as a "black hole" of materials and electricity in absolute terms. The pressure exerted in its own territory by the extraction of natural resources exceeds any value known until now across the EU and most of the world.

Furthermore, Madrid has succeeded in displacing a large share of its demand for non-metallic minerals to the nearby regions, particularly Castilla-La Mancha. However, DEpc and DMCpc in Madrid, the islands, País Vasco, Valencia and Cataluña were lower than expected. Densely populated regions containing big cities might be expected to have higher per capita values for consumption than less populated areas and rural regions, but this is not the case. This counter-intuitive fact appears regularly in material flow studies and has been explained with several arguments to which this thesis can contribute (Weisz *et al.* 2006).

First, methodologically, EW-MFA does not account for indirect flows, so the extent to which the material requirements of a region are supported by upstream requirements coming from other systems remains unknown. Given the quantitative (size) and qualitative (patterns of commercial specialization) dimensions of IrT, the influence of this factor might be crucial at the regional scale. Approaches focusing on consumption such as raw material equivalents might be more suitable for assessing this issue (Arto 2003, Kovanda *et al.* 2009, Bruckner *et al.* 2012, Schoer *et al.* 2012, Piñero *et al.* 2020, Rodríguez and Camacho 2020).

[6] Data from the Project can be consulted in the following link: https://land.copernicus.eu/pan-european/corine-land-cover

Second, electricity is not accounted for, so the material requirements of electricity generation are not included as imports. This point is crucial on the regional level. Finally, economies of scale and agglomeration arise in densely populated urban areas, where common public services and infrastructures might be used more efficiently (Fujita *et al.* 1999).

All in all, RMFA is a promising tool for exploring environmental pressures hidden within country-level indicators. Based on RMFA data, additional research in the field of regional division of labor (Murray 2012, Delgado *et al.* 2014, Piñero *et al.* 2020) (i.e. sources and sinks) and the evaluation of environmental policies on the regional level is currently being carried out. Further discussion, additional case studies and complementary methodological approaches (raw material equivalents, the water footprint and unequal ecological exchange) will hopefully expand the range of applications for this compilation.

Chapter 3

Biophysical trade and environmental burden shifting at subnational level: the case of Spain 1996-2010

This chapter was being edited for submission to the journal "Ecological Economics" by the time this thesis was delivered.

3.1 Abstract

Trade materialises the spatial disconnection between the places where production and consumption occur. Therefore, the environmental burdens related to extraction and processing of traded commodities can be shifted to territories different from those where these goods are eventually consumed. This chapter is devoted to exploring trade between the Spanish AC and between the Spanish AC and the rest of the world. More specifically, the chapter addresses 1) the roles played by the Spanish AC regarding biophysical trade flows (e.g., net importers, net exporters); 2) the magnitude of environmental burden shifting of the Spanish AC with the rest of the AC and the rest of the world; and 3) related methodological issues when dealing with subnational systems. Results show that interregional trade is a mechanism to displace specific environmental burdens across the subnational units of a country. Specialisation in raw material extraction and clear roles as net importers/exporters of materials can be identified for biomass products and non-metallic minerals despite methodological limitations. In this context, Madrid stands out as a net importer for all material categories, hence shifting their environmental burdens towards other Spanish regions and foreign countries. Further refinement of these accounts might support future policy design to compensate/mitigate/restore the environmental burdens related to inter-regional trade, in parallel to the claims for environmental justice made in the international arena.

3.2 Introduction

The role of trade as a mechanism for the allocation of environmental burdens has been intensely addressed by researchers devoted to explore the biophysical dimension of human-environment interactions (Ekins *et al.* 1994, Ropke 1994, Eisenmenger *et al.* 2016). Within these discussions, EW-MFA indicators have provided quantitative support to measure and keep track of these phenomena (Muradian and Martinez-Alier 2001, Moran *et al.* 2013, Wu *et al.* 2020).

Trade between territories materialises the spatial disconnection between production and consumption[7] (Yu *et al.* 2014) in a context where globalisation has resulted in a significant increase of international biophysical imports and exports (Dittrich and Bringezu 2010). Therefore the environmental burdens related to extraction and processing of traded commodities can be shifted to territories different from those where these goods are eventually consumed (Moran *et al.* 2009, Bruckner *et al.* 2012, Mayer and Haas 2016). Hence, environmental burden shifting (EBS) has become a main element within the debates on unequal exchange and the allocation of environmental responsibilities (Piñero *et al.* 2019, Schaffartzik *et al.* 2019).

Environmental burden allocation through trade has been mainly addressed from the view point of the bilateral commercial relationships between single countries (Giljum 2004) and groups of these (Schütz, Moll, *et al.* 2004). The lack of data has limited these studies at subnational level so far (Hammer *et al.* 2003), although several works have successfully completed that task for individual regions (Garmendia *et al.* 2016, Piñero *et al.* 2020). Addressing the interregional and international biophysical exchanges between the whole of the regions of a country remains a pending issue, though.

This chapter is devoted to exploring EBS between the Spanish AC and between the Spanish AC and the rest of the world, which makes it innovative in the context of the literature in the field of EW-MFA studies. More specifically, the aims of this chapter are 1) to determine the roles played by the Spanish AC regarding biophysical trade flows (e.g. net importers, net exporters); 2) measure the magnitude of EBS of the Spanish AC with the rest of the AC and the rest of the world; and 3) discuss the main methodological issues when subnational units are addressed.

[7] Consumption is here understood as "domestic demand", which from an economic point of view entails both final consumption and investment.

3.3 Methods

The database used in chapter 2 was also employed for the purposes of this chapter. The specifics of the database and methodological issues can be consulted in dedicated publications (Carpintero *et al.* 2014, Sastre *et al.* 2015). The most relevant general methodological aspects of the database have been synthetically exposed in the previous chapter. Specific methodological issues and limitations related to the purpose of this chapter are listed below.

3.3.1 Dealing with direct biophysical trade flows

The scope of our database is on direct flows, typically compiled from trade and freight statistics[8]. Direct flows do not address the upstream material requirements of trade; therefore, a share of the environmental burden related to imports and exports remains out of the scope of direct flows-based indicators. Raw material equivalent accounts have partially[9] overcome this limitation (Muñoz *et al.* 2009, Schoer *et al.* 2012, Wiedmann *et al.* 2015) showing different results as compared to direct flows, particularly for certain materials (Dittrich and Bringezu 2010, Dittrich *et al.* 2012). Being raw material equivalents a preferable approach in analytical terms, these accounts rely on databases which are seldom available at subnational level for the whole of a country's subnational units (Piñero *et al.* 2020), as it is the case for Spain. In any case, both direct flows and raw material equivalents can only indirectly reflect the complexity of the environmental consequences of human activities (Kovanda *et al.* 2009, Verones *et al.* 2017, Kovanda 2020).

In order to deal with the above-mentioned methodological constraints related to the use of direct flows and the limited capacity of high-level aggregation of material flow categories to relate to environmental burdens, three methodological tweaks (e.g. as compared to conventional EW-MFA studies) were applied in order to expand the analytical power of the database.

First, data was broken down into the three main degrees of processing according to Eurostat's standards (i.e. raw, semimanufactured, manufactured) for each of the main material flows categories (i.e. biomass, metallic minerals, non-metallic minerals, fossil fuels). Disaggregating material flows by degree of processing permits going one step further in profiling the AC's role as net importers and net exporters when using direct flows: i.e. if one AC is a net exporter of both raw, semimanufactured and manufactured products of one type of materials (e.g. non-metallic minerals), it can be reasonably assumed to be a net exporter for those products and so be taking the environmental burden of the extraction of that particular material which is being devoted to exports. Furthermore, if one AC is a net exporter of semimanufactured and manufactured products for one material category in a magnitude that surpasses net imports of raw materials for that material category, this region is also likely to be a net exporter for that particular material category. This is grounded in the fact that the raw material equivalents of

[8] According to the methodological specifications of all the data sources on trade and freight statistics from which our database has been fed, transit operations (e.g., re-exports) are filtered. This means that, for example, a commodity delivered from a foreign country, arriving to Andalucía by ship but whose destination is Extremadura by road, will be registered and allocated as an international import to Extremadura. Therefore, it will not be accounted for as an international import to Andalucía and former interregional export from Andalucía towards Extremadura.

[9] It must be noted that raw material equivalent accounts expand the scope of direct flows in a methodologically consistent manner, though "unused material flows" are out of their scope. Therefore these accounts do not include all the materials required for the economic process either (Adriaanse et al. 1997, Bringezu and Schütz 2001, Bringezu et al. 2004, Dittrich *et al*. 2012, Wang *et al*. 2013).

semimanufactured and manufactured products tend to be larger than one. Following this approach, the most evident trade roles could be identified using direct flows.
Second, material flows were broken down into more detailed categories of materials, which is helpful when it comes to relate EW-MFA indicators to more specific environmental burdens (Schoer *et al.* 2012). For this purpose, the four main material flow categories (i.e. biomass, metallic minerals, non-metallic minerals, and fossil fuels) were initially considered. After preliminary analytical work, both metallic minerals and fossil fuels were discarded from the analysis. Since there is not significant extraction of these resources in any AC, it is evident that most of the environmental burden corresponding to the extraction of metals and fossil fuels was shifted to foreign countries from all AC. In order to determine the subnational patterns of consumption of these materials, more sophisticated approaches such as raw material equivalents accounts would be required.

In the case of biomass, in order for the indicators to relate to more specific environmental burdens, biomass flows were also split into more detailed subcategories: agriculture biomass, livestock biomass, forest biomass, fish biomass and mixed biomass (i.e. including agricultural and animal products together). Since Eurostat's guidelines do not establish such level of detail for semimanufactured and manufactured biomass products, a discretional classification of trade and freight categories was made by the authors, according to their description. The correspondence between the Nomenclature uniforme des merchandises pour les Statistiques de Transport (NSTR, used in statistics of freight transport by road), the Combined Nomenclature (used in international trade and interregional cargo ships) and the proposed MFA categories is exposed in Table 3.1.

For its part, non-metallic minerals were assumed to be homogeneous regarding environmental burdens (e.g. derived from mining and quarrying) and therefore analysed altogether.

Table 3.1 **Correspondence between the NSTR classification, the combined nomenclature and semimanufactured and manufactured biomass products**

Material	Degree of processing	Subcategory	NSTR codes	CN codes
Biomass	Semimanufactured	Agriculture	045; 049; 161;162; 163; 166; 172; 895	11; 12; 13;14;19; 20; 52; 53
Biomass	Semimanufactured	Livestock	041; 144; 145	41; 50; 51
Biomass	Semimanufactured	Forest	051; 052; 055; 056	44; 45; 47
Biomass	Semimanufactured	Fish	148	-
Biomass	Semimanufactured	Mixed	099; 182	15; 16; 21;23
Biomass	Manufactured	Agriculture	111; 112; 113; 121; 122; 125; 128; 131;132; 133; 135; 136; 139	17; 18; 24; 40
Biomass	Manufactured	Livestock	091; 961	42; 43
Biomass	Manufactured	Forest	841; 842; 971; 972; 973; 975; 976	46; 48; 49
Biomass	Manufactured	Fish	-	-
Biomass	Manufactured	Mixed	-	22

Source: own elaboration.

Finally, interregional and international trade were analysed separately, which enhances the analysis of trade-related roles played by the AC (e.g. net exporter, net importer).

3.3.2 EW-MFA indicators as indicators of environmental burden

When it comes to analyse biophysical trade flows and derived environmental burdens, physical trade balances are the most widespread indicators (Schütz, Bringezu, et al. 2004, Garmendia *et al.* 2016). Either in absolute or relative terms (e.g. per capita, per hectare, etc.) it is often suggested that the larger the PTB, the more the environmental burden shifted (if resulting into net imports) or taken (if resulting into net exports). However, this interpretation faces at least two drawbacks.

First, unless material flows are broken down into more detailed categories, PTB allow for compensation between material categories. This means that the environmental burdens of metal extraction can be offset by the environmental burdens of fossil fuels if their PTB have opposite signs. From an environmental point of view the conclusions from such calculation does not lead to clear interpretations. For PTB to be environmentally meaningful, these should be calculated for groups of materials for which environmental burden are, to a certain extent, homogenous.

Second, the extraction of one specific material might entail different environmental burdens according to the conditions in which it is extracted (e.g. according to technology), even if referring to homogenous material categories.

Considering these two points plus the limitations derived from direct flows, it has to be acknowledged that EW-MFA indicators and particularly those stemming from our database cannot provide comprehensive information about specific environmental pressures, impacts, etc., related to resource extraction and trade.

Instead, if biophysical trade flows are compared to DE, imports can be interpreted as "avoided DE" and in this sense "shifted" somewhere else. Also, the share of DE virtually devoted to exports can be calculated.

Relating imports and exports to DE is in the vein of indicators such as "ecological footprint" (Wackernagel *et al.* 2008, Wiedmann and Barrett 2010) of concepts such as "ecological space" (Hayward 2007, Moran *et al.* 2009) since it relates material deficit/surplus to the extractive profile of a given territory. These indicators are focused on the "shifting" dimension of trade whereas "environmental burden" admittedly remains a working (virtual) concept.

3.3.3 On fishing statistics in the context of EW-MFA

Fishing statistics face several methodological issues to be considered for our purposes. First, although for EW-MFA the residence principle is preferred in order to calculate DE, in practice this principle is hard to follow at national level and even more difficult at subnational scale.

Applying the residence principle means that for the calculation of DE, "all landings by national vessels should be included, regardless of the geographic location of landings" (Eurostat 2018, p. 48). However, fishing statistics and particularly old datasets are not often organised in such way. By contrast, fish captures are reported in terms of "fresh" and "frozen". Fresh generally refers to captures made within Spanish jurisdictional waters, for which less than 24 hours passed between capture and landing (e.g. overnight fishing). In these conditions, it can be assumed that vessels belonging to one AC will operate in waters nearby to their home ports, and so fresh fish can be considered DE following the residence principle.

Frozen fish refers to captures immediately frozen on board, made beyond Spanish jurisdictional waters by Spanish and non-Spanish vessels. In principle only non-Spanish captures will be subject to tariffs therefore only captures from non-Spanish vessels would be registered in foreign trade statistics. Therefore, fish imports as reported by international trade statistics are underestimated.

Second, according to Eurostat's methodological provisions, aquaculture should not be accounted for within fish biomass extraction. However, in Spain and notably in Galicia, there are some types of aquaculture that do not require any external feeding and provide large amounts of fish biomass, notably shellfish. As far as these types of aquaculture are not included within EW-MFA accounts, DE of fish biomass would be underestimated. Whereas, if these products are effectively registered as exports, which creates an imbalance for fish products (e.g. allowing negative domestic consumption figures). This point is particularly relevant in Galicia where the extraction of aquaculture-based biomass reaches 200-250 kt per year.

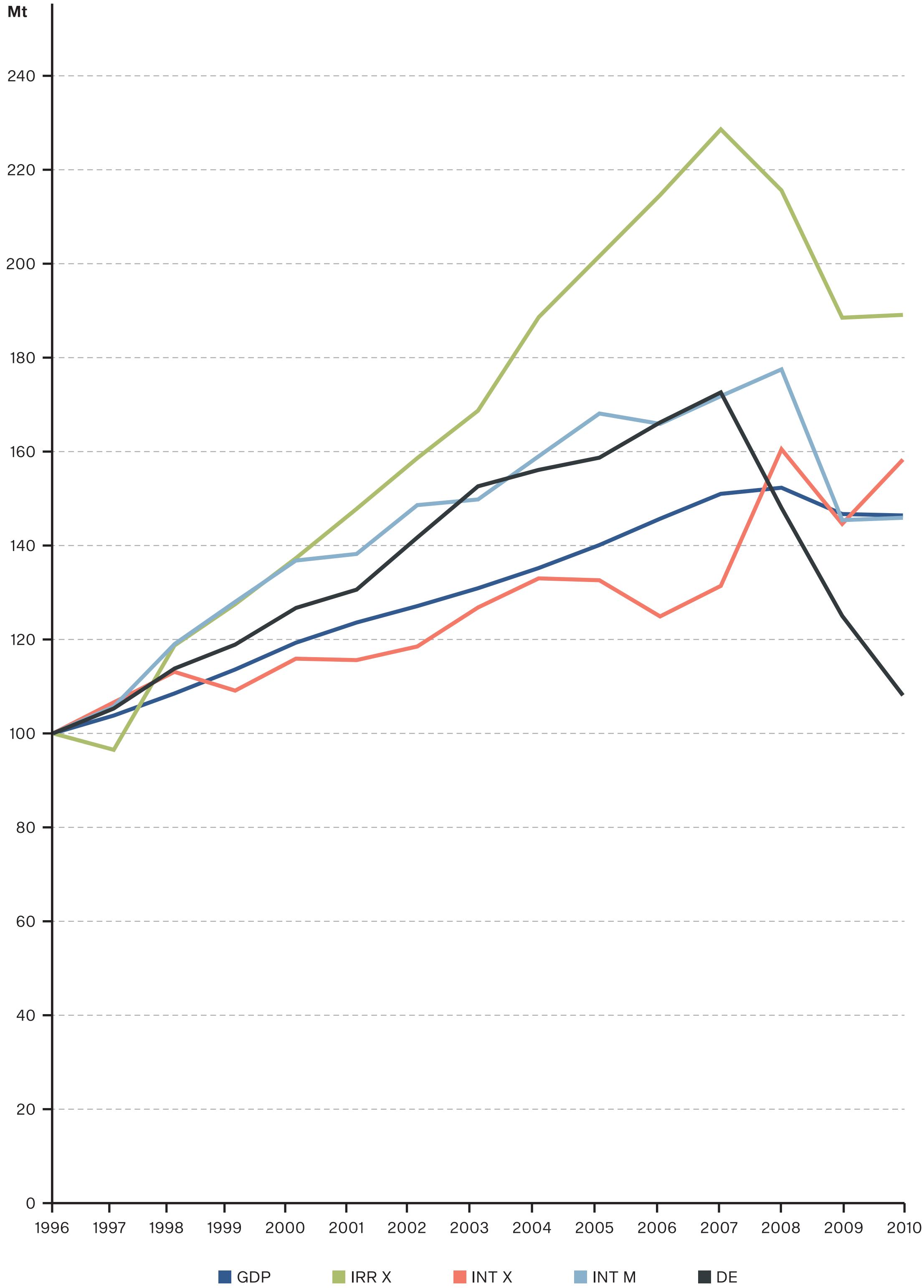
Finally, it should be acknowledged that a relevant amount of fish biomass is captured by informal fishermen for self-consumption and local supply, particularly seafood. More importantly, a share of fish captures (i.e. illegal fishing) are not declared (Freire and García-Allut 2000, Perez de Oliveira 2013) which contributes to the underestimation of DE and imports.

3.4 Results

The accumulated overall DE between 1996 and 2010 in Spain was 9,038 Mt. International direct imports reached 3,498 Mt whereas interregional direct imports were 4,451 Mt. This means that an amount equivalent to 38.7% of DE was imported from foreign countries. International exports (1,521 Mt) accounted for 16.8% of DE resulting into an international PTB of 1,977 Mt, equivalent to 21.9% of DE. In turn, an amount of materials equivalent to 49.2% of DE was traded between regions.

It is worth noting that between 1996 and 2007 (i.e. GDP growth period), the volume of interregional exports period grew faster than international trade, DE and GDP (Figure 3.1), which means that economic growth between 1996 and 2006 intensified the overall biophysical trade at subnational level. The following sections address how these general patterns materialised at regional level regarding each specific material flow.

Figure 3.1 **Biophysical trade, domestic extraction and gross domestic product in Spain, 1996-2010. 1996=100**



Source: own elaboration.
Note: GDP: gross domestic product; IRR: interregional; INT: international; X exports; M: imports; DE: domestic extraction.

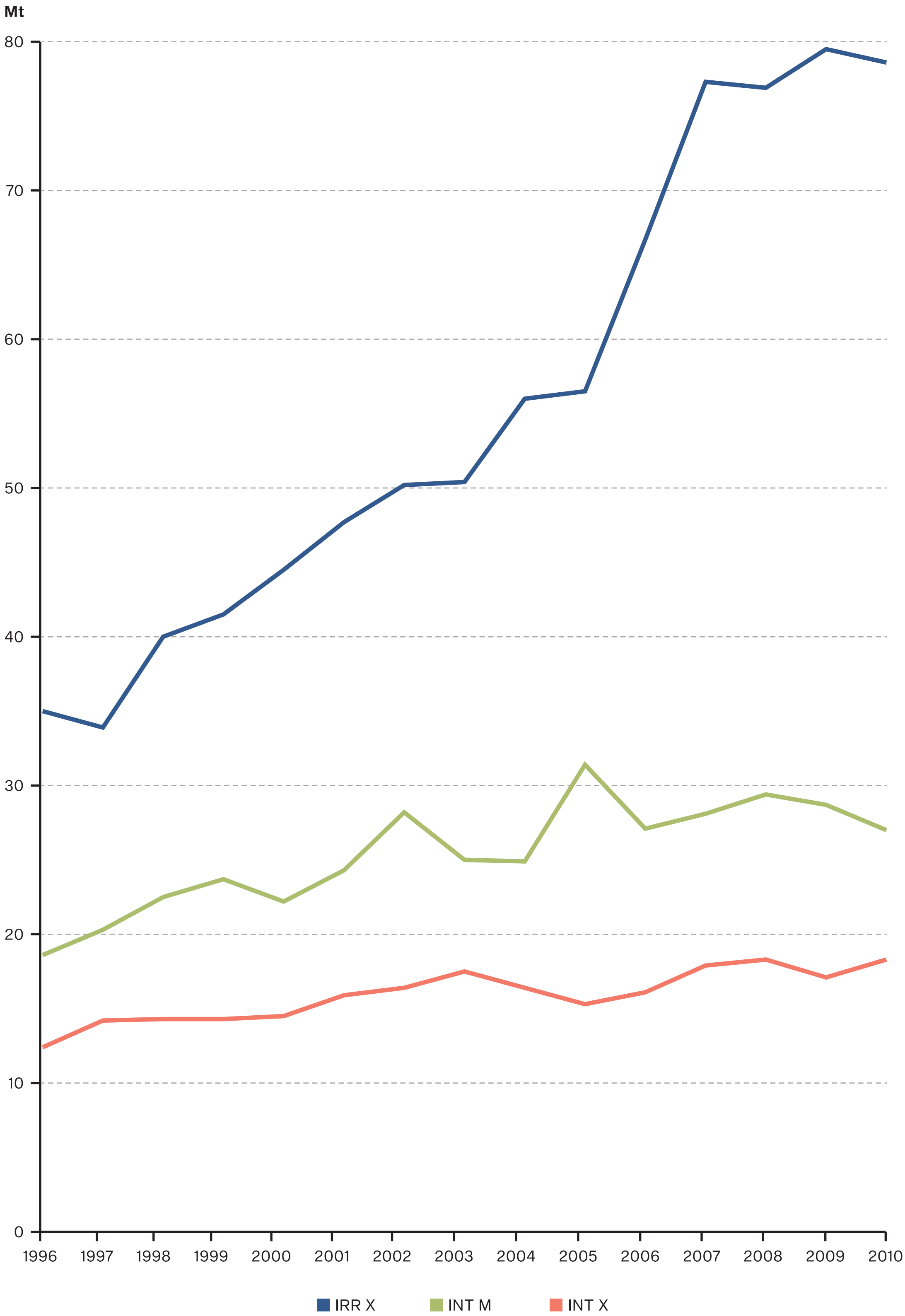
3.4.1 Agriculture biomass and animal products

According to EW-MFA methodological standards, livestock biomass is considered a stock and only feedstock is registered within DE accounts instead. However, animal products are accounted for within trade statistics, so in order to deal with this asymmetry, both agriculture and animal products are exposed separately in this section. Furthermore, trade statistics include products that are a mix of agriculture and animal biomass for which the denomination of "mixed biomass" has been applied. Where relevant, more detailed insight on the categories comprising "mixed biomass" (see Table 3.1) is given in order to complement the analysis of agriculture and livestock biomass.

As for DE of agricultural biomass, accumulated figures (1996-2010) ranged from 47.6 t/ha in Murcia to 21.8 t/ha in Madrid. Six additional regions showed values over 40 t/ha (Rioja, Extremadura, Cantabria, Andalucía, Castilla León, and Valencia). Other regions such as Navarra, País Vasco, Cataluña, Asturias, and Galicia were closer to the Spanish average figure (35.7 t/ha) whereas the rest were below 30 t/ha.

Biophysical trade of agricultural products followed a general increasing trend during the whole period (Figure 3.2). Interregional exports more than duplicated overall. Both raw, semimanufactured and manufactured products increased their exchanges, at different paces, though. Whereas raw materials increased by 73% manufactured products doubled and semimanufactured products increased fivefold. Interregional exports and the international volume of trade (i.e. imports plus exports) which were of similar size at the beginning of the period, however by 2010 interregional exports surpassed by 35% international volume of biophysical trade. All in all, Spain remained a net importer of agricultural products during between 1996 and 2010. Accumulated imports were 17.4% of accumulated DMI and amount equivalent to 21.1% of DE of agricultural biomass was outsourced.

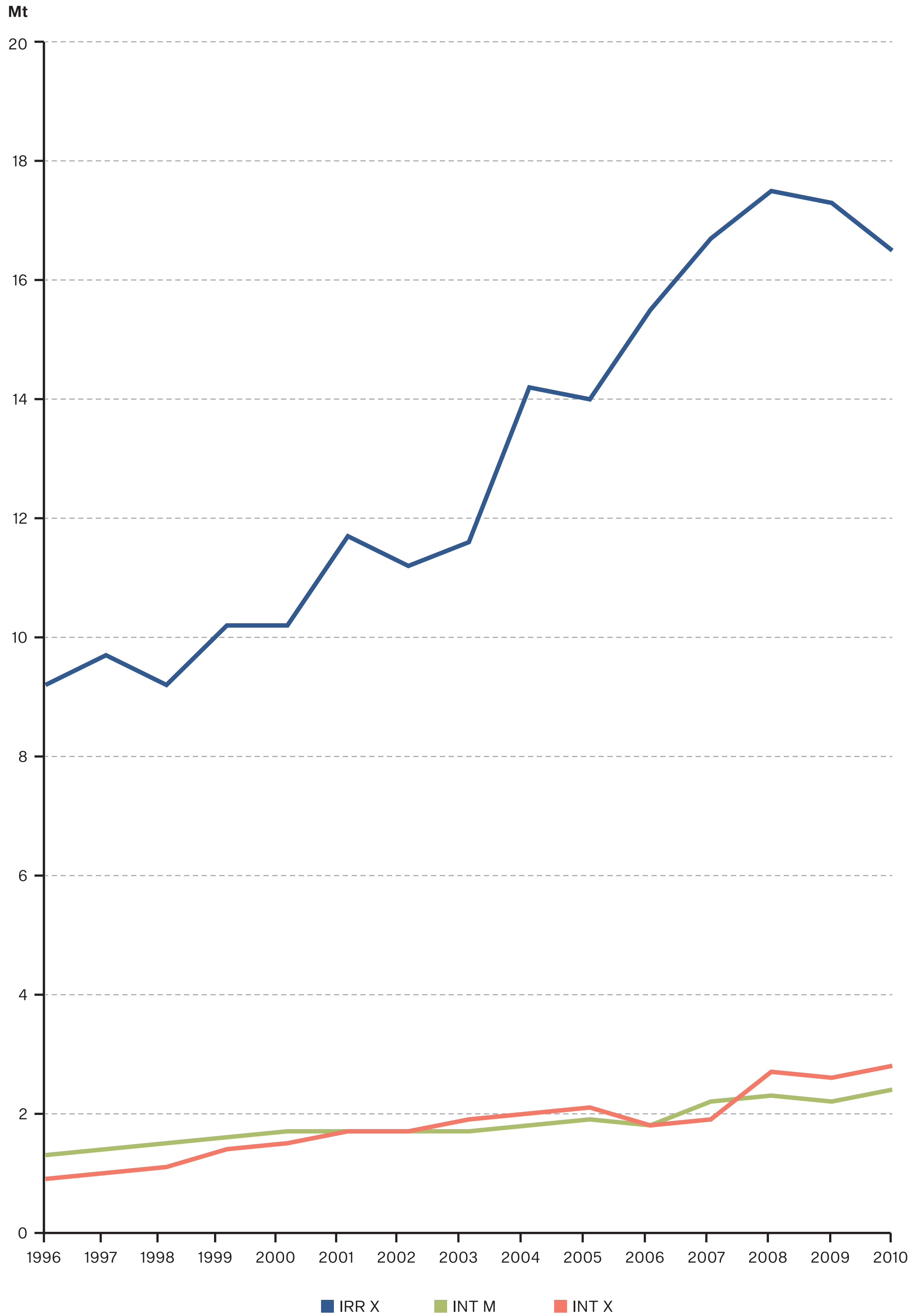
Figure 3.2 **Biophysical trade flows of agriculture biomass in Spain (1996-2010)**



Source: own elaboration.
Note: IRR: interregional; INT: international; X exports; M: imports.

Biophysical trade of animal products also grew both in the interregional and international markets (Figure 3.3). As it was the case for agriculture biomass, animal products were mostly traded between regions being the accumulated interregional exports more than three times larger than the volume of international biophysical trade. During the period 1996-2010 both interregional exports and international imports grew close to but below doubling their initial figures whereas international exports more than tripled. Spain's PTB changed several times staring the series as a net importer in 1996 and turning into a net exporter by 2010. Overall Spain's international PTB of animal products was only slightly positive and formed by net imports of semimanufactured and manufactured commodities and net exports of raw products.

Figure 3.3 **Biophysical trade flows of animal products in Spain (1996-2010)**



Source: own elaboration.
Note: IRR: interregional; INT: international; X exports; M: imports.

The biophysical trade profiles of the Spanish AC regarding biomass were varied. Baleares and Canarias were the only AC where the signs of their PTB for agricultural, livestock and mixed biomass pointed to the same direction: net imports. Therefore, these regions could be attributed a role of net importers of biomass in all their forms and degrees of processing. The overall PTB of agricultural products alone was 61.2% of DE in Baleares and 57.9% in Canarias. When livestock and mixed biomass is added this figure surpasses 100% in both regions. Considering that this figure is reached before any correction in terms of raw material equivalents is applied, both archipelagos are expected to have a very sharp dependency on imported biomass. In the case of Baleares imports are mostly provided by other Spanish AC. In Canarias, the international and interregional PTB were more balanced being international imports dominated by raw materials whereas the exchanges with the rest of the AC was in the form of manufactured and semimanufactured products.

Table 3.2 **Agriculture, livestock and mixed biomass: domestic extraction and interregional biophysical trade flows, accumulated 1996-2010 (Part 1)**

Unit		Mt	Mt	Mt	Mt	-	Mt	Mt	Mt	-	Mt	Mt	Mt	Mt	-
Indicator		**DE**	**M**	**M**	**M**	**M/DE**	**X**	**X**	**X**	**X/DE**	**PTB**	**PTB**	**PTB**	**PTB**	**PTB/DE**
DoP		**RAW**	**RAW**	**SM**	**MN**	**ALL**	**RAW**	**SM**	**MN**	**ALL**	**RAW**	**SM**	**MN**	**ALL**	**ALL**
Andalucía	AG	367.2	42.7	12.4	26.9	0.2	53.8	15.0	19.7	0.2	-11.1	-2.6	7.2	**-6.5**	**0.0**
	LV	-	16.8	4.3	0.4	-	8.9	2.1	0.3	-	7.9	2.1	0.0	**10.1**	**-**
	MX	-	0.0	3.9	0.0	-	0.0	14.1	1.0	-	-	-10.2	-1.0	**-11.2**	**-**
Aragón	AG	109.7	49.5	10.3	8.9	0.6	38.7	12.9	8.9	0.6	10.8	-2.7	0.0	**8.2**	**0.1**
	LV	-	7.2	1.8	0.2	-	15.3	0.5	0.2	-	-8.2	1.3	0.0	**-6.9**	**-**
	MX	-	0.0	2.4	0.0	-	0.0	1.0	0.0	-	-	1.4	0.0	**1.4**	**-**
Asturias	AG	31.9	10.8	2.8	5.9	0.6	1.8	0.9	3.7	0.2	8.9	2.0	2.2	**13.1**	**0.4**
	LV	-	7.6	1.6	0.0	-	8.3	3.1	0.1	-	-0.7	-1.5	-0.04	**-2.3**	**-**
	MX	-	0.0	0.7	0.0	-	0.0	0.2	0.0	-	-	0.5	0.0	**0.4**	**-**
Baleares	AG	12.4	3.0	1.5	1.7	0.5	0.2	0.1	0.0	0.0	2.8	1.3	1.7	**5.8**	**0.5**
	LV	-	1.1	0.8	0.0	-	0.1	0.1	0.0	-	1.1	0.8	0.0	**1.8**	**-**
	MX	-	0.0	1.4	1.7	-	0.0	0.1	0.0	-	-	1.4	1.7	**3.0**	**-**
Canarias	AG	18.0	1.8	2.7	1.9	0.4	1.8	0.1	0.0	0.1	0.0	2.6	1.8	**4.3**	**0.2**
	LV	-	0.1	0.5	0.0	-	0.0	0.0	0.0	-	0.1	0.5	0.0	**0.6**	**-**
	MX	-	0.0	3.2	3.3	-	0.0	0.1	0.0	-	-	3.1	3.3	**6.4**	**-**
Cantabria	AG	23.0	7.3	2.9	4.9	0.7	6.2	4.2	2.9	0.6	1.2	-1.3	2.1	**2.0**	**0.1**
	LV	-	2.8	0.5	0.0	-	6.2	0.4	0.0	-	-3.4	0.1	0.0	**-3.3**	**-**
	MX	-	0.0	0.4	0.0	-	0.0	0.3	0.0	-	-	0.1	0.0	**0.1**	**-**
Castilla y León	AG	384.1	40.1	15.7	16.3	0.2	61.2	12.3	28.5	0.265	-21.1	3.4	-12.1	**-29.8**	**-0.1**
	LV	-	18.6	2.1	0.4	-	27.7	4.3	0.7	-	-9.0	-2.2	-0.3	**-11.5**	**-**
	MX	-	0.0	3.6	0.0	-	0.0	1.8	0.0	-	-	1.9	0.0	**1.9**	**-**
Castilla-La Mancha	AG	214.7	35.2	14.9	20.6	0.3	51.6	16.7	43.1	0.519	-16.4	-1.8	-22.4	**-40.6**	**-0.2**
	LV	-	14.1	2.1	0.3	-	12.4	3.4	0.4	-	1.6	-1.4	-0.1	**0.1**	**-**
	MX	-	0.0	3.5	0.0	-	0.0	3.9	0.0	-	-	-0.4	0.0	**-0.4**	**-**
Cataluña	AG	113.6	50.1	13.4	25.5	0.8	62.6	16.5	28.6	0.9	-12.5	-3.2	-3.1	**-18.8**	**-0.165**
	LV	-	20.2	4.3	0.7	-	15.5	4.9	0.4	-	4.6	-0.7	0.3	**4.2**	**-**
	MX	-	0.0	4.7	0.0	-	0.0	7.4	1.8	-	-	-2.7	-1.8	**-4.5**	**-**

Source: own elaboration.
Note: DE: domestic extraction; M: imports. X: exports; PTB: physical trade balance; DoP: degree of processing; RAW: raw materials; SM: semimanufactured; MN: manufactured; AG agriculture biomass; LV: livestock biomass; MX: mixed biomass

Table 3.3 Agriculture, livestock and mixed biomass: domestic extraction interregional biophysical trade flows, accumulated 1996-2010 (Part 2)

Unit		Mt	Mt	Mt	Mt	-	Mt	Mt	Mt	-	Mt	Mt	Mt	Mt	
Indicator		DE	M	M	M	M/DE	X	X	X	X/DE	PTB	PTB	PTB	**PTB**	**PTB/DE**
DoP		RAW	RAW	SM	MN	ALL	RAW	SM	MN	ALL	RAW	SM	MN	**TOTAL**	**TOTAL**
Extremadura	AG	182.7	21.5	5.6	6.2	0.2	11.9	4.1	5.1	0.1	9.6	1.5	1.1	**12.2**	**0.1**
	LV	-	3.4	0.7	0.2	-	5.4	0.3	0.3		-2.0	0.4	-0.2	**-1.8**	**-**
	MX	-	0.0	1.4	0.0	-	0.0	1.5	0.0		-	-0.1	0.0	**-0.1**	**-**
Galicia	AG	92.3	15.3	6.1	9.0	0.3	4.0	3.6	4.8	0.1	11.3	2.5	4.2	**18.0**	**0.2**
	LV		4.6	1.8	0.1	-	22.4	1.3	0.1		-17.9	0.6	-0.1	**-17.4**	**-**
	MX		0.0	2.6	0.0	-	0.0	0.9	0.1		-	1.7	-0.1	**1.5**	**-**
Madrid	AG	17.5	38.6	19.8	32.2	5.2	19.3	14.2	21.5	3.1	19.3	5.6	10.6	**35.5**	**2.0**
	LV		26.9	6.4	0.4		7.1	7.1	0.3		19.8	-0.7	0.1	**19.2**	**-**
	MX		0.0	3.5	0.0		0.0	0.7	0.0		-	2.8	0.0	**2.8**	**-**
Murcia	AG	53.9	31.6	7.1	13.3	1.0	37.6	8.6	14.6	1.1	-6.0	-1.5	-1.3	**-8.9**	**-0.2**
	LV		4.6	1.3	0.5		5.7	0.6	0.3		-1.1	0.8	0.1	**-0.2**	**-**
	MX		0.0	1.2	0.0		0.0	1.6	0.0		-	-0.4	0.0	**-0.4**	**-**
Navarra	AG	40.5	20.7	4.4	4.4	0.7	17.6	9.7	8.0	0.9	3.2	-5.3	-3.6	**-5.7**	**-0.1**
	LV		3.0	0.9	0.2		5.7	2.0	0.1		-2.7	-1.1	0.1	**-3.8**	**-**
	MX		0.0	1.3	0.0		0.0	1.2	0.0		-	0.1	0.0	**0.1**	**-**
Pais Vasco	AG	27.8	14.4	7.7	14.4	1.3	17.0	6.8	10.9	1.2	-2.5	0.9	3.5	**1.9**	**0.1**
	LV		7.5	2.0	0.0		4.5	1.2	0.2		3.0	0.7	-0.2	**3.6**	**-**
	MX		0.0	1.7	0.0		0.0	2.0	0.2		-	-0.3	-0.2	**-0.5**	**-**
Rioja	AG	23.5	10.5	3.6	5.3	0.8	11.2	5.6	7.6	1.0	-0.8	-2.1	-2.3	**-5.1**	**-0.2**
	LV		1.7	0.1	0.4		1.6	0.1	0.1		0.1	0.1	0.3	**0.4**	**-**
	MX		0.0	0.3	0.0		0.0	0.5	0.0		-	-0.2	0.0	**-0.2**	**-**
Valencia	AG	93.7	17.1	3.8	0.8	0.2	58.6	16.2	24.0	1.1	-41.5	-12.4	-23.2	**-77.1**	**-0.8**
	LV		1.4	8.5	35.8		8.2	3.6	0.9		-6.8	4.9	34.9	**33.0**	**-**
	MX		0.0	0.2	0.0		0.0	4.3	1.9		-	-4.1	-1.9	**-6.0**	**-**
Total		**1,806.6**	**-**	**-**		**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Source: own elaboration.
Note: DE: domestic extraction; M: imports. X: exports; PTB: physical trade balance; DoP: degree of processing; RAW: raw materials; SM: semimanufactured; MN: manufactured; AG agriculture biomass; LV: livestock biomass; MX: mixed biomass.

Table 3.4	**Agriculture, livestock and mixed biomass: international biophysical trade flows, accumulated 1996-2010 (Part 3)**

Unit		Mt	Mt	Mt	-	Mt	Mt	Mt	-	Mt	Mt	Mt	Mt	-
Indicator		M	M	M	M/DE	X	X	X	X/DE	PTB	PTB	PTB	**PTB**	**PTB/DE**
DoP		RAW	SM	MN	ALL	RAW	SM	MN	ALL	RAW	SM	MN	**ALL**	**ALL**
Andalucía	AG	31.0	5.6	3.4	0.1	48.1	7.5	1.4	0.2	-17.1	-1.9	2.1	**-17.0**	0.0
	LV	0.8	0.0	0.1	-	1.4	0.0	0.1	-	-0.5	-0.01	0.02	**-0.5**	-
	MX	0.0	14.9	1.3	-	0.0	9.5	1.5	-	0.0	5.5	-0.2	**5.3**	-
Aragón	AG	8.9	0.9	0.9	0.1	3.3	3.7	0.4	0.1	5.5	-2.8	0.5	**3.2**	0.0
	LV	0.8	0.1	0.0	-	2.1	0.1	0.0	-	-1.3	-0.1	0.0	**-1.4**	-
	MX	0.0	0.5	0.1	-	0.0	0.9	0.3	-	0.0	-0.4	-0.3	**-0.7**	-
Asturias	AG	1.6	0.3	0.1	0.1	0.1	0.7	0.0	0.0	1.5	-0.4	0.1	**1.2**	0.0
	LV	1.1	0.0	0.0		0.64	0.09	0.04		0.4	-0.1	0.0	**0.3**	-
	MX	0.0	0.4	0.1		0.0	0.1	0.1		0.0	0.3	0.0	**0.3**	-
Baleares	AG	2.0	0.2	0.1	0.2	0.4	0.1	0.0	0.0	1.6	0.1	0.1	**1.8**	0.1
	LV	0.1	0.0	0.0	-	0.0	0.0	0.0		0.1	0.0	0.0	**0.1**	-
	MX	0.0	0.2	0.1	-	0.0	0.0	0.0		0.0	0.2	0.1	**0.3**	-
Canarias	AG	7.7	0.9	1.2	0.5	3.7	0.0	0.0	0.2	4.1	0.8	1.2	**6.1**	0.3
	LV	1.6	0.0	0.0	-	0.0	0.0	0.0		1.6	0.0	0.0	**1.6**	-
	MX	0.0	1.0	0.8	-	0.0	0.2	0.1		0.0	0.8	0.7	**1.5**	-
Cantabria	AG	2.0	0.5	0.4	0.1	0.1	0.2	0.8	0.0	2.0	0.3	-0.4	**1.9**	0.1
	LV	0.1	0.0	0.0		0.1	0.0	0.0		0.0	0.0	0.0	**0.0**	-
	MX	0.0	1.1	0.0		0.0	0.2	0.0		0.0	0.9	0.0	**0.9**	-
Castilla y León	AG	7.4	1.5	3.1	0.0	4.7	1.9	3.6	0.0	2.7	-0.4	-0.6	**1.8**	0.0
	LV	2.8	0.1	0.0		2.4	0.2	0.0		0.4	-0.1	0.0	**0.3**	-
	MX	0.0	1.4	0.1		0.0	0.0	0.5		0.0	1.4	-0.3	**1.0**	-
Castilla-La Mancha	AG	0.9	0.6	0.7	0.0	1.5	1.8	0.2	0.0	-0.6	-1.3	0.5	**-1.4**	0.0
	LV	0.9	0.1	0.0		1.53	0.04	0.01		-0.66	0.02	0.00	**-0.6**	-
	MX	0.0	0.5	0.5		0.0	0.6	5.4		0.0	-0.1	-4.9	**-5.0**	-
Cataluña	AG	105.3	43.5	13.2	1.426	14.8	9.8	3.8	0.3	90.6	33.6	9.4	**133.5**	1.2
	LV	6.0	1.2	0.5		10.2	0.6	0.2		-4.2	0.6	0.3	**-3.4**	-
	MX	0.0	38.9	2.6		0.0	12.5	2.7		0.0	26.4	-0.1	**26.3**	-

Source: own elaboration.
Note: DE: domestic extraction; M: imports. X: exports; PTB: physical trade balance; DoP: degree of processing; RAW: raw materials; SM: semimanufactured; MN: manufactured; AG agriculture biomass; LV: livestock biomass; MX: mixed biomass.

Table 3.5 **Agriculture, livestock and mixed biomass: international biophysical trade flows, accumulated 1996-2010 (Part 4)**

Unit		Mt	Mt	Mt	-	Mt	Mt	Mt	-	Mt	Mt	Mt	Mt	-
Indicator		M	M	M	M/DE	X	X	X	X/DE	PTB	PTB	PTB	**PTB**	**PTB/DE**
DoP		RAW	SM	MN	ALL	RAW	SM	MN	ALL	RAW	SM	MN	**TOTAL**	**TOTAL**
Extremadura	AG	2.7	1.4	0.2	0.0	3.4	3.4	0.3	0.0	-0.7	-2.0	-0.2	-2.9	0.0
	LV	0.3	0.0	0.0	-	0.4	0.0	0.0	-	0.0	0.0	0.0	0.0	-
	MX	0.0	0.6	0.1	-	0.0	1.2	1.0	-	0.0	-0.6	-0.9	-1.5	-
Galicia	AG	17.3	3.9	0.8	0.2	1.6	0.4	0.1	0.0	15.7	3.5	0.7	20.0	0.2
	LV	1.4	0.1	0.0	-	2.6	0.1	0.0	-	-1.3	0.0	0.0	-1.3	-
	MX	0.0	10.7	0.3	-	0.0	3.0	1.0	-	0.0	7.7	-0.7	7.0	-
Madrid	AG	19.7	3.8	4.7	1.6	3.3	1.2	1.5	0.3	16.4	2.6	3.2	22.3	1.3
	LV	4.2	0.0	0.4	-	1.7	0.1	0.0	-	2.4	-0.1	0.4	2.7	-
	MX	0.0	8.8	1.3	-	0.0	1.3	0.3	-	0.0	7.5	1.0	8.5	-
Murcia	AG	23.5	7.1	1.3	0.6	28.5	7.0	1.0	0.7	-5.0	0.2	0.3	-4.5	-0.1
	LV	0.4	0.3	0.0	-	0.4	0.2	0.0	-	-0.1	0.2	0.0	0.1	-
	MX	0.0	7.0	0.2	-	0.0	1.0	1.2	-	0.0	6.1	-1.1	5.0	-
Navarra	AG	4.0	1.5	0.4	0.1	2.6	3.6	0.2	0.2	1.4	-2.1	0.2	-0.5	0.0
	LV	0.3	0.0	0.0	-	0.4	0.0	0.0	-	-0.1	0.0	0.0	-0.1	-
	MX	0.0	0.8	0.1	-	0.0	0.4	0.4	-	0.0	0.4	-0.3	0.1	-
Pais Vasco	AG	8.8	3.2	3.1	0.5	0.2	0.5	4.2	0.2	8.6	2.7	-1.1	10.2	0.4
	LV	0.7	0.0	0.0	-	0.2	0.0	0.0	-	0.4	0.0	0.0	0.5	-
	MX	0.0	2.9	0.2	-	0.0	1.5	0.3	-	0.0	1.4	-0.2	1.3	-
Rioja	AG	1.0	0.5	0.4	0.1	0.6	0.8	0.3	0.1	0.4	-0.3	0.1	0.2	0.0
	LV	0.1	0.0	0.0	-	0.1	0.0	0.0	-	0.0	0.0	0.0	0.0	-
	MX	0.0	0.2	0.0	-	0.0	0.2	0.7	-	0.0	0.0	-0.7	-0.7	-
Valencia	AG	21.0	5.0	2.6	0.3	56.1	4.7	1.0	0.7	-35.1	0.4	1.5	-33.2	-0.4
	LV	1.7	0.9	0.2	-	0.7	0.4	0.1	-	1.0	0.6	0.2	1.8	-
	MX	0.0	2.2	0.5	-	0.0	1.3	2.0	-	0.0	0.8	-1.5	-0.6	-

Source: own elaboration.
Note: DE: domestic extraction; M: imports. X: exports; PTB: physical trade balance; DoP: degree of processing; RAW: raw materials; SM: semimanufactured; MN: manufactured; AG agriculture biomass; LV: livestock biomass; MX: mixed biomass.

Madrid and Cataluña are also net overall importers of all types of biomass in overall terms although their traits significantly differ. Madrid is a net importer for all categories of biomass at all degrees of processing except for semimanufactured animal products, particularly dairy products, for which is a net exporter both in the interregional and international context. Overall imports of agriculture products are more than three times larger than its DE. Indeed, overall net imports of animal products alone are larger than the DE of agricultural biomass. Except for raw agricultural biomass for which imports from other AC's and from abroad are more balanced, for the rest of categories most of the biophysical exchanges of Madrid occur with the rest of the Spanish regions, particularly exports.

For its part, Cataluña played differing roles in the interregional and international context. International imports of agricultural biomass were 42.6% larger than DE whereas net imports were 17.6% above DE. By contrast, Cataluña was a net exporter of agricultural biomass in the interregional market, though net exports are 16.5% of DE and one order magnitude below international net imports. Regarding animal products its role cannot be attributed since the signs of the PTB for different degrees of processing does not permit a conclusive insight. Net interregional exports of mixed biomass can be attributed mainly to oil and fat which in any case reinforces the interregional exporting role of Cataluña regarding agricultural products. International net imports of mixed biomass are mostly wastes from the food industry which in turn supports the net importing role of Cataluña in the international market.

Castilla-La Mancha was a net overall provider of all types of biomass. Regarding agricultural biomass, net exports of biomass at all degrees of processing were observed at regional level with aggregated exports around 51.9% of its DE. The same role cannot be confirmed at international level since the sign of manufactured products is positive whereas for raw and semimanufactured products it is negative. Animal products registered a positive PTB at regional level although the PTB of semimanufactured and manufactured animal products is negative and close to the net imports of raw materials which implies that despite the positive resulting PTB Castilla-La Mancha could indeed be an interregional net exporter of animal products. As for mixed biomass, the role of net exporter is supported by the sign of all degrees of processing at regional and international revel.

Castilla y León could also be attributed a role of overall net supplier, since both the individual PTB for agriculture and animal products is negative, and the positives PTB of mixed biomass cannot offset any of them. The PTB is formed on one hand by large amounts of net interregional exports of agricultural products (26.5% of DE) and animal products, net interregional imports of mixed biomass and net international imports of agriculture, animal and mixed biomass on the other hand. International net imports are configured so that the role of net importer cannot be confirmed according to the signs of the balances for the different degrees of processing.

Other regions were the role of overall net suppliers of agricultural products can be inferred are Valencia, Murcia, and La Rioja where the sign for both the three degrees of processing is negative. Also, in Navarra where overall net exports of semimanufactured and manufactured products are larger than net imports of raw materials. For all of them their role as interregional supplier is supported by the sign of their net interregional exports whereas in the international market their roles cannot be confirmed. When data on animal products is added to the analysis, Valencia and Rioja are net importers which nuances their next exports of agricultural products whereas the structure of the PTB is not conclusive in Navarra whereas in Murcia the sign could even be the opposite (i.e. net importer) given the structure of its regional PTB.

The overall roles of Asturias as a net importer of agricultural products and overall net exporter of animal products can also be depicted at regional level whereas it is not possible at international level.

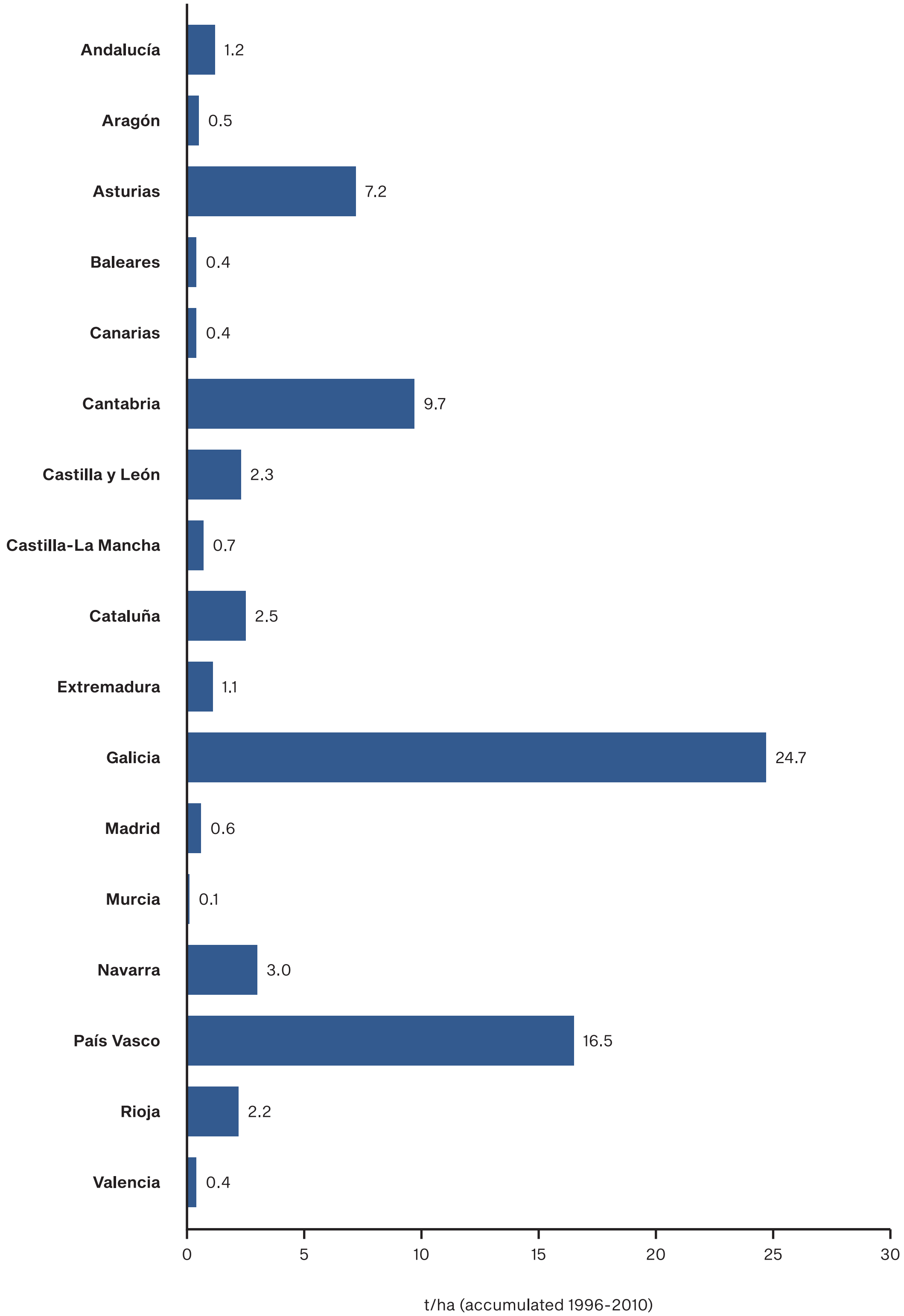
In the case of Andalucía, Aragón, Cantabria, and Extremadura their overall, interregional and international roles could not be ascertained given the composition of their PTB. Only in the case of Extremadura its role as net interregional exporter and net international exporter of agricultural products seems plausible given the structure of the PTB.

3.4.2 Forest biomass

Forest biomass extraction in Spain concentrated in the northern regions where environmental conditions are favourable for wood production (particularly in terms of precipitation), but also because of dedicated forest management policies devoted to the industrial production of eucalyptus and pine wood during the 20^{th} century (Vadell *et al.* 2016).

Galicia accumulated 46.5% of the Spanish DE while representing 5.8% of the Spanish surface. Similarly, País Vasco extracted 7.6% of total forest biomass extraction whereas its territory represents 1.4% of the Spanish surface (Figure 3.4). Both AC led the figures on accumulated (1996-2010) extraction per hectare with 24.7 t/ha in Galicia and 16.5 t/ha in País Vasco, followed by two additional northern regions: Cantabria (9.7 t/ha) and Asturias (7.2 t/ha). The rest of the AC showed accumulated values below 3.0 t/ha.

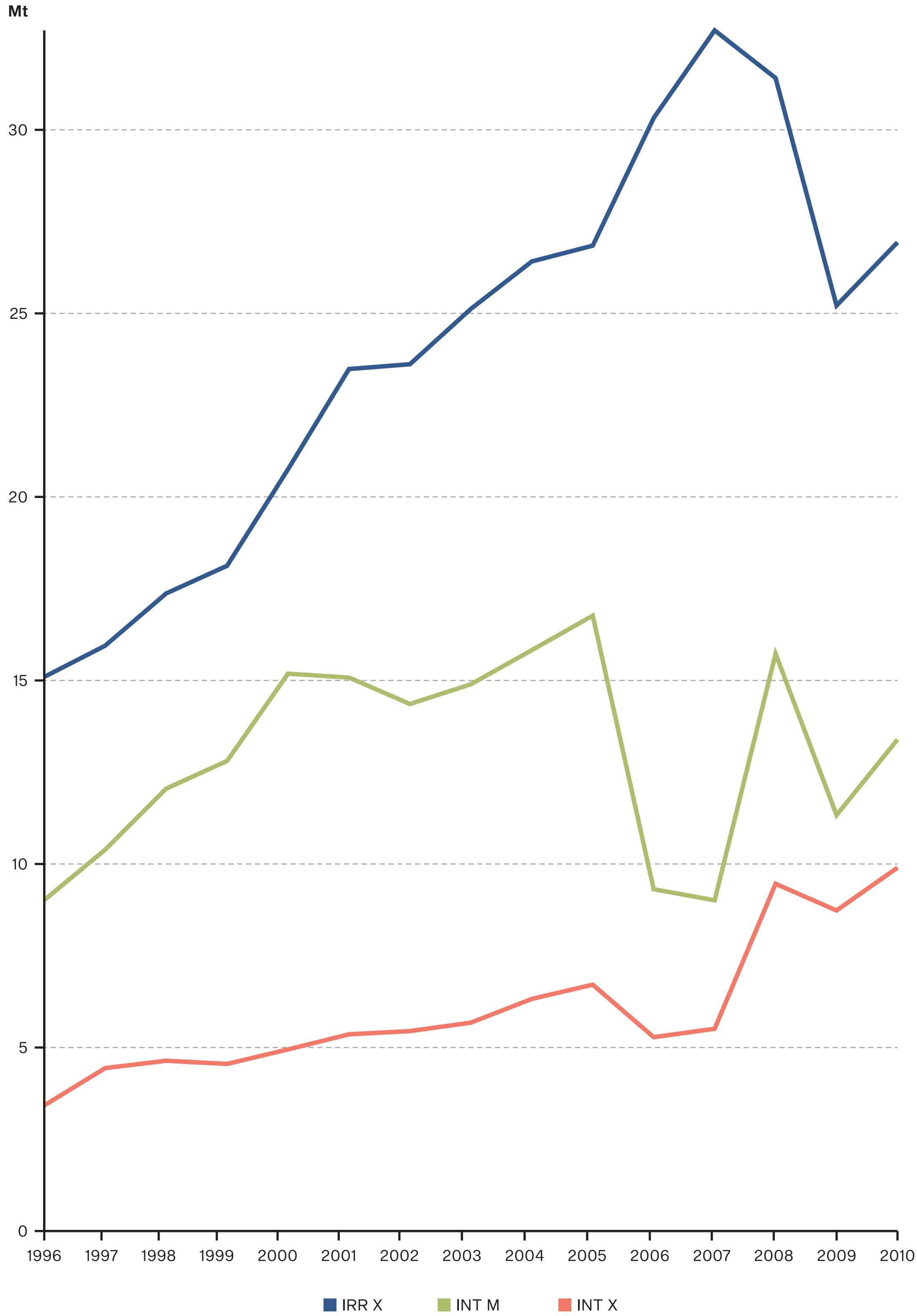
Figure 3.4 **Domestic extraction of forest biomass accumulated 1996-2010**



Source: own elaboration.

Regarding biophysical trade, both interregional and international biophysical exchanges followed a clear increasing path between 1996 and 2007. Interregional exports more than doubled due to a sharp increase of interregional trade of raw and manufactured products, whereas semimanufactured products followed an erratic path. In the international arena, exports almost tripled with a significant growth of raw materials (more than five-fold). International imports also increased although below two-fold, which in any case remained far above international exports.

Figure 3.5 Biophysical trade flows of forest biomass in Spain (1996-2010)



Source: own elaboration.
Note: IRR: interregional; INT: international; X exports; M: imports.

The volume of forest biomass in raw and semimanufactured forms exchanged with the rest of the world was larger than the volume of interregional biophysical exchanges for these products (Table 3.6 and Table 3.7). However, the opposite is true for manufactured products, for which interregional biophysical exports more than doubled the international biophysical volume of trade.

International imports of raw, semimanufactured and manufactured forest biomass products were 55.4% of overall DMI with a large share of semimanufactured and manufactured products. This means that in terms of raw material equivalent, the Spanish dependency on international forest biomass should be expected to be even sharper. This role can be attributed to 12 out of the 17 AC, which registered net positive international PTB for both raw, semimanufactured and manufactured forest biomass-related products. Of these, only in three regions imports were below DE (Galicia, Castilla-La Mancha and Castilla y León) which points to a significant disconnection between the AC's processing and consumption of forest biomass from local extraction. The magnitude of the international aggregated PTB was particularly striking in Madrid where it reached up to 39.9 times its DE.

Table 3.6 **Forest biomass: domestic extraction and interregional biophysical trade flows, accumulated 1996-2010**

Unit	Mt	Mt	Mt	Mt	-	Mt	Mt	Mt	-	Mt	Mt	Mt	-
Indicator	DE	M	M	M	*M/DE*	X	X	X	*X/DE*	PTB	PTB	PTB	***PTB/DE***
DoP	RAW	RAW	SM	MN	*ALL*	RAW	SM	MN	*ALL*	RAW	SM	MN	***ALL***
Andalucía	10.5	1.2	4.5	22.9	2.7	1.9	1.5	16.0	1.8	-0.7	3.0	6.9	***0.9***
Aragón	2.5	4.2	6.5	23.2	13.5	0.7	3.4	28.2	12.9	3.5	3.1	-5.0	***0.6***
Asturias	7.7	0.3	6.5	5.1	1.5	1.8	4.0	7.4	1.7	-1.4	2.4	-2.3	***-0.2***
Baleares	0.2	0.2	0.0	0.8	4.8	0.0	0.0	0.7	3.2	0.2	0.0	0.2	***1.5***
Canarias	0.3	1.1	0.0	1.3	8.6	0.0	0.6	0.3	3.3	1.1	-0.6	1.0	***5.3***
Cantabria	5.1	0.3	1.6	3.6	1.1	2.1	5.1	8.0	3.0	-1.8	-3.5	-4.4	***-1.9***
Castilla y León	22.1	4.7	9.5	19.4	1.5	2.9	10.0	24.8	1.7	1.8	-0.6	-5.4	***-0.2***
Castilla-La Mancha	5.2	6.0	8.8	33.0	9.2	3.7	8.0	34.6	8.9	2.3	0.8	-1.6	***0.3***
Cataluña	8.2	1.0	4.0	43.0	5.9	2.5	3.1	34.7	4.9	-1.5	0.9	8.2	***0.9***
Extremadura	4.5	0.5	0.6	3.1	0.9	1.5	1.3	2.3	1.2	-1.0	-0.8	0.8	***-0.2***
Galicia	73.0	0.8	3.5	12.4	0.2	1.3	13.9	17.1	0.4	-0.5	-10.4	-4.7	***-0.2***
Madrid	0.5	1.5	3.3	35.9	89.9	0.9	1.3	27.1	64.9	0.5	2.0	8.8	***25.0***
Murcia	0.1	0.6	2.4	10.2	154.2	1.2	0.7	7.0	103.7	-0.6	1.8	3.2	***50.5***
Navarra	3.2	1.7	2.6	9.9	4.5	0.8	2.6	10.1	4.3	0.9	0.0	-0.2	***0.2***
Pais Vasco	11.9	2.2	6.4	18.9	2.3	2.2	8.9	27.2	3.2	0.0	-2.5	-8.3	***-0.9***
Rioja	1.1	0.4	1.6	4.2	5.7	0.6	1.2	3.8	5.2	-0.3	0.5	0.4	***0.5***
Valencia	0.9	3.1	1.0	0.1	4.7	3.2	5.2	34.1	47.3	-0.1	-4.2	-34.0	***-42.7***
Total	**156.9**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Source: own elaboration.
Note: DE: domestic extraction; M: imports. X: exports; PTB: physical trade balance; DoP: degree of processing; RAW: raw materials; SM: semimanufactured; MN: manufactured.

Table 3.7 **Forest biomass: international biophysical trade flows, accumulated 1996-2010**

Unit	Mt	Mt	Mt	-	Mt	Mt	Mt	-	Mt	Mt	Mt	-
Indicator	M	M	M	M/DE	X	X	X	X/DE	PTB	PTB	PTB	***PTB/DE***
DoP	RAW	SM	MN	ALL	RAW	SM	MN	ALL	RAW	SM	MN	***TOTAL***
Andalucía	8.3	13.3	2.1	2.3	0.4	4.1	1.6	0.6	7.9	9.2	0.6	1.7
Aragón	1.5	7.2	1.1	3.9	0.1	0.6	7.1	3.1	1.4	6.5	-6.1	0.7
Asturias	0.6	0.9	0.3	0.3	0.0	2.8	0.1	0.4	0.6	-1.8	0.3	-0.1
Baleares	0.0	0.5	0.2	3.6	0.0	0.0	0.0	0.1	0.0	0.5	0.2	3.6
Canarias	0.0	0.9	2.2	10.8	0.0	0.3	0.3	2.1	0.0	0.6	1.9	8.7
Cantabria	1.8	2.8	3.3	1.5	0.5	0.9	0.4	0.3	1.3	1.9	2.9	1.2
Castilla y León	2.2	4.8	2.1	0.4	1.0	2.6	1.7	0.2	1.3	2.3	0.4	0.2
Castilla-La Mancha	0.3	1.9	1.3	0.7	0.1	0.5	0.6	0.2	0.3	2.8	1.6	0.9
Cataluña	2.8	15.0	16.3	4.2	1.0	4.6	13.6	2.4	1.8	10.4	2.7	1.8
Extremadura	0.2	0.5	0.3	0.2	0.7	1.2	0.0	0.4	-0.5	-0.7	0.2	-0.2
Galicia	9.5	16.2	1.7	0.4	2.8	13.8	1.1	0.2	6.7	2.4	0.6	0.1
Madrid	0.2	6.5	17.6	53.8	0.0	1.3	4.9	13.9	0.2	5.1	12.7	39.9
Murcia	0.1	0.8	0.6	16.6	0.0	0.3	0.1	4.5	0.1	0.5	0.5	12.1
Navarra	2.0	4.9	0.8	2.4	1.2	1.5	2.9	1.8	0.8	3.3	-2.2	0.6
Pais Vasco	3.0	9.3	4.1	1.4	0.1	1.2	6.5	0.6	2.9	8.1	-2.3	0.7
Rioja	0.5	1.1	0.2	1.6	0.0	0.4	0.0	0.5	0.5	0.6	0.2	1.2
Valencia	1.6	12.4	6.9	23.3	0.1	3.5	1.4	5.5	1.5	8.9	5.6	17.8
Total	**34.6**	**99.0**	**61.1**	**1.2**	**8.0**	**39.6**	**42.3**	**0.6**	**26.7**	**60.8**	**19.6**	**0.7**

Source: own elaboration.
Note: DE: domestic extraction; M: imports. X: exports; PTB: physical trade balance; DoP: degree of processing; RAW: raw materials; SM: semimanufactured; MN: manufactured.

In the interregional context, up to five regions can be attributed a net interregional exporter role. Three of them coincide with those registering large DE/ha figures: Galicia, País Vasco and Cantabria). In these regions its interregional PTB balanced out international net imports so they can be generally conceptualised as global suppliers of forest-related biomass, however their structural features are different. Cantabria is a net exporter of both raw, semimanufactured and manufactured products and its overall negative PTB corresponds to 71.8% of its DE. Galicia is a net exporter of semimanufactured and manufactured products while being an overall net importer of raw materials; net exports represent 8.1% of DE. País Vasco's exports of manufactured forest products (18.9% of DE) offset net imports of both raw and semimanufactured products. Furthermore, Castilla y León is also a net exporter of semimanufactured and manufactured forest biomass products whose figures offset its net imports of raw materials.

Valencia appeared as the most relevant net interregional exporter of manufactured forest biomass-related products although this region does not have significant DE nor imports of raw and semimanufactured products. This implies that for the case of Valencia, manufactured products (notably furniture) mostly made of wood but also containing large proportion of other materials such as textiles and metals are clearly distorting these accounts. Considering its low DE, Valencia has a strong wood related industry, exporting large amounts of products to the rest of AC, at the expense of net international imports.

Among those AC for whose overall interregional role remained uncertain, Aragón, Castilla-La Mancha and Navarra showed net interregional imports of raw and semimanufactured forest biomass products while manufactured product resulted into net exports, which might point to dynamic wood transformation industries, particularly in Navarra and Aragón where the same role is played regarding international trade.

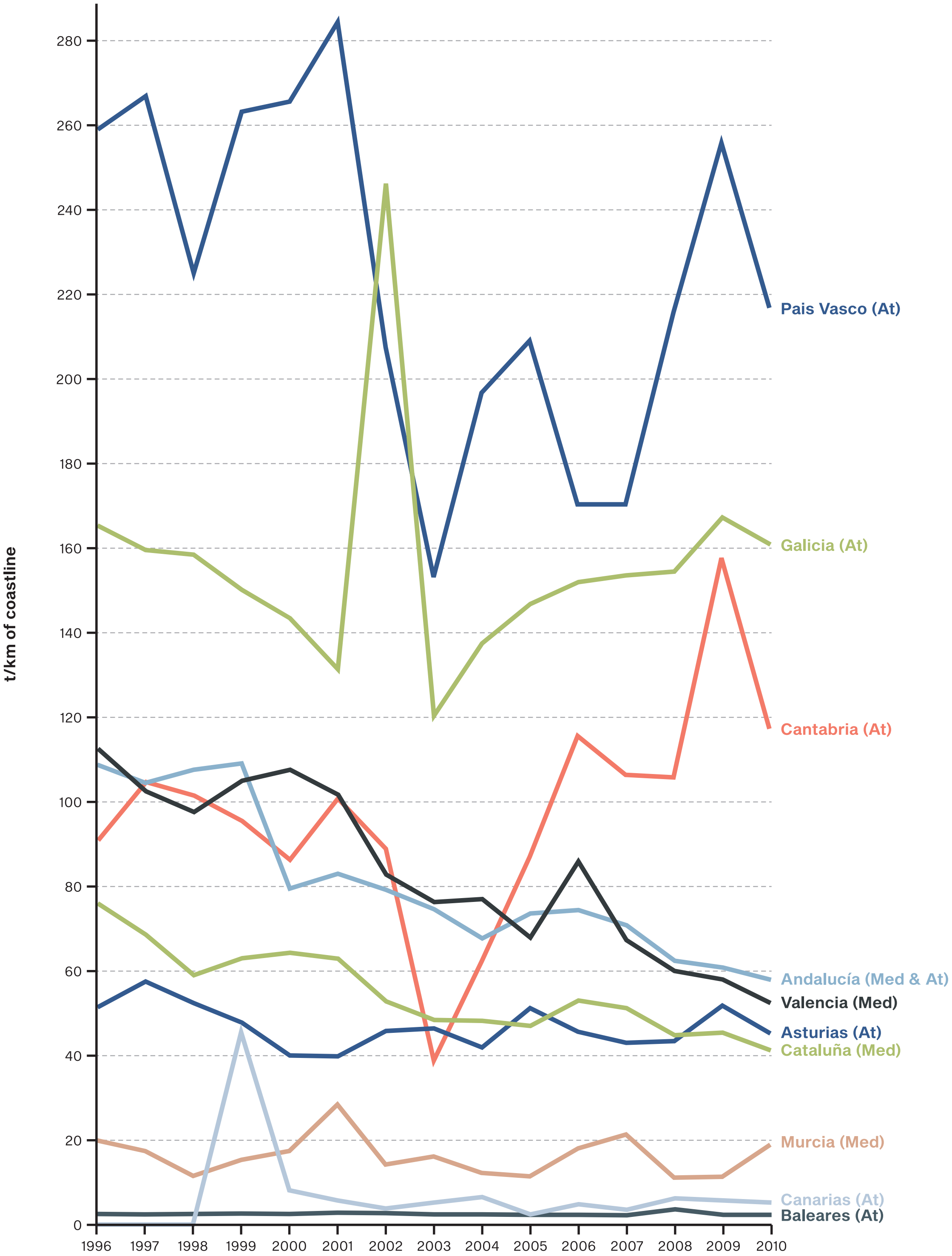
Andalucía, Murcia and Rioja played the opposite role, exporting raw forest biomass to the rest of AC while importing semimanufactured and manufactured products, being the 3 of them importers of forest biomass from the rest of the worlds in the three degrees of processing.

3.4.3 Fish biomass

Almost the whole of DE of fish biomass were captures from marine waters at coastal regions[10]. Figure 3.6 displays DE per km of coastline for the Spanish coastal regions. Differing values were found with a leading role of the Atlantic regions. Pais Vasco stood out with average figures of 224 t/km of coastline followed by Galicia (157 t/km) and Cantabria (97 t/km). In the Mediterranean basin, Andalucía and Valencia led with average values over 80 t/km followed by Cataluña (55 t/km). Both these three regions registered steady decreasing trends of about 50% in captures between 1996 and 2010 while the northern regions showed oscillating trends but no significant reductions. The lowest values were found in the islands.

[10] See section 3.3 for methodological details of what DE means in the context of fish biomass. No significant amounts of continental fish biomass were registered.

Figure 3.6 **Domestic extraction of marine fish biomass in the Spanish coastal regions, 1996-2010**



Source: own elaboration.
Note: At: Atlantic Ocean; Med: Mediterranean Sea.

As for the interregional market (Table 3.8) Cantabria and Galicia could be attributed the role of net suppliers. In both cases exports are well above their DE so this role was necessarily subsidised by international imports or unaccounted DE (see the dedicated methodological note on fishing above in this chapter). In Cantabria, the overall PTB was slightly positive (6.6% of DE) whereas in Galicia overall net exports surpassed DE by 50% resulting into a negative DMC figure. As it was exposed in section 2.4, it is acknowledged that imports and domestic extraction is underestimated when fishing statistics are considered for EW-MFA purposes at regional level. According to Galicia's fishing statistics, DE of fish biomass from aquaculture non requiring external fed were around 200 kt/year. This amount would add up 3 Mt to Galicia's DE leaving the overall PTB below 1.0 Mt.

For its part, Rioja registered net interregional exports of fish biomass even though it is an inner region. Since for inner regions international imports should be easy to identify, our hypothesis in this case is that either interregional imports or/and exports of fish biomass were somehow wrongly registered.

Table 3.8 Fish biomass: domestic extraction and interregional biophysical trade flows, accumulated 1996-2010

Unit	Mt	Mt	Mt	Mt	-	Mt	Mt	Mt	-	Mt	Mt	Mt	-
Indicator	DE	M	M	M	M/DE	X	X	X	X/DE	PTB	PTB	PTB	***PTB***
DoP	RAW	RAW	SM	MN	ALL	RAW	SM	MN	ALL	RAW	SM	MN	***ALL***
Andalucía	1.15	2.82	0.46	0.00	2.9	1.97	0.15	0.00	1.8	0.86	0.31	0.00	***1.16***
Aragón	0.00	1.31	0.06	0.00	-	0.89	0.10	0.00	-	0.42	-0.03	0.00	***0.38***
Asturias	0.26	0.28	0.69	0.06	4.0	0.00	0.44	0.05	1.9	0.28	0.26	0.00	***0.00***
Baleares	0.05	0.29	0.10	0.00	7.3	0.06	0.03	0.00	1.6	0.23	0.08	0.00	***0.31***
Canarias	0.16	0.05	0.02	0.00	0.5	0.18	0.02	0.00	1.2	-0.13	0.01	0.00	***-0.12***
Cantabria	0.41	0.66	0.06	0.00	1.7	0.87	0.08	0.00	2.3	-0.21	-0.02	0.00	***-0.23***
Castilla y León	0.01	1.86	0.24	0.00	-	0.84	0.06	0.00	-	1.02	0.18	0.00	***1.20***
Castilla-La Mancha	0.01	0.98	0.17	0.00	-	0.31	0.04	0.00	-	0.67	0.13	0.00	***0.80***
Cataluña	0.58	3.26	0.56	0.00	6.6	1.97	0.09	0.00	3.6	1.29	0.46	0.00	***1.75***
Extremadura	0.04	0.43	0.05	0.00	13.7	0.05	0.02	0.00	2.0	0.39	0.03	0.00	***0.41***
Galicia	3.52	1.83	0.08	0.00	0.5	8.89	2.05	0.00	3.1	-7.06	-1.97	0.00	***-9.03***
Madrid	0.00	4.48	0.64	0.00	-	2.42	0.13	0.00	-	2.06	0.52	0.00	***2.58***
Murcia	0.07	1.76	0.16	0.00	28.7	0.73	0.07	0.00	12.0	1.03	0.09	0.00	***1.12***
Navarra	0.00	0.42	0.09	0.00	-	0.34	0.10	0.00	-	0.07	0.00	0.00	***0.07***
Pais Vasco	0.83	2.33	0.36	0.00	3.3	2.91	0.32	0.00	3.9	-0.59	0.05	0.00	***-0.54***
Rioja	0.00	0.19	0.05	0.00	-	0.40	0.18	0.00	-	-0.21	-0.13	0.00	***-0.34***
Valencia	0.6	0.1	4.9	0.0	7.7	3.3	0.3	0.0	5.6	-3.22	4.58	0.00	***1.4***
Total	**7.7**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Source: own elaboration.
Note: DE: domestic extraction; M: imports. X: exports; PTB: physical trade balance; DoP: degree of processing; RAW: raw materials; SM: semimanufactured; MN: manufactured.

Table 3.9 **Fish biomass: international biophysical trade flows, accumulated 1996-2010**

Unit	Mt	Mt	Mt	-	Mt	Mt	Mt	-	Mt	Mt	Mt	
Scope	INT	INT	INT	IRR	INT	INT	INT	IRR	INT	INT	INT	***INT***
Indicator	M	M	M	M/DE	X	X	X	X/DE	PTB	PTB	PTB	***PTB***
DoP	RAW	SM	MN	ALL	RAW	SM	MN	ALL	RAW	SM	MN	***TOTAL***
Andalucía	1.37	0.00	0.00	1.2	0.61	0.00	0.00	0.5	0.75	0.00	0.00	***0.75***
Aragón	0.50	0.00	0.00	-	0.02	0.00	0.00	-	0.48	0.00	0.00	***0.48***
Asturias	0.11	0.00	0.00	0.4	0.01	0.00	0.00	0.0	0.10	0.00	0.00	***0.10***
Baleares	0.03	0.00	0.00	0.5	0.00	0.00	0.00	0.0	0.03	0.00	0.00	***0.03***
Canarias	1.07	0.00	0.00	6.6	0.57	0.00	0.00	3.5	0.50	0.00	0.00	***0.50***
Cantabria	0.37	0.00	0.00	0.9	0.11	0.00	0.00	0.3	0.26	0.00	0.00	***0.26***
Castilla y León	0.37	0.00	0.00	-	0.07	0.00	0.00	-	0.30	0.00	0.00	***0.30***
Castilla-La Mancha	0.04	0.00	0.00	-	0.02	0.00	0.00	-	0.02	0.00	0.00	***0.02***
Cataluña	2.01	0.00	0.00	3.5	0.61	0.00	0.00	1.1	1.39	0.00	0.00	***1.39***
Extremadura	0.02	0.00	0.00	-	0.03	0.00	0.00	0.7	-0.01	0.00	0.00	***-0.01***
Galicia	8.33	0.00	0.00	2.4	4.74	0.00	0.00	1.3	3.59	0.00	0.00	***3.59***
Madrid	1.48	0.00	0.00	-	0.20	0.00	0.00	-	1.28	0.00	0.00	***1.28***
Murcia	0.30	0.00	0.00	4.5	0.22	0.00	0.00	3.3	0.08	0.00	0.00	***0.08***
Navarra	0.30	0.00	0.00	-	0.04	0.00	0.00	-	0.26	0.00	0.00	***0.26***
Pais Vasco	1.22	0.00	0.00	1.5	1.08	0.00	0.00	1.3	0.13	0.00	0.00	***0.13***
Rioja	0.05	0.00	0.00	-	0.00	0.00	0.00	-	0.04	0.00	0.00	***0.04***
Valencia	1.5	0.0	0.0	2.4	0.4	0.0	0.0	0.6	1.1	0.0	0.0	***1.1***
Total	**19.1**	**0.0**	**0.0**	**23.7**	**8.7**	**0.0**	**0.0**	**14.5**	**10.3**	**0.0**	0.0	***10.3***

Source: own elaboration.
Note: DE: domestic extraction; M: imports. X: exports; PTB: physical trade balance; DoP: degree of processing; RAW: raw materials; SM: semimanufactured; MN: manufactured.

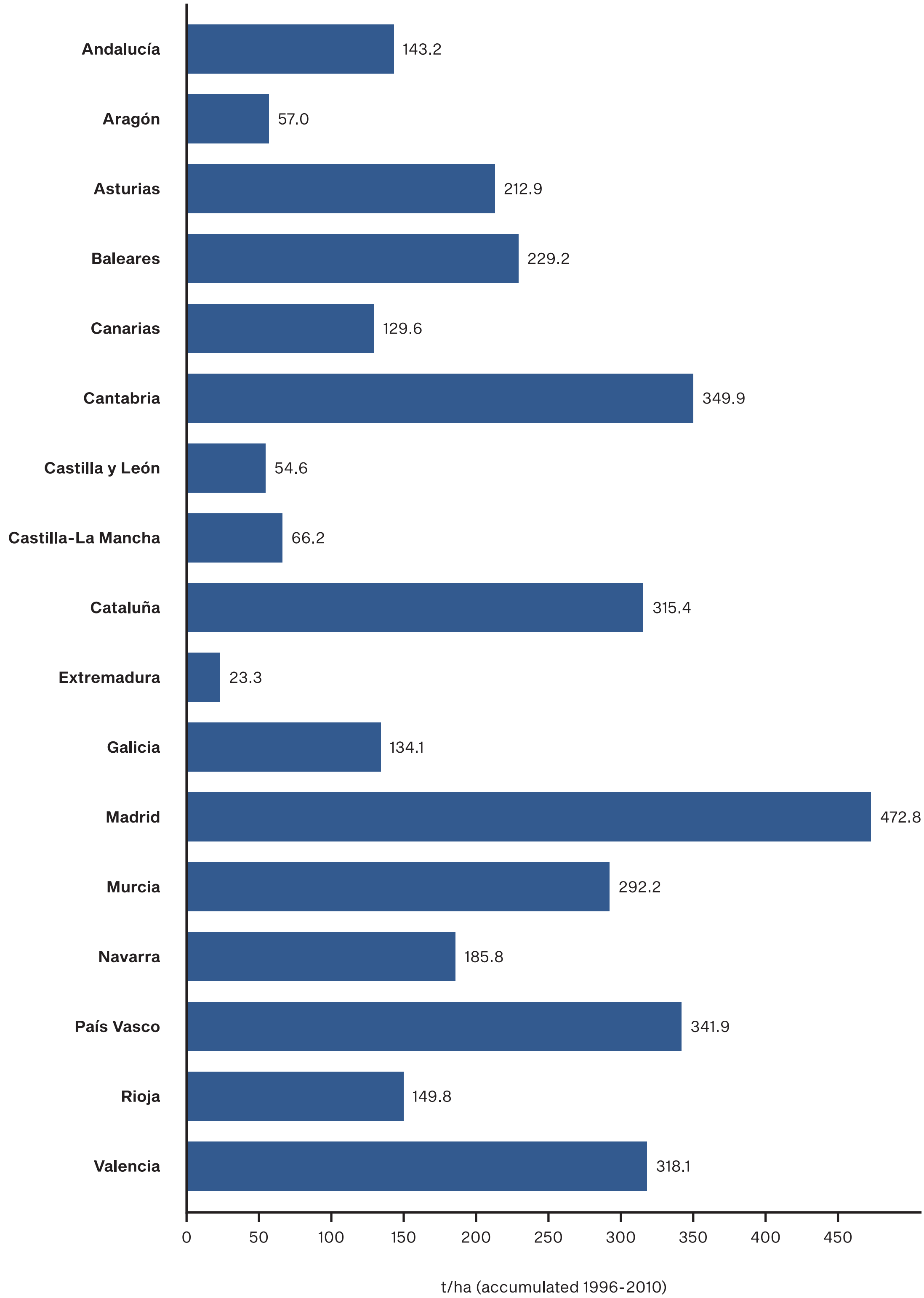
International imports[11] (Table 3.9) were 71.2% of overall DMI, which implies that DE provided less than 25% of the AC's fish biomass demand in Spain. Considering aquaculture in Galicia would diminish dependency figures, though. International imports provided fish biomass equivalent to 6.6 times DE in Canarias, 3.5 in Murcia, 2.4 in Galicia and Valencia, and 1.2 in Andalucía. International PTB/DE was also well above 1.0 in these regions except in Galicia where international imports approximately equalled DE. In Cantabria, Asturias and Pais Vasco this figure was below one. Therefore, it is confirmed that most of the Spanish regions, both inner and coastal, rely on fish biomass captured out of Spanish jurisdictional waters.

3.4.4 Non-metallic minerals

Non-metallic minerals comprise industrial minerals and construction minerals. Accumulated (1996-2010) DE of non-metallic minerals reached 6,661 Mt, which accounts for 73.7% of overall DE. In terms of accumulated DE in tonnes per hectare, Spain's average figure was 131.7 t/ha. Madrid more than tripled this value with 472.8 t/ha and other regions such as Cantabria, Pais Vasco, Cataluña and Murcia were more than twice above the average. The opposite occurred in Extremadura where accumulated extraction was below 20% the average value, whereas in Aragon and Castilla y León it was less than half.

[11] International imports of fish includes captures from international waters not belonging to any particular country's jurisdiction, captures in other countries' jurisdictions and semimanufactured and manufactured fish products from other countries.

Figure 3.7 Domestic extraction of non-metallic minerals, accumulated 1996-2010



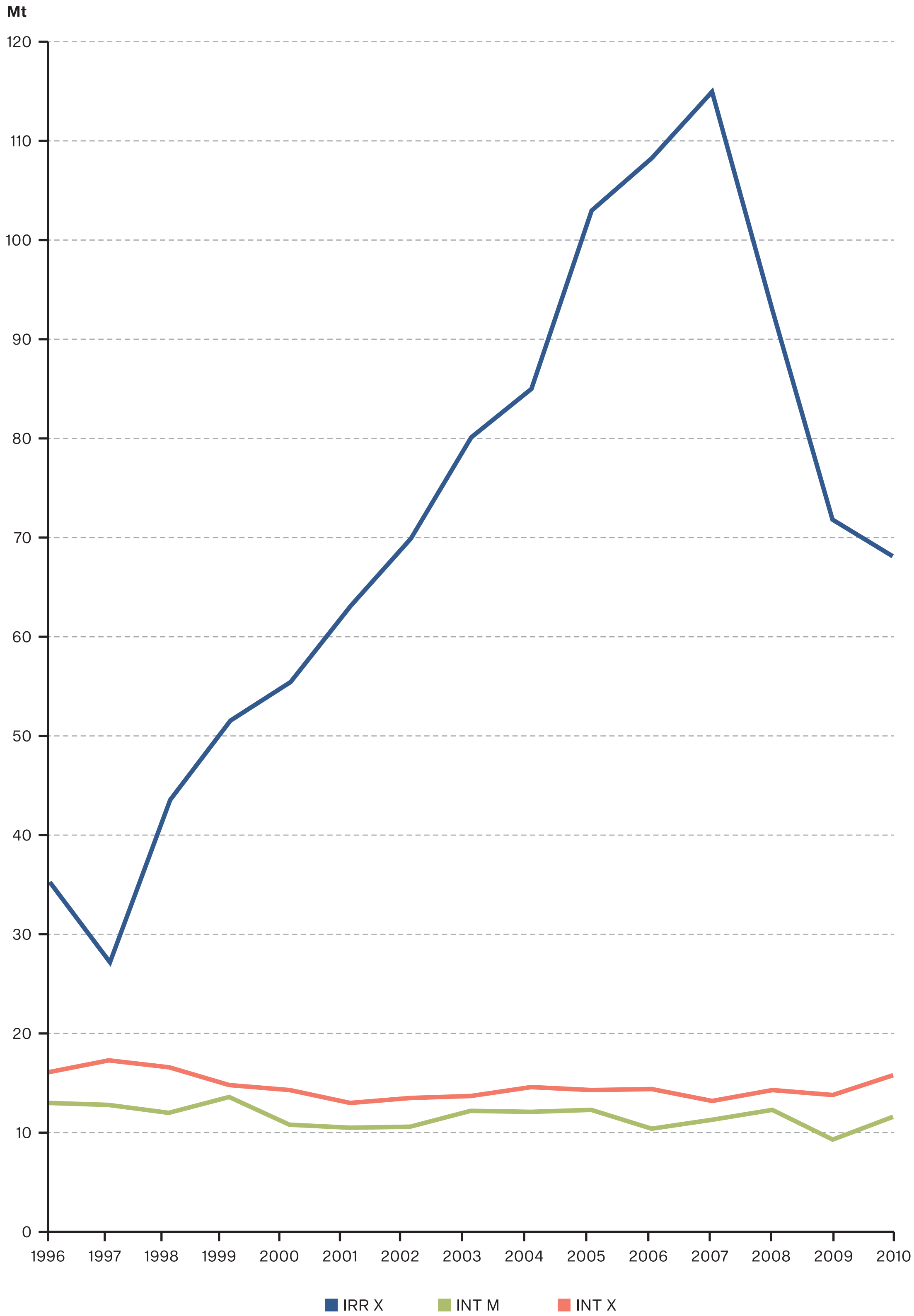
Source: own elaboration.

International imports of raw non-metallic minerals were 108.6 Mt and related semimanufactured forms of these materials reached 140.0 Mt. Together they added up the equivalent to 3.7% of DE which is a low figure as compared to those found for biomass products. For its part 153.6 Mt of raw non-metallic minerals and 64.7 Mt of semimanufactured product were exported resulting into an overall PTB of 30 Mt.

As anticipated in chapter 2, interregional biophysical trade of non-metallic minerals was more dynamic than international biophysical trade. Accumulated interregional exports of non-metallic minerals (1,070.1 Mt) were 2.7 times the accumulated international volume of trade. Overall, an amount equivalent to 16.1% of DE of non-metallic minerals was exchanged between regions.

Regarding trends (Figure 3.8) between 1996 and 2010, whereas international imports and exports remained relatively constant, interregional exports experienced a sharp increase, tripling by 2006 and remaining at almost twice the figure of 1996 by the end of the period. Indeed, interregional exports grew faster than both DE and GDP.

Figure 3.8 **Biophysical trade flows of non-metallic minerals in Spain (1996-2010)**



Source: own elaboration.
Note: IRR: interregional; INT: international; X exports; M: imports.

Focusing on biophysical trade profiles, three regions could be attributed overall net exports since both raw and semimanufactured products have the same sign. These are Castilla-La Mancha where net exports reached 22.6% of DE, Rioja (15.9%) and Navarra (14.4%). These three regions have in common their role as net exporters in the interregional context, however only Navarra was also a net international exporter whereas for the other regions their role cannot be ascertained. In any case, interregional imports and exports are up to two order magnitude above international imports and exports, so the overall PTB is certainly conditioned by their interregional role.

Table 3.10 Non-metallic minerals: domestic extraction and interregional biophysical trade flows, accumulated 1996-2010

Unit	Mt	Mt	Mt	-	Mt	Mt	-	Mt	Mt	-	
Indicator	DE	M	M	M/DE	X	X	X/DE	PTB	PTB	***PTB***	***PTB/DE***
DoP	RAW	RAW	SM	ALL	RAW	SM	ALL	RAW	SM	***ALL***	***ALL***
Andalucía	1,254.3	15.3	40.7	0.04	22.7	46.2	0.05	-7.4	-5.5	***-12.9***	***-0.01***
Aragón	271.9	18.4	28.2	0.17	36.0	28.6	0.24	-17.6	-0.4	***-18.0***	***-0.07***
Asturias	225.7	13.7	11.6	0.11	5.3	26.2	0.14	8.4	-14.6	***-6.2***	***-0.03***
Baleares	114.4	0.8	5.8	0.06	0.3	0.7	0.01	0.5	5.0	***5.5***	***0.05***
Canarias	96.5	0.2	10.8	0.11	0.0	0.1	0.00	0.2	10.6	***10.8***	***0.11***
Cantabria	186.2	19.2	11.7	0.17	13.1	15.3	0.15	6.1	-3.6	***2.4***	***0.01***
Castilla y León	514.5	24.9	55.0	0.16	87.4	34.4	0.24	-62.5	20.6	***-42.0***	***-0.08***
Castilla-La Mancha	526.1	55.1	56.2	0.21	114.6	114.1	0.43	-59.5	-57.9	***-117.4***	***-0.22***
Cataluña	1,012.7	28.7	33.4	0.06	19.5	32.8	0.05	9.2	0.6	***9.8***	***0.01***
Extremadura	97.0	5.8	28.7	0.36	6.7	6.4	0.14	-0.9	22.3	***21.4***	***0.22***
Galicia	396.6	15.9	31.4	0.12	10.2	9.1	0.05	5.7	22.3	***28.0***	***0.07***
Madrid	379.5	108.2	93.0	0.53	48.6	37.4	0.23	59.6	55.6	***115.2***	***0.30***
Murcia	330.6	24.3	42.2	0.20	52.0	31.1	0.25	-27.7	11.1	***-16.6***	***-0.05***
Navarra	193.0	19.0	13.7	0.17	35.1	23.7	0.30	-16.1	-10.0	***-26.1***	***-0.14***
Pais Vasco	247.2	61.1	29.1	0.36	17.2	20.4	0.15	43.8	8.6	***52.5***	***0.21***
Rioja	75.6	14.6	13.9	0.38	19.7	15.6	0.47	-5.1	-1.6	***-6.8***	***-0.09***
Valencia	739.7	99.3	56.8	0.21	36.0	103.1	0.19	63.3	-46.4	***16.9***	***0.02***
Total	**6,661.4**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Source: own elaboration.
Note: DE: domestic extraction; M: imports. X: exports; PTB: physical trade balance; DoP: degree of processing; RAW: raw materials; SM: semimanufactured.

Table 3.11	**Non-metallic minerals: international biophysical trade flows, accumulated 1996-2010**

Unit	Mt	Mt	-	Mt	Mt	-	Mt	Mt	Mt	-
Indicator	M	M	M/DE	X	X	X/DE	PTB	PTB	**PTB**	PTB/DE
DoP	RAW	SM	ALL	RAW	SM	ALL	RAW	SM	**TOTAL**	TOTAL
Andalucía	26.3	34.6	0.0	56.1	7.7	0.1	-29.8	26.9	**-2.8**	0.00
Aragón	1.0	3.0	0.0	3.3	0.6	0.0	-2.3	2.4	**0.1**	0.00
Asturias	1.8	1.6	0.0	6.2	1.4	0.0	-4.4	0.1	**-4.3**	-0.02
Baleares	0.1	2.0	0.0	0.4	0.0	0.0	-0.4	2.0	**1.6**	0.01
Canarias	9.9	18.5	0.3	0.0	0.0	0.0	9.9	18.5	**28.4**	0.29
Cantabria	0.5	2.1	0.0	3.0	2.9	0.0	-2.5	-0.9	**-3.4**	-0.02
Castilla y León	0.9	3.6	0.0	3.8	0.5	0.0	-2.9	3.1	**0.2**	0.00
Castilla-La Mancha	0.4	0.7	0.0	2.7	0.1	0.0	-2.3	0.6	**-1.7**	0.00
Cataluña	16.7	12.4	0.0	21.1	27.9	0.0	-4.4	-15.4	**-19.9**	-0.02
Extremadura	0.8	0.3	0.0	1.6	0.2	0.0	-0.8	0.1	**-0.7**	-0.01
Galicia	6.8	6.0	0.0	24.0	1.6	0.1	-17.2	4.4	**-12.8**	-0.03
Madrid	1.5	7.5	0.0	8.2	1.8	0.0	-6.7	5.8	**-0.9**	0.00
Murcia	0.7	12.7	0.0	2.6	1.2	0.0	-1.9	11.5	**9.6**	0.03
Navarra	1.1	1.1	0.0	2.2	1.8	0.0	-1.1	-0.6	**-1.8**	-0.01
Pais Vasco	6.5	2.2	0.0	2.1	6.3	0.0	4.4	-4.2	**0.2**	0.00
Rioja	0.0	0.0	0.0	0.2	0.0	0.0	-0.1	0.0	**-0.1**	0.00
Valencia	28.8	31.5	0.1	16.2	10.5	0.0	12.6	21.0	**33.6**	0.05
Total	**103.7**	**140.0**	**0.7**	**153.6**	**64.7**	**0.4**	**-49.9**	**75.3**	**25.4**	0.0

Source: own elaboration.
Note: DE: domestic extraction; M: imports. X: exports; PTB: physical trade balance; DoP: degree of processing; SM: semimanufactured.

Other overall net exporting regions are Asturias, Cantabria and Cataluña were net exports of semimanufactured products overcome net imports of raw materials. In these three regions the exporting PTB is below 5% of DE. Asturias could be attributed a role of net interregional exporter whereas the opposite is true for Cataluña and Cantabria's interregional role would be uncertain. In the international arena, Cataluña and Cantabria accumulated net exports whereas Asturias would remain uncertain.

On the side of overall net importers, this role seems clear in Madrid, País Vasco and the islands where both overall raw and semimanufactured products registered net imports. Within this group of regions, Canarias and Madrid stood out with overall net imports reaching 40.6% and 30.1% of DE respectively. In the case of Madrid interregional imports were 53.0% of DE, being Madrid's DE the highest across the AC. For its part, Canarias was the only region were international exchanges surpassed its interregional volume of trade, which is reasonable given its geographical location. In the case of Extremadura and Galicia the overall positive accumulated PTB was formed by large net imports of semimanufactured products surpassing net exports of raw materials.

All these six regions were net importers in the interregional context whereas in the international market their roles differed. Canarias showed net imports for all degrees of processing. País Vasco played a net international exporter role supported by net international exports of semimanufactured products larger than their net imports of raw materials. Baleares' net international importer role is grounded on large imports of semimanufactured products. For the rest of the regions, no international role could be attributed.

3.5 Discussion

3.5.1 EBS related to agricultural and animal products

For those AC for which commercial roles can be attributed, the profiles are varied. Baleares, Canarias are clearly dependant on the rest of Spain and the rest of the world in order to supply themselves with food related products. Besides local agriculture and fishing patterns might have been abandoned at some point during the Spanish economy's transformation and integration into the EU (Hercowitz 2001, Carpintero 2005, Murray 2015), the growing specialisation of these island in mass tourism should be conditioning the metabolism of both archipelagos (Murray 2012, Ginard-Bosch and Ramos-Martín 2016).

Madrid registered net imports for all categories except for a slightly negative PTB for semimanufactured livestock products, particularly dairy products, which impedes assigning a net importer role to the region according to our criteria. However, given the magnitude of net imports for the rest of the products (e.g. more threefold its DE for agricultural products), it would not be surprising that Madrid had been playing the role of net importer from both the rest of Spain and the rest of the world. This is a common case among capital cities-regions specialised in services and disconnected from its local environment for food supply (Barles 2009, Rosado *et al.* 2014). In fact this could have been the case for Madrid since the eighties (Frías and Naredo 1987) and the most recent studies still reach similar conclusions (Rama *et al.* 2021).

Two complementary types of commercial roles can be identified for those regions being net importers of agricultural biomass and exporters of livestock products and vice versa. In the first group we could find Asturias and Cantabria and likely Galicia (Piñero *et al.* 2020), whereas La Rioja and Valencia would play the complementary role.

The case of Catalonia depicts a region that is transforming international biomass and channelling their products into the interregional market, which fits well with the powerful food industry located in that region. Also, the case of Castilla-La Mancha illustrates the (nuanced) case for net exporter regions both in the interregional and international arena.

All in all, even if there are information gaps, particularly regarding livestock, a first scratch on the allocation of environmental burdens related to agricultural and livestock products can be drafted through this approach.

Table 3.12 **Biophysical trade of agriculture biomass, livestock biomass and mixed biomass in Spain at subnational level (1996-2020), roles and magnitude**

Material	Agriculture						Livestock/Animal			Mixed		
Indicator	Role			PTB/DE			Role			Role		
Scope	IRR	INT	OVA	IRR	INT	OVA	IRR	INT	OVA	IRR	INT	OVA
Andalucía	-	-	-	-	-	-	M	-	M	-	-	X
Aragón	-	-	-	-	-	-	-	-	-	M	X	-
Asturias	M	-	M	0,4	-	0,4	X	-	X	-	M	M
Baleares	M	M	M	0,5	0,1	0,6	M	M	M	M	M	M
Canarias	M	M	M	0,2	0,3	0,6	M	M	M	M	M	M
Cantabria	M	-	-	0,1	-	-	-	X	-	M	M	M
Castilla y León	-	-	-	-	-	-	X	-	X	M	-	-
Castilla-La Mancha	X	-	X	-0,2	-	-0,2	X	-	X	X	X	X
Cataluña	X	M	M	-0,2	1,2	1,0	-	-	-	X	-	-
Extremadura	M	X	-	0,1	0,0	-	-	-	-	X	X	X
Galicia	M	M	M	0,2	0,2	0,4	-	-	-	-	-	-
Madrid	M	M	M	2,0	1,3	3,3	-	-	-	M	M	M
Murcia	X	-	X	-0,2	-	-0,2	-	-	-	X	-	-
Navarra	X	-	X	-0,1	-	-0,2	-	-	-	M	-	-
Pais Vasco	M	-	M	0,1	-	0,4	-	M	-	X	-	-
Rioja	X	-	X	-0,2	-	-0,2	M	M	M	X	X	X
Valencia	X	-	X	-0,8	-	-1,2	M	M	M	X	-	X

Source: own elaboration.
Note: PTB: physical trade balance; DE: domestic extraction; IRR: interregional; INT: international; OVA: overall; M: net importer; X: net exporter.

3.5.2 EBS related to forest biomass

Regarding forest biomass, all regions for which an international role could be attributed registered net imports which confirms a general dependency on other countries' forest resources. The magnitude highly varies ranging from Madrid, where there is not significant extraction and international net imports surpass DE by 40 times, to large extractors such as Galicia, País Vasco and Castilla y León where this share is below one. In the interregional context only those regions with significant DE values could be attributed net interregional exporter roles whereas the rest where net interregional importers led by Madrid and Murcia. Overall, there seemed to exist a certain specialisation pattern on forest biomass across northern regions justified by meteorological and policy reasons. Galicia and more intensely Cantabria could be potentially being burdened by other Spanish AC although both rely on imports from abroad.

Table 3.13 Biophysical trade of forest biomass in Spain at subnational level (1996-2020), roles and magnitude

Indicator	Role			PTB/DE		
Scope	IRR	INT	OVA	IRR	INT	OVA
Andalucía	M	M	M	9,3	17,8	2,6
Aragón	-	-	-	-	-	-
Asturias	-	-	-	-	-	-
Baleares	M	M	M	0,3	0,8	5,1
Canarias	-	M	M	-	2,5	14,0
Cantabria	X	M	X	-9,8	6,1	-0,7
Castilla y León	X	M	-	-4,1	4,0	-
Castilla-La Mancha	-	M	M	-	4,6	1,2
Cataluña	M	M	M	7,7	14,9	2,8
Extremadura	-	-	-	-	-	-
Galicia	X	M	X	-15,6	9,7	-0,1
Madrid	M	M	M	11,3	18,0	64,9
Murcia	M	M	M	4,3	1,0	62,7
Navarra	-	-	-	-	-	-
Pais Vasco	X	-	-	-10,9	-	-
Rioja	M	M	M	0,6	1,3	1,7
Valencia	-	M	-	-38,3	15,9	-

Source: own elaboration.
Note: PTB: physical trade balance; DE: domestic extraction; IRR: interregional; INT: international; OVA: overall; M: net importer; X: net exporter.

3.5.3 EBS related to fish biomass

Environmental burdens derived from fish biomass are clearly put on coastal regions since continental captures are negligible. Besides methodological concerns, it remains clear that Spain is displacing fish consumption burdens towards world common fisheries. Both Cantabria and Galicia are net interregional exporters of fish biomass which reflects specialisation on the one hand and a certain ecological status that permitted such extraction and exports on the other hand. The same cannot be said about the Mediterranean basin, whose regions saw a general decline in captures and a general dependency on both interregional and international inputs.

The case of fish biomass is interesting to reflect on whether any commercial amount of any material at any administrative level should be considered and environmental burden shifting. As discussed below, environmental burden "allocation" might be a better concept to describe these phenomena when the system under study does not have the capacity to make significant extractions of specific products, which becomes more common as we focus on smaller subnational units.

Table 3.14 Biophysical trade of fish biomass in Spain at subnational level (1996-2020), roles and magnitude

Indicator	Role			PTB/DE		
Scope	IRR	INT	OVA	IRR	INT	OVA
Andalucía	M	M	M	1,0	0,7	1,7
Aragón	-	M	M	*	*	*
Asturias	M	M	M	0,0	0,4	2,5
Baleares	M	M	M	5,7	0,5	6,1
Canarias	-	M	M	-0,7	3,1	2,3
Cantabria	X	M	M	-0,6	0,6	0,1
Castilla y León	M	M	M	*	*	*
Castilla-La Mancha	M	M	M	*	*	*
Cataluña	M	M	M	3,0	2,4	5,5
Extremadura	M	X	M	*	*	*
Galicia	X	M	X	-2,6	1,0	-1,5
Madrid	M	M	M	*	*	*
Murcia	M	M	M	16,7	1,2	17,8
Navarra	M	M	M	*	*	*
Pais Vasco	-	M	-	-0,7	0,2	-0,5
Rioja	-	M	-	*	*	*
Valencia	-	M	M	2,1	1,7	10,9

Source: own elaboration.
*Note: PTB: physical trade balance; DE: domestic extraction; IRR: interregional; INT: international; OVA: overall; * means inner region, with non-existent or very low continental fish biomass extraction. Source: Own elaboration; M: net importer; X: net exporter.*

3.5.4 EBS related to non-metallic minerals

As expected, there is a sharp concentration of non-metallic minerals trade in the interregional market. In general, the profiles already identified in the previous chapter can be confirmed through these methodological developments in the present one. Madrid and País Vasco successfully displaced the burden of quarries towards nearby regions, e.g. Castilla-La Mancha, Asturias, La Rioja, Navarra and Cantabria. In the case of Madrid, net imports reached up to 30% of DE which is a high figure considering the significant share of transport in the costs of these materials. The counter part is found in Castilla-La Mancha where an amount equivalent to 22% of DE was deemed to be exported (very likely to Madrid and Valencia).

For the case of non-metallic minerals, semimanufactured product might have lower raw material equivalents as compared other products. In this sense, this approach hides regions with large and very low transformation capacity for non-metallic minerals into semimanufactured products as compared to DE. For example, Valencia has a large transformation capacity. Valencia registered large net imports of raw materials that surpassed net exports of semimanufactured products, therefore under our approach it would be playing an uncertain role. However, the fact that Valencia's raw imports is 1.4 times semimanufactured net exports makes Valencia a very likely net importing region of non-metallic minerals since the raw material equivalents related to cement and similar products is often lower than 1.4. Following the same rationale, Castilla y León is classified as uncertain being net raw exports 3 times larger than semimanufactured net exports. This is a clear flaw of this approach. In the absence of proper raw material equivalent accounts it could be fine-tuned using tone/tone raw material equivalent factors for key products such as cement.

Table 3.15 Biophysical trade of non-metallic minerals in Spain at subnational level (1996-2020), roles and magnitude

Material	Non-metallic minerals					
Indicator	Role			PTB/DE		
Scope	IRR	INT	OVA	IRR	INT	OVA
Andalucía	X	-	-	-0,01	-	-
Aragón	X	M	-	-0,07	0,0	-
Asturias	X	-	X	-0,03	-	-0,05
Baleares	M	-	M	0,05	-	0,06
Canarias	M	M	M	0,11	0,3	0,41
Cantabria	-	X	X	-	0,0	-0,01
Castilla y León	-	M	-	-	0,0	-
Castilla-La Mancha	X	-	X	-0,22	-	-0,23
Cataluña	M	X	X	0,01	0,0	-0,01
Extremadura	M	-	M	0,22	-	0,21
Galicia	M	-	M	0,07	-	0,04
Madrid	M	-	M	0,30	-	0,30
Murcia	-	M	-	-	0,0	-
Navarra	X	X	X	-0,14	0,0	-0,14
Pais Vasco	M	-	M	0,21	-	0,21
Rioja	X	-	X	-0,09	-	-0,16
Valencia	-	M	-	-	0,0	-

Source: own elaboration.
Note: PTB: physical trade balance; DE: domestic extraction; IRR: interregional; INT: international; OVA: overall; M: net importer; X: net exporter.

3.5.5 Methodological issues and limitations

Three main methodological challenges have been faced along this chapter. The first is dealing with direct flows, which jeopardises the analytical power derived from our database. Ten years after the last year registered in our series no relevant improvements have occurred regarding data availability at regional level (e.g. input output tables at subnational level are not available for all AC), so direct flows remain the best available approach if the whole of the Spanish regions are to be addressed. To alleviate this limitation, biophysical trade flows have been split into 3 categories according to their degree of processing: raw, semimanufactured and manufactured. Analysing the sign of these three categories allows for further insight in order to profile each region as net importer/exporter. When the sign of these three categories converged, it has been assumed that the profile indicated by the sign could be attributed. Furthermore, when the magnitude of semimanufactured and manufactured products was larger and of opposite sign than that of raw materials, it has been assumed that the profile indicated by semimanufactured and manufactured products could be attributed. This assumption is grounded in the fact that processed commodities have a raw material equivalent equal to or larger than one. When none of these conditions were accomplished, the role of the AC has been considered uncertain. In addition, it has been assumed that imports and exports of semimanufactured and manufactured products are homogenous regarding their raw material equivalents. This approach is intended to spot the most evident profiles regarding the AC roles as net exporter/importer in the interregional, international and overall context.

Given the relevance of semimanufactured and manufactured products in the Spanish international and interregional biophysical trade, either omitting or aggregating these flows might lead to very different results. However, the uncertainties faced when these flows are analysed as direct flows cannot be skipped either. In this sense, further insight and validation can only be provided by proper raw material equivalent accounts. In the meantime, partial validation can be searched for in studies applying raw material equivalents to individual AC. To the author's knowledge, results in both Galicia (Piñero *et al.* 2020) and País Vasco (Garmendia *et al.* 2016) have reached similar conclusions to those obtained in this chapter.

The second limitation is related to the fact that high-level aggregation material flow categories might not be appropriate when it comes to approach environmental burdens and their shifting through trade. As a response to this limitation, material flow categories have been analysed separately. This decision is related to the fact that when PTB are calculated, we should not allow the compensation between non-homogenous material flow categories, otherwise the resulting indicators might become confusing from an environmental point of view. In any case, the methodological choices made in this regard are open to further discussion to find a compromise for EW-MFA indicators, and particularly PTB, to be environmentally sound and manageable. Ideally, the more homogenous the material flow categories analysed the more meaningful becomes PTB as an indicator for EBS.

Related to the above, the third limitation emerges when it comes to measure and compare the magnitude of environmental burden shifting. As noted in section 2.3, PTB faces several issues as a measurement of environmental burden shifting. We have opted by relating imports, exports and PTB to DE in order to approach the amount of DE avoided though imports or driven by exports and, in this particular sense, "shifted" or "taken" through trade. Considering that our database deals with direct flows, the interest of the resulting figure is indicative at best, since three degrees of processing are mixed within the same calculation.

3.5.6 EW-MFA indicators do not properly indicate environmental pressures, impacts, etc.

The complex nature of EW-MFA as indicators human-environmental interactions has been pointed out since the early works in the field (Cleveland and Ruth 1998, Giljum 2004). However, the environmental interpretation of EW-MFA indicators in the literature often become lax. These are often referred as indicators of environmental/ecological **pressures** (Schütz, Moll, *et al.* 2004, Bruckner *et al.* 2012, Dittrich *et al.* 2012, Schoer *et al.* 2012, Sastre *et al.* 2015); to be **proxies** for environmental pressure (Krausmann *et al.* 2009, Haberl *et al.* 2019); or pointing environmental **impacts** (Giljum 2004, Bruckner *et al.* 2012, Dittrich *et al.* 2012, Haberl *et al.* 2019).

These causal relationships are often mentioned without defining what is understood by "pressure" or "impact". The widespread use of the DPSIR (driver, pressure, state, impact, response) framework (OECD 1993, EEA 1995, Ness *et al*. 2010) and the IPAT formula (Chertow 2000, Roca 2002) would make it a reasonable hypothesis to assume these definitions as the default implicit meaning of these terms. However, in practice its use is not backed up by any reference whereas the terms are often exchanged within the same text showing a certain inconsistency in their use. In general, the seldom nuanced (Infante-Amate and Krausmann 2019) assumption behind EW-MFA indicators seems to be "more tones implies more aggregate environmental impact/pressure" even though any EW-MFA practitioner is fully aware of this not being thorough.

It is my view that the unintended oversimplification of the environmental meaning of EW-MFA indicators might jeopardise its policy relevance in the long term. In consequence, the phenomenon EW-MFA are an indicator of may be better contained in the also widespread term **"burden"** (Schütz, Moll, *et al.* 2004, Bruckner *et al.* 2012, Dittrich *et al.* 2012, Wiedmann *et al.* 2015, Wiedmann and Lenzen 2018, Kolcava *et al.* 2019). The unspecific character of "burden" might be an advantage to comprehensively refer to the complex mix of the effects (be it pressure, impact, changes of state, etc.) derived from resource extraction an trade while avoiding an erratic use of terms such as environmental "pressure" and "impact" (Verones *et al.* 2017).

When it comes to using EW-MFA indicators to assess environmental burden shifting between territories[12], additional issues arise. Shifting in this context is widely understood as avoiding local raw material extraction by importing materials extracted somewhere else. Hence, any amount of biophysical trade is implicitly equalled to environmental burden shifting which might be certainly naïve in a globalised world. Under this framework, those systems registering biophysical net imports succeed in substituting the extraction of certain resources with imports, therefore shifting the environmental burden of resource extraction. Net exporters would be the other side of the coin, taking that burden. However, in certain systems and at certain scales, the unavailability of specific materials makes biophysical imports the only possible way for the provision of certain goods (e.g. metal ores, fossil fuels): a burden cannot be shifted if it cannot be taken in the first place. So, from a formal point of view environmental burden shifting could be better conceptualised as environmental burden **allocation**. In the case of Spain this is relevant for metal ores and fossil fuels for which imports could not be substituted with domestic extraction, therefore the environmental burden of the Spanish AC's consumption is allocated somewhere else.

[12] The term "environmental burden shifting" is also used in the context of life cycle as referred to between impact categories (Bohnes and Laurent 2019).

Related to the above, the use of indicators such as total PTB hinders the environmental interpretation of the indicator, since it allows for the offsetting between heterogeneous environmental burdens related to those materials comprising the PTB (e.g. the environmental burden of metal imports can offset the burden of biomass exports). As pointed out by other authors (Schoer *et al.* 2012), this issue can easily be overcome by breaking down biophysical trade flows by category (e.g. biomass, metals, non-metallic minerals, fossil fuels) when it is deemed to refer to their specific environmental burdens. Even if the environmental burden of biomass extraction might significantly differ between sites, these burdens seem reasonably homogenous as compared to those from metal ores. By making this distinction one can refer, for example, to the net environmental burdens of biomass extraction, which might be a more profitable indicator[13].

Integrating the points made above and considering the multiple drawbacks of our database, direct flows can yet be useful to track the environmental burden allocation of non-metallic minerals at subnational level given the specific features of these materials. Furthermore, it can provide an interim picture for biomass flows. However, the methodological limitations attached to the use of direct flows plus Spain's lacking endowment of fossil fuels and metals made the analysis uninteresting for these materials.

3.5.7 Concluding remarks and further research

According to the results of this chapter, interregional trade can be considered a mechanism to displace environmental burdens across the subnational units of a country. Despite the methodological limitations derived from the use of direct flows, specialisation in raw material extraction and clear roles as net importers/exporters of materials have been identified for biomass products and non-metallic minerals. This finding calls for further research on the methodological side (i.e. using RME accounts) and for attention on the dissimilar patterns occurring within countries, particularly in medium-sized and large ones.

Furthermore, in parallel to national income redistribution mechanisms, EBS at subnational levels might call for an extrapolation of this concept to the environmental field. Thus, it could be reasonable to design mechanisms to compensate/mitigate/restore the environmental burdens related to interregional trade.

Whereas in the international arena environmental justice and unequal trade issues are hardly addressed given the number of institutions and agents involved in global value chains, this task could be easier within the national domains. In the case of Spain, there are plenty of instruments to deal with EBS at subnational level (e.g. fiscal policy, regulation, market instruments, etc.). Although EBS is not currently an issue itself within the environmental agenda of the country, it could be synergistic with broader debates and policies such as rural depopulation (Collantes and Pinilla 2011, Pinilla and Sáez 2017, Mesa 2019, Viñas 2019), the need for an enhanced environmental fiscal policy in Spain (Puig-Ventosa *et al.* 2015), the implementation of EU -wide circular economy policies, public investment, industrial policy, etc.

Further refinement and the calculation of raw material equivalents would be required for EW-MFA indicators to support such policy design, though.

[13] Though the more detailed the material category the more environmentally meaningful the indicator, it must be acknowledged that some type of aggregation (and derived offsetting) is necessary for a compromise between consistency and manageability.

Chapter 4

Mind the gap: a model for the EU recycling target applied to the Spanish regions

The content of this chapter was published in *Waste Management* (Sastre *et al.* 2018). References have been revised and updated. Tables and figures have been revised and updated to fit within the format. Minor changes have been introduced to the main text.

4.1 Abstract

The recycling targets for municipal solid waste included in the EU Waste Framework Directive (WFD) are a relevant driver for sustainable waste management in the EU. According to the WFD, Member States should reach 50% recycling rate by 2020 while 65% was approved for 2035. The aims of this paper are 1) to formalise the WFD definition of recycling rate, by converting it into a model that permits a systematic comparison across systems; and 2) to test the model by using a case study, in order to explore the analytical insights derived from the results, focused on the gap between the current management situation and the EU targets. To this end, a model is presented for the case of Spain at the AC level, which is relevant because the Autonomous Communities have to comply with the EU recycling targets according to the Spanish National Waste Management Plan. Results show that most Spanish regions will have to undertake profound changes regarding waste management in order to comply with the WFD targets for 2020. These changes are related to increasing separate collection (of food and garden waste, particularly), improving waste treatment efficiency and limiting the disposal of unsorted waste. The model informs policy-makers about the gap between the current performance of a given system (country, region, municipality) and the WFD target and identifies trade-offs between management strategies. It also contributes to the debate on more ambitious targets and several methodological issues such as the relevance of having a consistent definition of "municipal solid waste" accompanied by waste-stream specific definitions of "recycling".

4.2 Introduction

Sustainable municipal solid waste (MSW) management is one of the main environmental concerns in the EU, for which waste management regulation plays a principal role (European Union 2013). The European Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008, on waste and repealing certain Directives (Waste Framework Directive, WFD), amended by Directive 2018/851, is a central piece of legislation in this context. The WFD has contributed to creating a common playing field regarding waste management in the EU, with the intention of increasing recycling and minimising landfilling across Member States (MS). Since the WFD was adopted, recycling of MSW in the EU grew from 36.8% in 2008 to 46.6% in 2017 (Eurostat 2019).

In this context, the recycling target has been a crucial driver for improvement of waste management. Article 11 (2) of the WFD states that *"by 2020, the preparing for re-use and the recycling of* [municipal solid] *waste materials such as at least paper, metal, plastic and glass from households and possibly from other origins as far as these waste streams are similar to waste from households, shall be increased to a minimum of overall 50% by weight"* (European Union 2008). This target has posed a challenge to the EU Member States, in terms of unifying MSW management criteria and accounting methods, that has resulted in dissimilar results across countries: although the average recycling rate in the EU was 46.6% in 2017, 12 countries were below 30.0%, whereas 8 countries had already reported 50.0% (Eurostat 2019). In 2015, the Circular Economy Package included a proposal to revise several legislative initiatives (i.e. including the WFD) and to implement an action plan with an aim of *""closing the loop" of product lifecycles through greater recycling and re-use, and bring benefits for both the environment and the economy"* (European Commission 2015a). This proposal resulted into the amendment of the WFD through the Directive 2018/851, including a revised MSW recycling target, set at 55% by 2025, 60% by 2030 and 65% by 2035 (European Union 2018a).

The aim of this chapter is twofold. Firstly, to formalise the WFD definition of recycling rate, by converting it into a model that permits a systematic comparison across systems (i.e. MS, regions, municipalities, etc.). Secondly, to test the model by using a case study, in order to explore the analytical insights derived from the results, focused on the gap between the current management situation and the EU targets. The case of the Spanish regions for the year 2014[14] have been chosen. On the one hand because the National Waste Management Plan requires the AC to achieve the recycling target that are set in the WFD. On the other hand, because of the dissimilar waste management approaches that have been adopted to date in each region.

[14] The choice of the reference year is according to the availability of data to feed the model.

4.3 Overview of municipal waste management in Spain

4.3.1 Spanish legal and administrative framework on waste management

According to Spanish Law 22/2011 of 28th July 2011 on Waste and Contaminated Soils, the competences for MSW management rely upon national, regional and local administrative bodies. At the national level, the Ministry for the Ecological Transition and for the Demographic Challenge (MITECO) is responsible for the implementation, amendments and enforcement of the Law. Moreover, the MITECO is in charge of developing National Waste Management Plans, which should include minimum quantitative targets beyond those outlined in the European Directives, qualitative goals and general policy orientations. Furthermore, the responsibility for the compliance with the WFD targets lies at the national level and the MITECO is the administrative body that is in charge of tracking and reporting progress back to the EU.

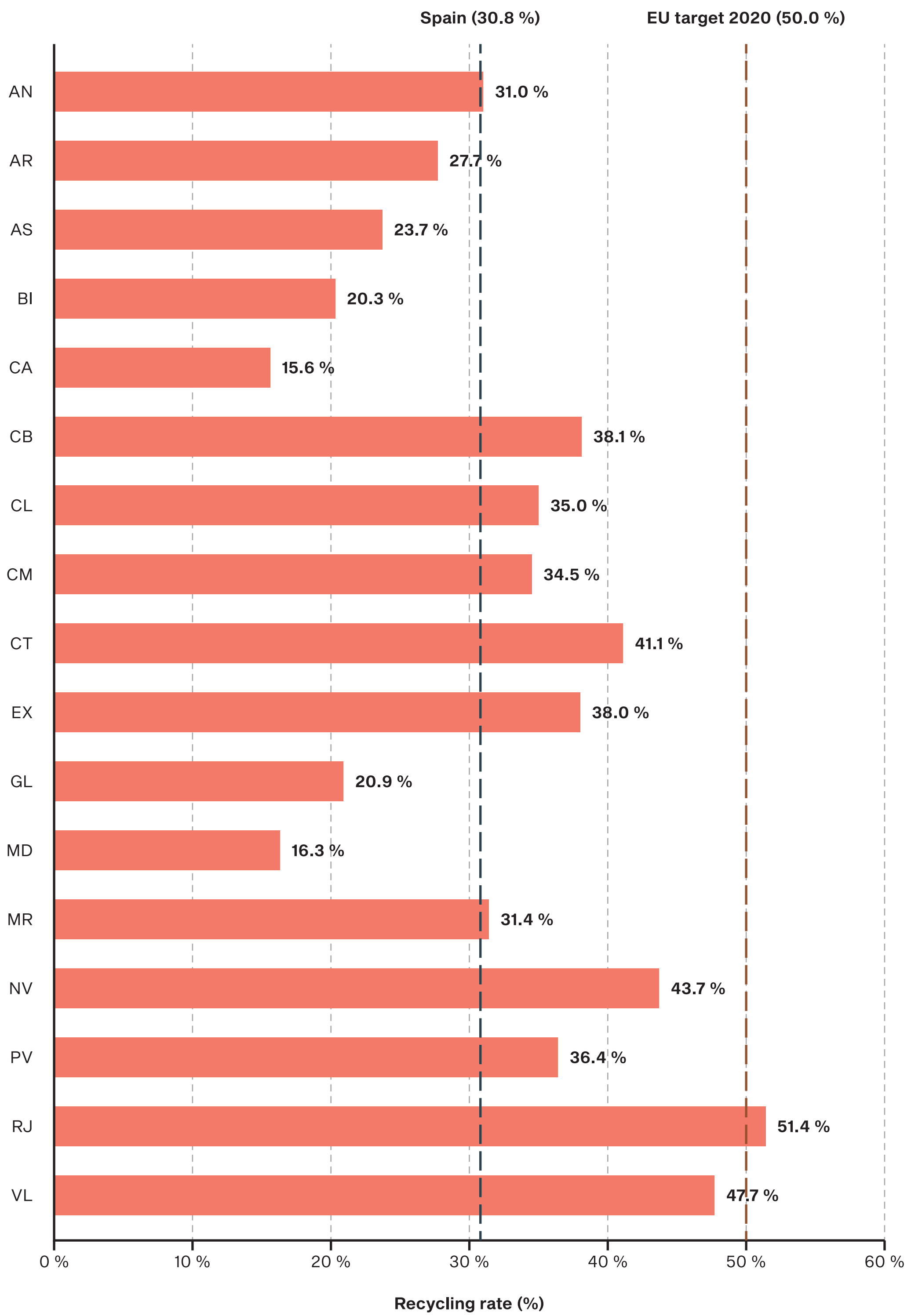
Most of the executive competences on waste management lie at AC level. They are responsible for the development of Regional Waste Management Plans (RWMP), including regional targets that should be the same or above those set at national level. AC can also adopt regional legislation on waste. Thus far, in 13 out of 17 ACs have implemented regional specific legislation on waste.

Lastly, municipalities collect MSW and undertake its treatment. Municipalities often merge into associations (i.e. mancomunidades, consorcios, diputaciones) in order to collectively manage MSW, by sharing waste treatment facilities.

According to the WFD, MS should have National Waste Management Plans. In Spain, the National Waste Management Framework Plan (PEMAR) for the period 2016-2022 was passed on 6th November 2015 (Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente 2015). Among other relevant issues, the PEMAR modified the allocation of responsibilities across administrative scales by stating: "[...] in order to guarantee the accomplishment of targets at the national level, the Autonomous Communities must achieve at least the same targets regarding waste generated in their territory [...]" (Ministerio de Agricultura Alimentación y Medio Ambiente 2015). Therefore, AC are required to comply with the 50% recycling rate by 2020. In the case of non-compliance, the national government could channel hypothetical penalties applied by the EU and received at the national level towards the corresponding AC (according to Organic Law 2/2012, of 27th April 2012, on Budgetary Stability and Financial Sustainability).

According to Eurostat (Eurostat 2019), the overall recycling rate of Spain was 30.8% in 2014. This ranged from 51% in La Rioja to 15% in the Canary Islands (Figure 4.1).

Figure 4.1 **Recycling rates at regional level in Spain, 2014**



Source: Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente (2016).
Notes: recycling rates are calculated according to method 4 as defined in the Commission Decision 2011/753/EU.

4.3.2 Municipal solid waste collection

MSW collection is carried out through five general collection models in Spain (Table 4.1). These models are generally based on collection using street containers plus an additional network of recycling centres (i.e. civic amenities) for some specific waste streams (e.g. bulky waste, waste from electronic and electrical equipment, oil, etc.). Collection models differ according to the number and type of waste streams that are collected separately, which may comprise paper and cardboard (*PC*), glass packaging (*GP*), light packaging (*LP*), food and garden waste (*FGW*) and residual unsorted waste (*USW*). Model 1 is mainly found in Cataluña, Pamplona (Navarra) and Guipúzcoa (País Vasco); Model 2 can be found in some municipalities of Navarra, Galicia and Cataluña, and the cities of Valladolid (Castilla y León) and Cordoba (Andalucía); Model 3 is limited to some counties in Cataluña; Model 4 (sometimes complemented by the separate collection of garden waste) is the most commonly used in the rest of Spain; and Model 5 is limited to a few rural areas.

Table 4.1 **Municipal solid waste collection models in Spain**

Model 1	Model 2	Model 3	Model 4	Model 5
GP	GP	GP	GP	GP
PC	PC	PC + LP	PC	PC
LP	USW + LP	USW	LP	USW
USW			USW	
FGW	FGW	FGW		

Source: adapted from Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente (2016).
Notes: GP: Glass packaging; PC: Paper and cardboard; LP: Light packaging; FGW: Food and garden waste; FW: food waste; USW: Unsorted residual waste.

In general, Model 1 performs better regarding separate collection (SC) rates, whereas, the lowest standard of performance corresponds to Model 5 (Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente 2015), although the information available does not permit a full ranking of all models. SC rates are higher where door-to-door collection is implemented (Colomer *et al.*, 2010; Jofra-Sora and Freire-González, 2014), although to date these systems are uncommon in Spain. SC rates at regional level range from 9.6% in Murcia to 33.6% in Navarra.

4.3.3 Municipal solid waste treatment and disposal

MSW treatment and disposal differ between waste streams. Separately collected *PC* and *GP* are taken to dedicated recovery plants with recycling[15] rates over 90%; *LP* is treated at light packaging sorting plants (LP_p) where the average recycling efficiency was 71.9% in 2014 (Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente 2016).

Unsorted residual waste (*USW*) can be either pre-treated at mechanical-biological treatment plants in order to recover valuable materials or directly disposed of in incinerators or landfills.

[15] In the context of this chapter, "recycling" refers to the legal definition of the word, which often differ from a strictly physical definition of the term.

In Spain, there are three types of mechanical-biological treatment plants. Firstly, there are plants where only mechanical sorting (M_p) is carried out. Secondly, there are plants where mechanical sorting plus biostabilisation of organic matter and composting (MB_p) is undertaken. Thirdly, there are plants where, besides mechanical sorting, organic matter is treated through anaerobic digestion ($MBAD_p$) prior to composting and biostabilisation. Each type of facility has different recycling efficiencies ranging from 10% to 61% (Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente 2016).

Lastly, *FGW* is usually treated at dedicated composting or anaerobic digestion facilities (FGW_p). In a few cases, *FGW* is treated in separate treatment lines or together with *USW* at mechanical-biological treatment plants. In 2014, FGW_p recycled from 43% to 90% of the inputs (Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente 2016).

In 2014, 3.9 Mt of *MSW* were separately collected, compared to 16.9 Mt of *USW*. With respect to *USW*, 6% was treated at M_p, 45% was treated at MB_p and 18% was treated at $MBAD_p$. The non-treated amounts of *USW* were either incinerated (5%) or landfilled (26%) (Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente 2016).

4.4 Methodological approach

4.4.1 The model

The approach consists in expressing the WFD recycling targets as a mathematical model. This model permits the calculation of all the possible combinations that satisfy a certain recycling rate for a given system (e.g. country, region, city, etc.). Next, the results are displayed in ternary plots. This approach enables a systematic analysis of the distance to the targets for any system (i.e. the Spanish AC in this case) in quantitative and qualitative terms.

According to the WFD and its accompanying methodological provisions (European Commission 2011), the rate of preparation for reuse and recycling (R) of a given system is formulated as the recycled amount of MSW divided by the total amount of MSW generated (W). Given that MSW comprises several waste streams, it can be formalised as follows:

[1]

$$R = \sum [W_c R_w],$$

where:

W_c is the collection share of a specific waste stream over W; and R_w is the recycling rate for a given waste stream W_i.

The Commission Decision 2011/753/EU sets four calculation methods for R depending on which specific waste streams comprise W. For calculation method 1, W includes paper, metal, plastic and glass waste from households. Method 2 allows for including further waste streams similar to those of households. Method 3 includes all household waste except discarded vehicles, sludge and mineral wastes. Finally, in method 4, W consists of "municipal waste", for which no provisions on the specific waste streams to be included are found, either in the WFD or in Commission Decision 2011/753/EU. Therefore, in method 4 the definition of W relies upon the Member States.
Spain chose to report under calculation method 4, including *PC*, *GP*, *LP*, *FGW*, non-packaging glass (*G*), non-packaging metals (*MET*), non-packaging plastic (*PLA*), wood (*WD*), textiles (*TEX*), waste electric and electronic equipment (*WEEE*), waste batteries and accumulators (*BA*) and bulky waste (*BK*). Therefore, in Spain, R is formulated as:

[2]

$$R = [PC_c\, R_{pc}] + [GP_c\, R_{gp}] + [FGW_c\, R_{fgw}] + [LP_c\, R_{lp}] + [G_c\, R_g] + [MET_c\, R_{met}] + [PLA_c\, R_{pla}] + [WD_c\, R_{wd}] + [TEX_c\, R_{tex}] + [WEEE_c\, R_{weee}] + [BA_c\, R_{ba}] + [BK_c\, R_{bk}] + [MBT\, R_{mbt}],$$

where:

R is the overall recycling rate of the system; PC_c is the share of separately collected paper and cardboard over MSW generation in one year; R_{pc} is the recycling efficiency of PC_c; GP_c is the share of separately collected glass packaging over MSW; R_{gp} is the recycling efficiency of GP_c; FGW_c is the share of separately collected FGW treated at dedicated FGW_p over MSW generation; R_{fgw} is the recycling efficiency of FGW_c; LP_c is the share of separately collected light packaging over MSW generation; R_{lp} is the recycling efficiency at LP_p; G_c is the share of non-packaging glass that is collected separately over MSW generation; R_g is the recycling efficiency of G_c; MET_c is the share of separately collected non-packaging metals over MSW generation; R_{met} is the recycling efficiency of MET_c; PLA_c is the share of separately collected non-packaging plastic over MSW generation; R_{pla} is the recycling efficiency of PLA_c; WD_c is the share of separately collected wood over MSW generation; R_{wd} is the recycling efficiency of WD_c; TEX_c is the share of separately collected textiles over MSW generation; R_{tex} is the recycling efficiency of TEX_c; $WEEE_c$ is the share of separately collected waste electrical and electronic equipment over MSW generation; R_{weee} is the recycling efficiency of $WEEE_c$; BA_c is the share of separately collected batteries and accumulators over MSW generation; R_{ba} is the recycling efficiency of BA_c; BK_c is the share of separately collected bulky waste over MSW generation; R_{bk} is the recycling efficiency of BK_c; *MBT* is the share of *USW* treated at M_p, MB_p and $MBAD_p$ over MSW generation; and R_{mbt} is the recycling efficiency of *MBT*.

Waste stream-specific collection rates can be added up to calculate the overall separate collection rate (SC) as follows:

[3]

$$SC = PC_c + GP_c + FGW_c + LP_c + G_c + MET_c + PLA_c + WD_c + TEX_c + WEEE_c + BA_c + BK_c.$$

Next, *D* is defined as the share of untreated *USW* that is disposed of in landfills and incinerators as a primary destination, hence:

[4]

$$SC + MBT + D = 1$$

The figures for waste stream-specific collection rates and *D* are shown in Table 4.2. Waste stream-specific collection rates for separately collected waste have an upper limit corresponding to their share of waste composition (Table 4.3). For its part, waste stream-specific recycling rates can be defined as constants or variables, depending on legal provisions (Table 4.4).

Table 4.2 Stream-specific collection and disposal rates at regional level in Spain, 2014

Region	PC_c	GP_c	FGW_c	LP_c	G_c	MET_c	PLA_c	WD_c	TEX_c	$WEEE_c$	BA_c	BK_c	MBT	D
AN	2.36	2.02	2.12	1.88	-	0.11	0.06	0.25	0.07	0.07	0	6.2	73.43	11.43
AR	4.39	3.17	-	2.84	0.08	0.07	0	0.13	0.12	0.17	0	1.57	46.27	41.19
AS	9.91	6.51	1.47	1.99	-	0.15	0.19	0.72	0.1	0.38	0	3.13	-	75.44
BI	5.4	4.32	3.42	2	0	0.04	0.05	0.02	0.03	0.16	0	2.86	6.05	75.65
CA	2.45	2.49	0.13	1.3	0.01	0.04	0	0.05	0.04	0.18	0.05	2.93	34.42	55.9
CB	3.48	3.58	-	1.8	0.03	0.11	-	-	0.27	0.18	0.02	6.92	77.1	6.51
CL	4.13	3.88	-	1.98	-	0.1	0.03	0.15	0.05	0.75	0.02	1.25	87.37	0.29
CM	2.98	2.35	-	1.99	-	0.04	0.04	0.16	0.09	0.35	0.02	4.37	67.58	20.03
CT	7.69	4.38	11.95	3.41	0.22	0.14	0.08	1.01	0.08	0.15	0.02	2.83	38.32	29.72
EX	8.35	1.53	-	2.26	-	0.55	0	-	0.03	0.04	0	0.9	81.58	4.76
GL	2.81	3.47	0.86	1.98	-	0.25	2.39	1.01	0.02	0.64	0.01	1.33	68.42	16.82
MD	3.75	3.23	0.55	5.14	0.03	0.07	0.02	0.24	0.03	0.35	0.01	2.18	41.43	42.99
MR	1.94	3.31	-	1.93	0.01	0.03	0.03	0.12	0.02	0.3	0.09	1.74	88.89	1.61
NV	9.02	6.55	8.34	7.97	-	0.02	0.63	1.35	0.47	0.44	0.02	1.16	26.07	37.95
PV	14.88	6.8	0.79	4.39	0.04	0.05	0.17	1.22	1.47	0.48	0.01	0.89	21.13	47.68
RJ	5.92	5.38	-	3.72	-	0.02	0.01	0.5	0.13	0.04	0.01	0.68	83.59	-
VL	2.73	3.7	-	1.91	0.02	0.1	0.09	0.13	0.21	0.17	0	2.09	88.8	0.04

Source: Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente (2016); Instituto Nacional de Estadística (2014).
Notes: PC_c is the separate collection of paper and cardboard; GP_c is the separate collection of glass packaging; FGW_c is the separate collection of food and garden waste; LP_c is the separate collection of light packaging; G_c is the separate collection of non-packaging glass; MET_c is the separate collection of non-packaging metals; PLA_c is the separate collection of non-packaging plastic; WD_c is the separate collection of wood; TEX_c is the separate collection of textiles; $WEEE_c$ is the separate collection of waste electrical and electronic equipment; BA_c is the separate collection of waste batteries and accumulators; BK_c is the separate collection of bulky waste; MBT is the share of total waste collection treated at mechanical-biological treatment plants. D is the share of untreated waste disposal in landfills and incinerators.

Table 4.3 Waste composition: upper limits to waste stream-specific collection

Waste stream	(%)
PC	18.73
GP	6.94
FGW	42.72
LP	14.03
G	0.22
MET	0.55
PLA	2.39
WD	1.35
TEX	1.47
WEEE	0.75
BA	0.09
BK	6.92
RES	3.83

Source: Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente (2016); APPLUS (2012), and own elaboration.
Notes: PC: paper and cardboard: GP: glass packaging; FGW: food and garden waste; LP: light packaging; G: non-packaging glass; MET: non-packaging metals; PLA: non-packaging plastic; WD: wood; TEX: textiles; WEEE: waste electric and electronic equipment; BA: waste batteries and accumulators; BK: bulky waste; RES: residual waste. The limit for PC, GP, FGW and LP correspond to the shares found in waste composition analyses for Spain (APPLUS 2012). Regarding the limit for the remaining waste streams, the higher separate collection rate found across regions has been taken (Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente 2016), which is consistent with the waste characterisations. Residual waste has been calculated as the difference between 100% and the rest of the variables.

Table 4.4	**Stream-specific recycling rates at regional level in Spain, 2014**

Region	R_{pc}	R_{gp}	R_{fgw}	R_{lp}	R_{g}	R_{met}	R_{pla}	R_{wd}	R_{tex}	R_{weee}	R_{ba}	R_{bk}	R_{mbt}
AN	1.00	1.00	0.43	0.67	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.25
AR	1.00	1.00	-	0.74	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.35
AS	1.00	1.00	0.75	0.77	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	-
BI	1.00	1.00	0.49	0.66	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.42
CA	1.00	1.00	0.75	0.64	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.19
CB	1.00	1.00	-	0.79	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.29
CL	1.00	1.00	-	0.75	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.27
CM	1.00	1.00	-	0.64	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.34
CT	1.00	1.00	0.57	0.62	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.37
EX	1.00	1.00	-	0.52	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.31
GL	1.00	1.00	0.91	0.60	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.42
MD	1.00	1.00	0.74	0.81	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.17
MR	1.00	1.00	-	0.74	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.25
NV	1.00	1.00	0.80	0.58	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.50
PV	1.00	1.00	0.75	0.70	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.35
RJ	1.00	1.00	-	0.75	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.43
VL	1.00	1.00	-	0.75	1.00	1.00	0.86	0.86	0.80	0.92	1.00	0.92	0.42

Source: Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente (2016) and Instituto Nacional de Estadística (2014).
Notes: R_pc is the recycling efficiency for paper and cardboard; R_gpis the recycling efficiency for glass packaging; R_fgw is the recycling efficiency for food and garden waste; R_lp is the recycling efficiency for light packaging; R_g is the recycling efficiency for non-packaging glass; R_met is the recycling efficiency of non-packaging metals; R_pla is the recycling efficiency for non-packaging plastic; R_wd is the recycling efficiency for wood; R_tex is the recycling efficiency for textiles; R_weee is the recycling efficiency for waste electrical and electronic equipment; R_ba is the recycling efficiency for waste batteries and accumulators; R_bk is the recycling efficiency for bulky waste; R_mbt is the recycling efficiency at mechanical-biological treatment plants. The values for R_pc and R_gp are set as 1, according to Commission Decision 2011/753/EU. The figures for R_fgw, R_lp and R_mbt follow the methodological rules provided in Commission Decision 2011/753/EU and are based on input data from Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente (2016). For the remaining variables, nationwide values provided by INE (2014) were taken.

Taking these inputs, the model has been developed as a Python script that, departing from the waste-stream-specific recycling rates of each AC, calculates all the possible combinations of *SC* (including all the combination of the 13 variables comprising *SC*), *MBT*, and *D* that satisfy R=0.5 (WFD target for 2020) and R=0.65 (target proposed for 2035). The model works as follows.

First, the variables (i.e. SC, MBT and D), are given a maximum and a minimum value. The variables refer to the share of specific waste streams over waste generation. The minimum value for all variables is zero. The maximum value for each variable is determined by its share in waste composition for those variables enclosed in SC (see Table 4.5), and it is 1 for MBT and D.

Next, through an iterative process, all the combinations for each value and each variable are calculated. For those combinations complying with eq. 2 and eq. 4, the resulting vector containing the values of the 14 variables is stored. Next, SC is calculated adding up the corresponding variables (see eq. 3), and it is stored along with MBT and LD for a later plotting in the ternary diagram. For an easier interpretation, the resulting point cloud is represented as the boundaries of the cloud.

Since the variables are continuous in nature, the potential number of combinations is infinite. In order to deal with this issue, the variables have been transformed into discrete vectors for the simulation, by conferring them a "resolution" (Table 4.5). For example, according to the model, disposal (D) ranges from 0 to 1. "D" has been given a resolution of 0.03. This means that the input values of D to the model have been set at intervals of 0.03 points from 0 to 1 (i.e. the input values being 0, 0.03, 0.06, 0.09... 1). The resolution of each variable has been adjusted according to the range of values each variable can take and the maximum number of permutations a regular computer (i.e. up to 8 GB RAM) can manage under the proposed model architecture.

Table 4.5 Resolution of the variables in the model

Waste stream	Resolution
PC	0.03
GP	0.03
FGW	0.05
LP	0.02
MBT	0.01
D	0.03
G	0.001
MET	0.002
PLA	0.01
W	0.002
TEX	0.003
WEEE	0.003
BA	0.0003
BK	0.02

Source: own elaboration.

The resulting combinations are finally plotted into a ternary diagram as points (Cossu 2009, Farmer *et al.* 2015, Pomberger *et al.* 2017, Jung and Moon 2018), which are later interpolated and converted into areas, simplifying its representation.

4.4.2 Representing the results through ternary plots

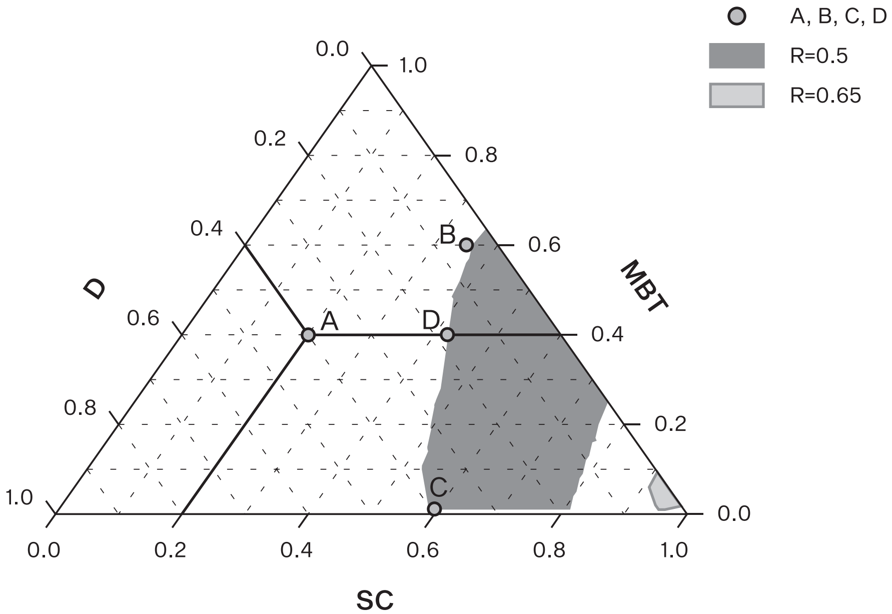
Ternary plots are triangular diagrams displaying the proportions of three variables that add up to a constant. Geologists have extensively employed these plots, for example, to illustrate textural features of sediments (Flemming 2000, Štípská and Powell 2005). For an overview on the theoretical grounds of ternary plots and an application to waste management see Pomberger *et al.* (2017).

Here, we use ternary diagrams to plot the combinations of *SC*, *MBT* and *D* that satisfy *R*=0.5 and *R*=0.65 in comparison to the current situation for a given reference system (e.g. an AC). This representation allows understanding the gap between the EU recycling target and implementation of EU waste legislation in each AC, through the distance between the spot representing the current situation and the areas representing compliant combinations of *SC*, *MBT* and *D*, thus showing alternative paths towards the accomplishment of targets and the related trade-offs.

In Figure 4.2, an example of a hypothetical system illustrates how to read the results of the model in this study. Dashed lines indicate how ternary diagrams are read and, therefore, how individual points relate to all three axes. Point "A" represents the values for a given system; in this case, it represents a combination of *SC* (20%, in turn enclosing a combination of the variables affecting *SC* (20%), *MBT* (40%) and *D* (40%). The areas represent the combinations of *SC*, *MBT* and *D* that accomplish *R*=0.5 and *R*=0.65 for this system's treatment technologies. Point

"B" represents the combination of variables that permit 50% recycling (it is within the area for *R*=0.5) with the lowest *SC* value (35%), together with a combination of 60% *MBT* under the current technology, and 5% *D*. Point "C" represents the maximum value for *D* within the area. Keeping direct disposal at 40%, which is the current value for the system (point "A"), would entail a minimum *SC* of 60% and reducing *MBT* close to zero. Therefore, scenarios maximising disposal would imply *MBT* overcapacity. Finally, point "D" illustrates the trade-offs related to keeping the *MBT* value of point "A" (40%). In this case, disposal would have to decrease to 18% and separate collection would have to increase until a minimum of 60%.

Figure 4.2 **How to read model results plotted in a ternary diagram: example**



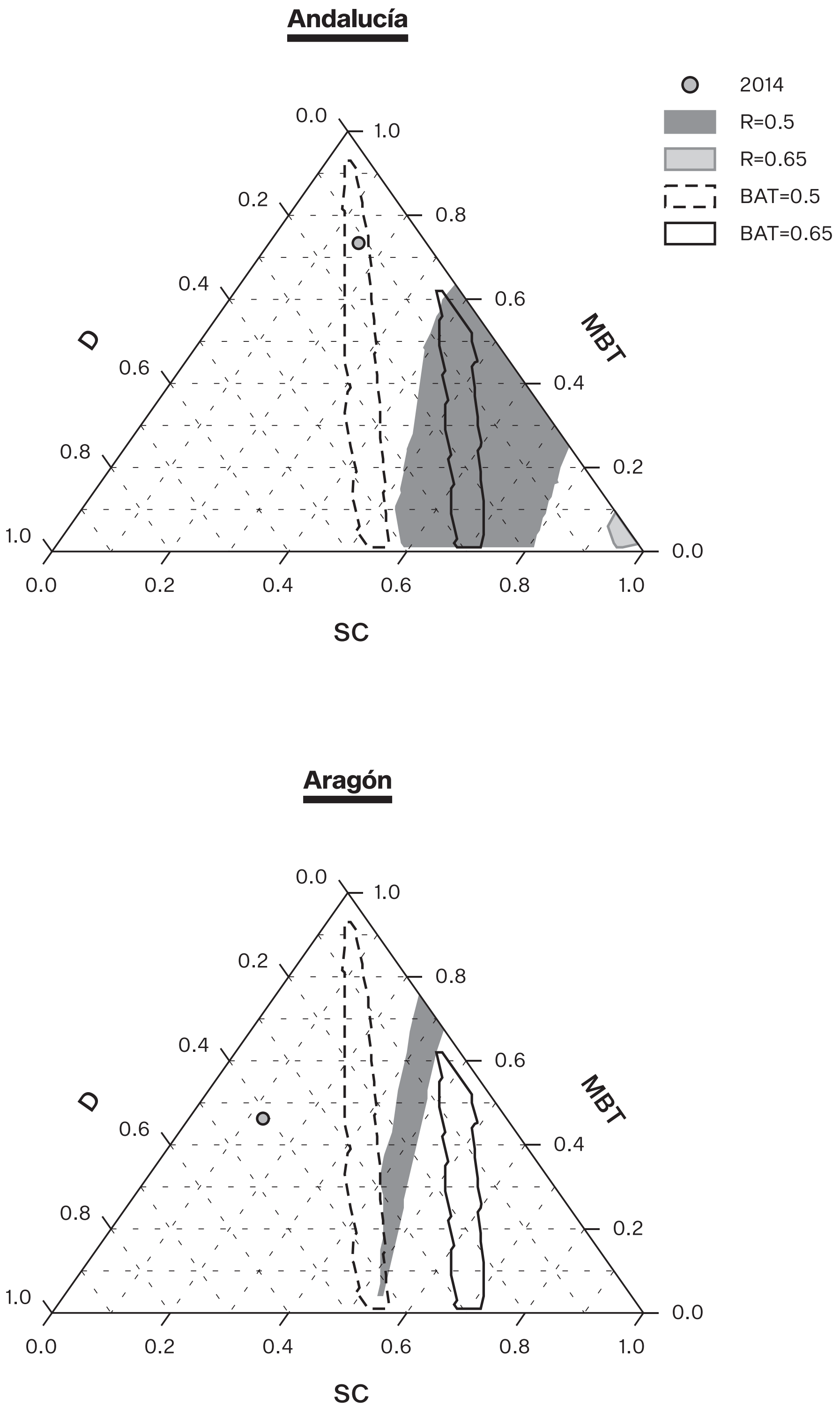
Source: own elaboration.
Notes: SC: separate collection rate; MBT: mechanical-biological treatment rate; D: rate of direct disposal (landfilling and incineration) of unsorted waste.

The values for SC enclose specific combinations of 13 variables comprising *SC* (*LP*, *FGW*, *WEEE*, etc.). Therefore, the minimum *SC* to reach *R*=0.5 (35%) will not met by all of the possible combinations of the 13 variables comprising *SC* adding up 35%, but by a limited number of them. The practical consequences of this are addressed in detail in the discussion section of the paper. From a visual point of view, the fact that each value of *SC* encloses the sum of the values of 13 variables explains why two areas for two different targets may overlap: each single value of *SC* can be achieved through different combinations of 13 waste streams; and one combination of *SC*, *MBT* and *D* (one point in the graph), may result in different global recycling rates.

4.5 Results

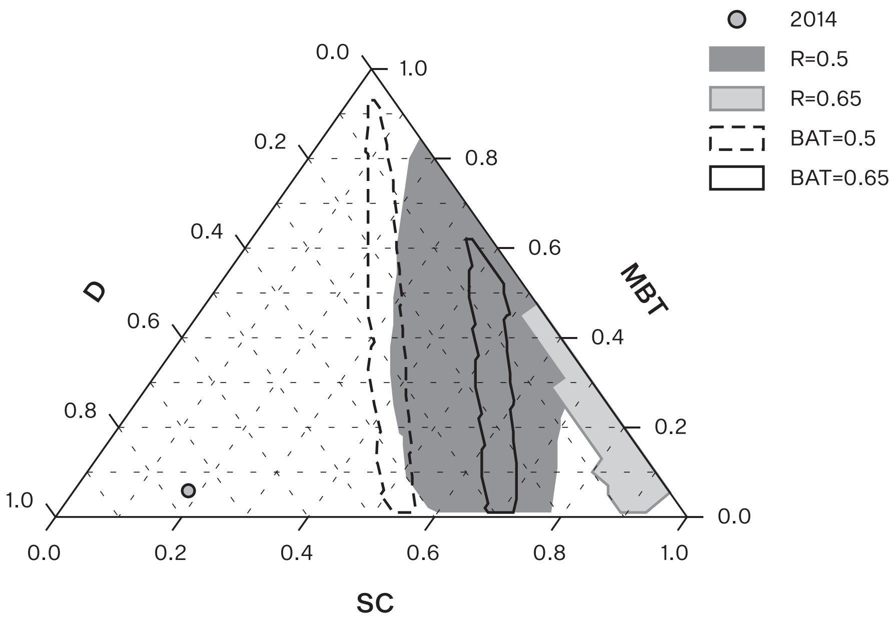
The results of the model are displayed in 16 ternary plots (Figure 4.3), one per AC, except for the case of Asturias, where the value for *MBT* is zero. Each ternary plot includes: a spot representing the current combination of *SC*, *MBT*, and *D*; two shadowed areas corresponding with the combinations of the same variables that result in 50% and 65% recycling rate for the region waste-stream specific recycling efficiency; and two contoured areas representing the combinations of *SC*, *MBT*, and *D* that result in 50% and 65% recycling rate for a hypothetical scenario in which the maximum recycling efficiency is assumed for all waste streams, which is referred to as “best available techniques” (BAT) scenario.

Figure 4.3 **Results of the model applied to the Spanish regions, plotted in ternary diagrams**

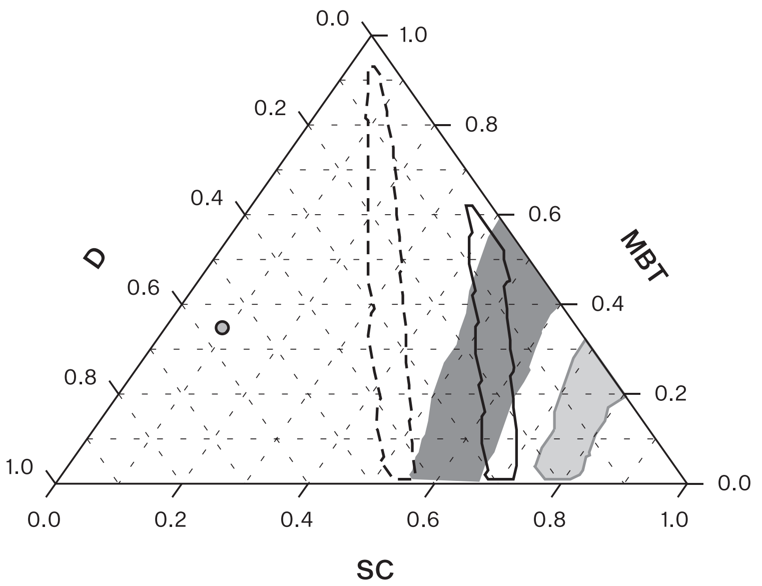


Source: own elaboration.

Baleares

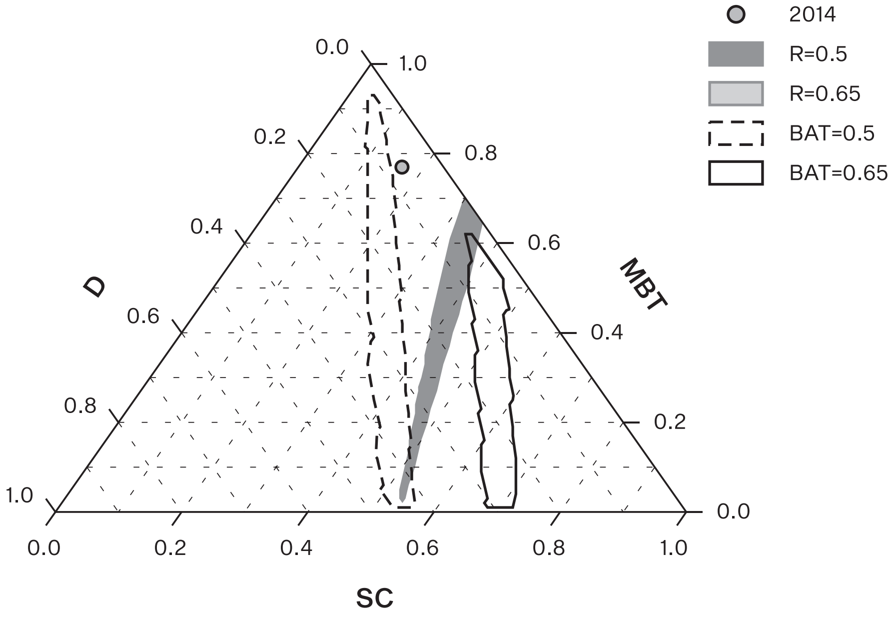


Canarias

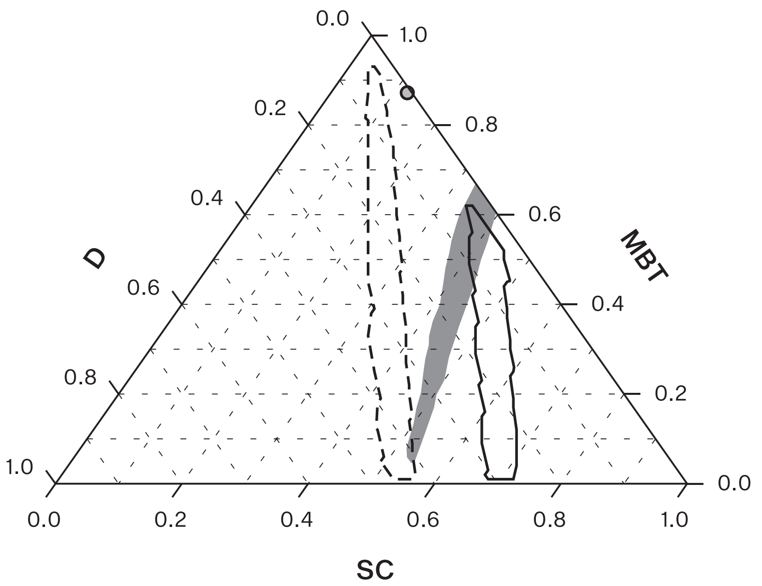


Source: own elaboration.

Cantabria

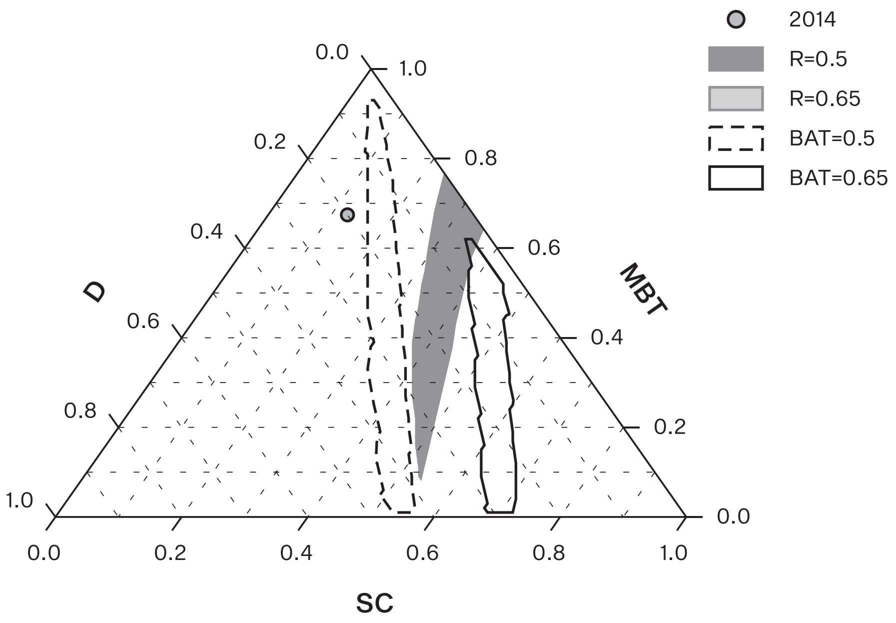


Castilla y León

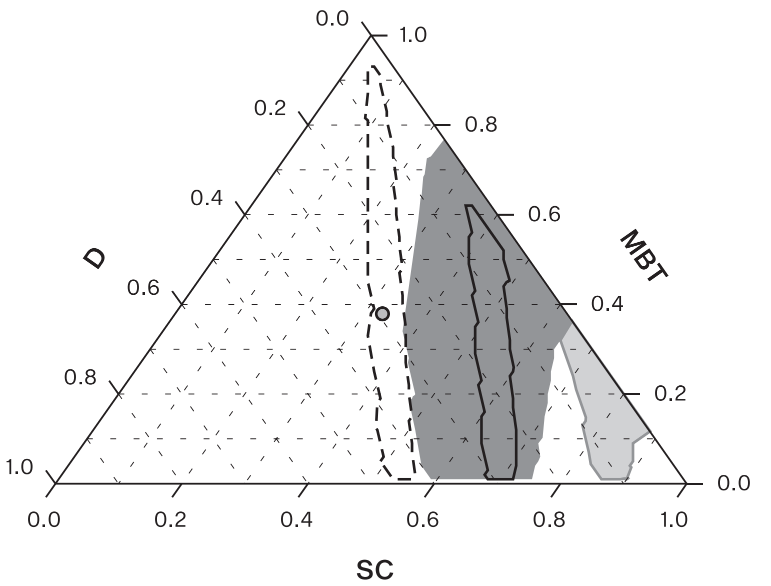


Source: own elaboration.

Castilla-La Mancha

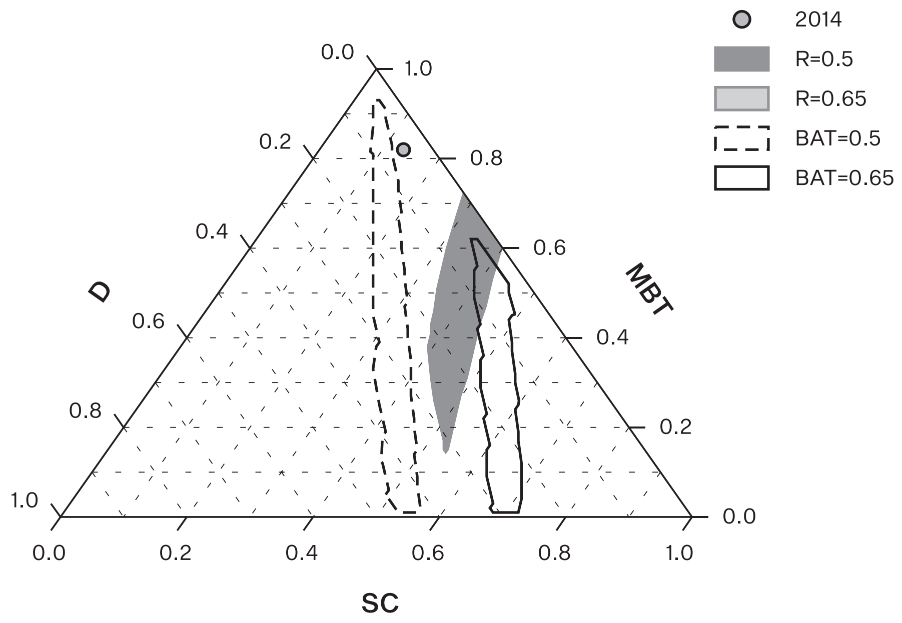


Cataluña

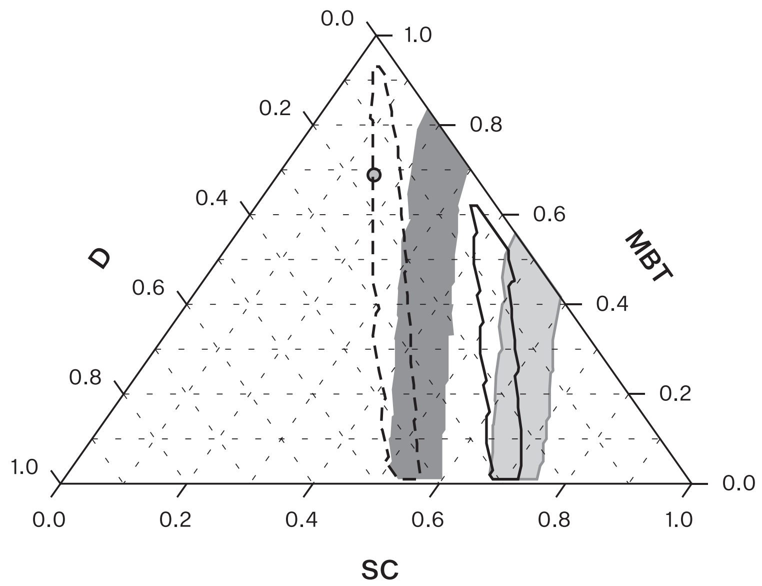


Source: own elaboration.

Extremadura

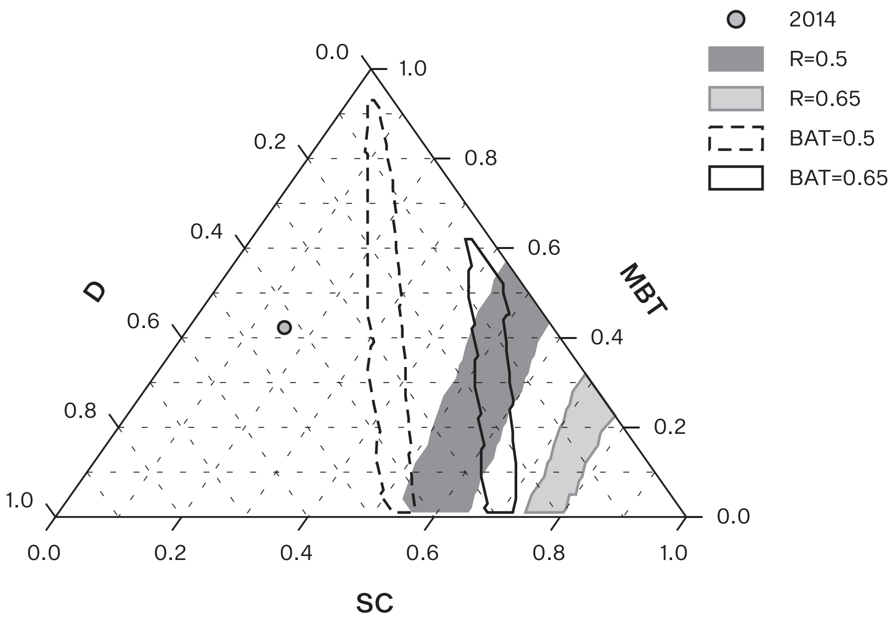


Galicia

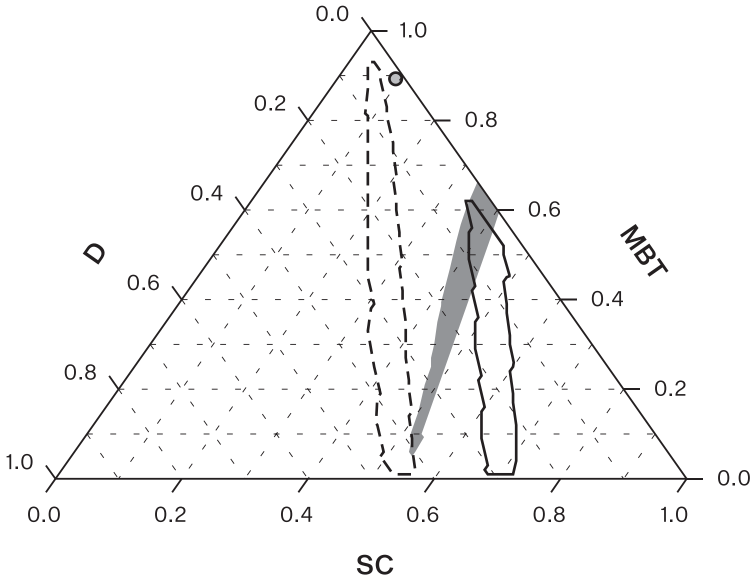


Source: own elaboration.

Madrid

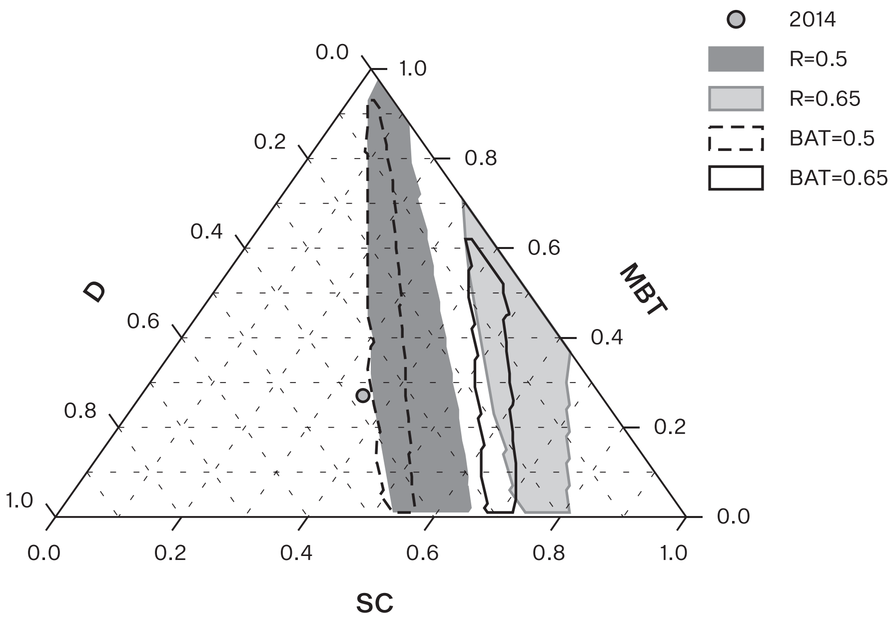


Murcia

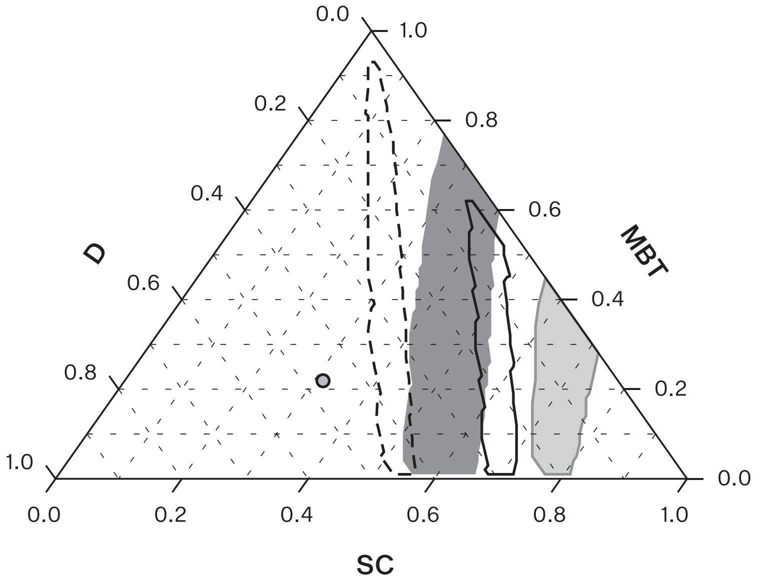


Source: own elaboration.

Navarra

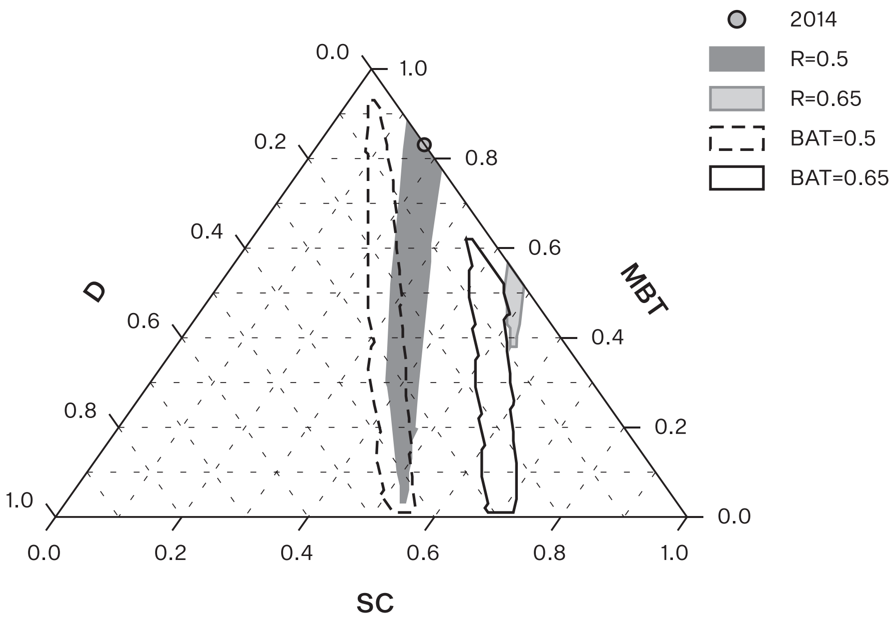


País Vasco

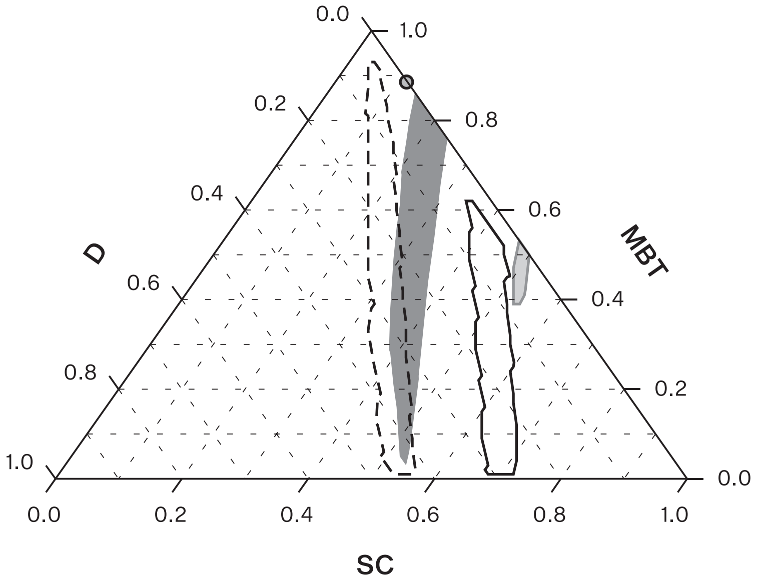


Source: own elaboration.

Rioja



Valencia



Source: own elaboration.

This representation permits the analysis of MSW management and the distance to the targets for each region as well as approaching the role of technology. Table 4.6 shows the individual minimum distance to targets for *SC*, *MBT*, and *D* in 2020 and 2035. Table 4.7 summarises the required performance for these variables at each region in order to comply with the WFD target in 2020 and 2035.

Table 4.6 Gap between the 2020 and 2035's recycling targets and current performance in the Spanish Autonomous Communities

	SC		SC		SC	
Region	R=0.5	R=0.65	R=0.5	R=0.65	R=0.5	R=0.65
AN	0.21	0.80	-0.12	-0.71	0	-0.11
AR	0.10	:	0.31	:	0	:
AS	0.30	0.55	n.a.	n.a.	-0.30	-0.50
BI	0	0.34	0.75	0.39	-0.40	-0.70
CA	0.32	0.59	0.20	-0.07	-0.16	-0.37
CB	0.13	:	-0.06	:	0	:
CL	0.20	:	-0.19	:	0	:
CM	0.11	:	0.09	:	0	:
CT	0	0.34	0.36	-0.08	0	-0.21
EX	0.13	:	-0.09	:	0	:
GL	0.02	0.30	0.11	-0.17	0	0
MD	0.27	0.55	0.12	-0.14	-0.03	-0.23
MR	0.23	:	-0.22	:	0	:
NV	0	0	0.68	0.36	0	-0.16
PV	0	0.27	0.50	0.17	-0.08	-0.29
RJ	0	0.25	0.05	-0.25	0	0
VL	0.02	0.33	-0.02	-0.33	0	0

Source: own elaboration.
Note: ":" means that the model did not find any combination of variables that would allow for accomplishment using the current technology. "n.a." means not applicable. The values for SC refer to the difference (in percentage points) between current values of SC and SC required for accomplishment (e.g. Andalusia should increase SC a minimum of 21 points before 2020). The values for MBT refer to the difference (in percentage points) between the current values of MBT and the maximum value of MBT required for accomplishment (e.g. negative values mean over capacity). The values for D refer to the difference (in percentage points) between D and the maximum value of D required for accomplishment.

Table 4.7	Summary of the performance (P) required within each region to comply with the WFD target in 2020 and 2035

Region	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
AN	√	√	√	√	√	√	x	√	x	x
AR	√	n.a.	√	x	n.a.	x	x	n.a.	√	√
AS	√	√	√	x	n.a.	x	√	√	√	x
BI	x	√	√	x	x	x	√	√	√	x
CA	√	√	√	x	√	x	√	√	√	x
CB	√	n.a.	√	√	n.a.	√	x	n.a.	x	√
CL	√	n.a.	√	√	n.a.	√	x	n.a.	x	√
CM	√	n.a.	√	x	n.a.	√	x	n.a.	x	√
CT	x	√	√	x	√	x	x	√	x	x
EX	√	n.a.	√	√	n.a.	√	x	n.a.	x	√
GL	√	√	√	x	√	√	x	x	x	x
MD	√	√	√	x	√	x	√	√	√	x
MR	√	n.a.	√	√	n.a.	√	x	n.a.	x	√
NV	x	x	x	x	x	x	x	√	√	x
PV	x	√	√	x	x	x	√	√	√	x
RJ	x	√	√	x	√	√	x	x	x	x
VL	√	√	√	√	√	√	x	x	x	x
Total	**12**	**10**	**16**	**6**	**7**	**9**	**5**	**8**	**7**	**6**

Source: own elaboration.
Notes: "n.a." not applicable. P1: under the current technology, all scenarios entail an increase in SC before 2020; P2: under the current technology, all scenarios entail an increase in SC before 2035; P3: under the BAT, all scenarios entail an increase in SC before 2035; P4: under the current technology, all scenarios entail MBT overcapacity before 2020; P5: under the current technology, all scenarios entail MBT overcapacity before 2035; P6: under the BAT, all scenarios entail MBT overcapacity before 2035; P7: under the current technology, all scenarios entail a decrease in D before 2020; P8: under the current technology, all scenarios entail a decrease in D before 2035; P9: under the BAT, all scenarios entail a decrease in D before 2035; P10: all scenarios entail an increase in the overall waste treatment efficiency before 2035.

4.5.1 Separate collection

12 regions should necessarily increase *SC* in order to accomplish the target in 2020 under their current technology (P1, Table 4.7). The most striking case is the Canary Islands, where the minimum *SC* value for accomplishment provides a four-fold increase in the current separate collection rate of the region. In a similar manner, Andalucía, Asturias, Castilla y León, Madrid and Murcia would have to more than double their current figures. Increases must also occur in Aragón, Cantabria, Castilla-La Mancha, Extremadura, Galicia and Valencia. However, adopting the SC minimisation strategy would imply a different allocation of *D* and *MBT*. For example, the minimum *SC* is reached when *D* becomes zero. Thus, the minimum *SC* would entail significant reductions of *D* in Andalucía, Aragón, Canarias, Castilla-La Mancha and Madrid.

Also, in Andalucía, Cantabria, Castilla y León, Extremadura, Murcia and to a lesser extent Valencia, under the current waste treatment efficiency levels, any accomplishment scenario would entail MBT overcapacity before 2020.

In Baleares, Cataluña, Navarra and Pais Vasco, the 50% target could be achieved with the current *SC* levels, although this would be at the expense of significant increases of *MBT* and reductions of *D*. In Rioja, the target was already accomplished in 2014.

As for the year 2035 target, a group of six regions show no value under the current technologies (Aragón, Cantabria, Castilla-La Mancha, Castilla y León, Extremadura and Murcia), hence the contour corresponding to *R*=0.65 could not be represented in their corresponding plots. This indicates that the current collection scheme (e.g. without the separate collection of food and garden waste) and the waste treatment efficiency at these regions (i.e. waste stream-specific recycling efficiencies) will not be able to recycle 65% of MSW, therefore, collection schemes and waste treatment technology in these AC will have to be upgraded in order to achieve the year 2035 target.

There is a second group of regions where there is no such limitation, although the minimum *SC* values that are required to reach 65% recycling is well over their current figures, ranging from 25 points in Rioja to 80 points in Andalusia. Again, the minimum *SC* is reached when *D* becomes zero, which is relevant to Andalucía, Asturias, Baleares, Canarias, Cataluña, Galicia, Madrid and País Vasco. In Andalucía, Canarias, Cataluña, Galicia, Rioja, Madrid and Valencia, the minimum *SC* that is necessary for accomplishment would require a decrease in *MBT*.

Finally, Navarra could comply with the year 2035 target under the current technology and *SC* levels, by increasing *MBT* while reducing *D* to zero.

It is noteworthy that several waste streams (i.e. packaging materials, WEEE) have specific collection and recycling targets according to the EU legislation (European Union 1994). These targets are set as shares of materials to be recycled over the total amount of these materials placed in the market. To the best knowledge of the authors, there are not such data at regional level in Spain; therefore, these sectoral targets could not be integrated. Integrating these additional targets may increase the minimum aggregated separate collection rates that are required to achieve 50% recycling in some regions.

4.5.2 Mechanical-biological treatment

Andalucía, Cantabria, Castilla y León, Extremadura, Murcia and Valencia should necessarily reduce the proportion of *USW* treated this way before 2020, as the existing capacity is higher than the maximum value of *MBT* that is compatible with R=0.5 under the current technology. If a technological upgrade does not occur, these regions would experience M-BT overcapacity before 2020.

The rest of the regions could even increase *MBT* while complying with the target, however, *MBT* maximization strategies would entail trade-offs in the proportion of *SC* (increase) and *D* (reduction). For example, Aragón could reach *R*=0.5 with its current figure for *MBT*, if *SC* grows from 0.13 to 0.34 and *D* drops from 0.41 to 0.20.

Regarding 65% recycling, some of the regions that are not forced to lower *MBT* before 2020 will have to do so before 2035 if treatment efficiency levels are maintained. This is the case with Canarias, Cataluña, Galicia, Rioja and Madrid. For their part, only Baleares, Pais Vasco and Navarra could accomplish the 65% recycling rate with their current technology without reducing *MBT*, although in exchange for significant increases of *SC* and reductions of *D*.

Furthermore, in the BAT scenario, the maximum value for *MBT* is slightly above 60%, which is below the current *MBT* figures for Andalusia, Cantabria, Castilla-La Mancha, Castilla y León, Extremadura, Galicia, Rioja, Murcia and Valencia. This means that these regions will experience *MBT* overcapacity before 2035, unless a dramatic increase in waste treatment efficiency occurs beforehand.

4.5.3 Disposal of untreated waste

When it comes to disposal, in the absence of technological improvements, five regions (Asturias, Baleares, Canarias, Pais Vasco and to a lesser extent Madrid) should necessarily reduce the primary disposal of *USW* in landfills and incinerators before 2020 in order to comply with the target. The maximum value for *D* under the BAT scenario is 46%; therefore, Asturias, País Vasco and the islands would have to decrease the direct disposal of untreated waste, even if technology were significantly improved.

The rest of the regions could achieve the year 2020 recycling target without necessarily diminishing *D*, by balancing out *SC* and *MBT*. For example, Andalucía could achieve 50% recycling with its current figure for *D*, but *SC* should rise from 0.15 to 0.40 and *MBT* would, therefore, decrease from 0.73 to 0.49.

Regarding the year 2035 target, besides the six regions where treatment efficiency must be increased, under the current technology eight regions (Andalucía, Asturias, Baleares, Canarias, Cataluña, Madrid, Navarra and Pais vasco) will need to reduce landfilling and incineration, ranging from 11 points in Andalucía to 70 points in Baleares. In Galicia, Rioja and Valencia, the current *D* levels permit 65% recycling if *SC* significantly increases and *MBT* reduces accordingly.

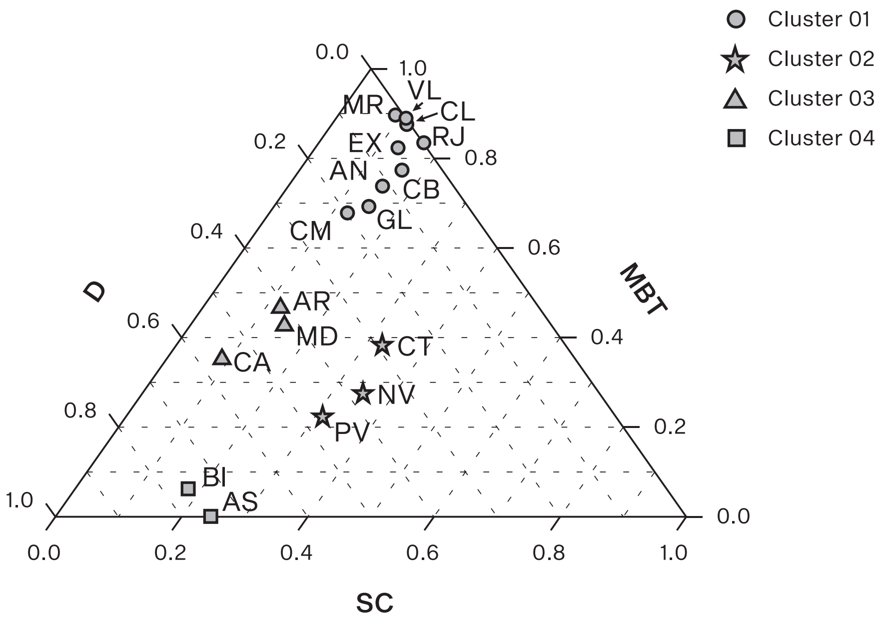
The maximum level of *D* in the BAT scenario for 2035 is around 30%. Even in the event of such an overall efficiency increase, Aragón, Asturias, Baleares, Canarias, Madrid, Navarra, Pais Vasco, and to a lesser extent Cataluña, would have to decrease *D*.

It is noteworthy that there are specific EU targets that limit the amount of biodegradable waste to be landfilled from 2016 onwards (European Union 1999), which will, in turn, be revised within the circular economy package. These targets could further restrict the maximum amount of waste that is allowed to be directly landfilled in some regions, compared to the disposal levels that derive from compliance with the WFD. In practice, this means that if the target of the Landfill Directive was considered at the regional level, the areas representing compliance could be smaller for some regions.

4.5.4 Profiling MSW management strategies at regional level

Besides a systematic analysis and comparison of the gap to target, ternary plots allow profiling the MSW management strategies AC have carried out so far in terms of the combination of SC, MBT and D (Figure 9). The following groups are supported by a K-means clustering using Euclidean distances.

Figure 4.4 **Profiling of the Spanish regions regarding municipal solid waste management strategies**



Source: own elaboration.

There is a first group of regions (represented as circles in Figure 4.4) where *MBT* technologies have been significantly prioritised: Andalucía, Cantabria, Castilla-La Mancha, Castilla y León, Extremadura, Galicia, Rioja, Murcia and Valencia. This strategy has permitted those regions with high R_{mbt} to reach notable recycling figures. For example, Rioja has already met the 2020 target, whereas, *R* is over 0.4 in Cantabria and Valencia. However, all of these three regions would not be able to meet the 65% target at the current *MBT* levels, even in the BAT scenario, which points them to a technological lock-in after 2020.

Moreover, it also implies a certain reliance on one specific group of technologies and, more importantly, upon the definition of R_{mbt}, which will be explained later in this paper. These points are relevant for those regions planning *MBT* capacity increases, particularly where investments in additional facilities are involved.

There is a second group of regions that is formed by Navarra, Cataluña and Pais Vasco (represented as stars in Figure 9), which have prioritised *SC* in comparison to other regions (i.e. *SC* above 30%): both Navarra and Cataluña reach *R* over 40%, while País Vasco surpasses 37%. In Navarra and Cataluña, the strategy comprises the separate collection of *FGW*, whereas, in País Vasco the strategy has primarily focused on PC_c and GP_c.

A third cluster includes Baleares and Asturias (represented as squares Figure 4.4), which stand out for their high disposal rate, being over 75%, plus low and non-existent mechanical biological treatment rates, respectively.

A last group of regions (triangles in Figure 4.4) show mixed features and, in general, *D* values above the average (27.41%). Within this group is Aragón (42.19%), Canarias (55.90%) and Madrid (42.99%).

Finally, from a technological point of view, the distance between each region's overall treatment efficiency and the BAT in the country can be ascertained by comparing areas and contours for each target. For example, whereas in Navarra most of the area for R=0.5 coincides with the contour of BAT, the opposite is true for Extremadura. This indicates that treatment efficiency of Navarra is closer to the BAT than that of Extremadura.

4.6 Discussion

At least three sets of issues can be discussed: those related to the aforementioned target-implementation gap with respect to the Spanish regions and the changes that should take place in order to achieve the set recycling goals by 2020 and 2035; how the model might be relevant for policy makers; and methodological issues.

4.6.1 Gap to target

Most of the Spanish regions were far from compliance with the WFD in 2014. The target-performance distance suggests that profound changes should occur for the targets to be achieved; otherwise, the accomplishment the WFD for Spain would seems unlikely. It is also observed that the aforementioned gap is dissimilar across regions, which illustrates the different MSW management strategies that have been taken so far. This gap has at least three relevant branches: 1) the lack of widespread separate collection and treatment of biowaste; 2) low treatment efficiency, particularly at mechanical-biological treatment facilities; and 3) a more general dimension related to MSW management policy.

4.6.2 The biowaste gap

The results show that *SC* will have to be significantly increased in most regions, which can hardly be achieved unless the separate collection of *FGW* is undertaken, given its relevance within the composition of MSW in Spain (i.e. 42.72%). Although it is theoretically feasible, the options to reach R=0.5 without involving the separate collection of *FGW* are limited: as the separate collection rate for each waste stream approximates to its maximum, further improvements of their specific separate collection rates generally become more difficult to achieve due to the law of diminishing returns (Kinnaman 2006). Therefore, when it comes to push *SC* figures, *FGW* must enter into the equation, possibly in coalition with more systemic changes, as it has been acknowledged within the national waste management plan (Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente 2015). This becomes evident for the 2035 target: in regions where the separate collection of food and garden waste is not undertaken, the possibility to comply under the current technology is either limited in comparison to other regions (Rioja and Valencia) or it does not exist (Aragón, Cantabria, Castilla-La Mancha, Castilla y León, Extremadura and Murcia).

Currently, 9 out of 17 regions have implemented the separate collection of *FGW* to some extent (Andalucía, Baleares, Canarias, Cataluña, Galicia, Madrid, Navarra, País Vasco and Valencia), whereas, 14 regions separately collect garden waste only. However, only in Cataluña and Navarra did the separate collection of *FGW* reach significant figures in 2014 (11.9 and 8.8% of total waste collected, respectively), while in the rest of regions it did not surpass 5%. The separate collection of FGW is currently carried out through several models in Spain, ranging from additional street containers (e.g. Donostia, in País Vasco) to door-to-door collection (e.g. Sant Sadurní d'Anoia, in Cataluña). Therefore, there are neither technical barriers nor lack of experience impeding a widespread implementation of the separate collection of *FGW* in Spain (Gallardo *et al*. 2012).

Besides collection, proper *FGW* treatment is crucial in order to ensure a high recycling rate of *FGW* (Amlinger *et al*. 2008, Colazo *et al*. 2015). Four regions (Asturias, Baleares, Cataluña, and País Vasco) already treat all separately collected *FGW* at dedicated FGW_p. Five regions (Andalucía, Canarias, Galicia, Madrid and Navarra) treat *FGW* either at FGW_p or at M-BT (mechanical-biological treatment) plants. Four regions treat *FGW* at M-BT plants only (Aragón, Castilla y León, Murcia and Valencia) and one region (Cantabria) did not report any separate treatment of *FGW* (Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente 2016).

This paper shows that regions implementing proper separate collection and treatment of *FGW* are notably closer to the 2020 target. Thus far, the lack of a sound nation-wide framework on biowaste collection and treatment has led to the results that are described in the above. Although the last national waste management plan (PEMAR) included orientations in this sense, this policy gap remains.

4.6.3 The technological gap

Mechanical biological treatment has played a relevant role within the regional MSW management strategies by processing large shares of *USW*, which is likely related to the accomplishment of the Landfill Directive's target on landfilling of biodegradable waste (Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente 2015). However, in the light of the results of the present study, this technology will likely change its role in the short and midterm.

Mechanical biological treatment facilities show waste stream-specific recycling rates ranging from 0.17 to 0.43 across ACs. These figures are low compared to the recycling targets to be achieved and to the recycling rates of other technologies treating separately collected materials. Therefore, despite the huge investments undertaken in M-BT technologies in Spain (supported by EU funds), relying on this technology reveals itself to be a non-feasible waste management strategy when challenging targets are pursued.

Results suggest that in order to reach the WFD recycling target, ACs will have to either upgrade M-BT technology or assume M-BT overcapacity in the midterm (see Table 13), or both. As stated in the previous section, because *SC* is required to grow, it is likely that *FGW* will have to eventually be collected separately and properly treated. While *FGW* collection might require the deployment of additional services in most ACs, high-quality *FGW* treatment can be carried out at current MB_p and $MBAD_p$, as long as it is not mixed with *USW* (Ponsá *et al*. 2008, López *et al*. 2010). To the extent that regional policymakers anticipate these issues, overcapacity might be restricted to mechanical sorting capacity for *USW*, and additional investments in stand-alone *FGW* treatment plants could, therefore, be minimised.

An additional issue regarding M-BT is that the definition of recycling at M-BT facilities has been redefined following the amendments made to the WFD and other relevant legislation on waste (European Union 2018a) for the 2025 and 2035 targets. This is a crucial point for Spain and for other MS. In Spain, according to the EU legal provisions (European Commission 2011), recycling at mechanical biological treatment plants was calculated as: (inputs minus rejects)/(inputs). While material recovery is easily measured as the quantity of metals, plastic and other materials recovered, figures on composting are ambiguous. The organic outputs from M-BT facilities are low-quality organic materials known as biostabilised materials, which can only be accounted for as recycled when these are devoted to certain recovery operations (i.e. R10 operation) (European Union, 2008). In Spain, the AC were not required to provide any evidence on the final destination of biostabilised materials, be it R10 operations, disposal in landfills or incineration. Therefore, all biostabilised materials were accounted for as recycled (i.e. adding up to *R*). (Ministerio de Agricultura y Pesca Alimentación y Medio Ambiente, personal communication, 2017).

Even in the event that all biostabilised materials were being correctly accounted for as recycled, the greater the amount of *W* that a system treats at mechanical biological treatment plants, the greater the exposure of such system to the change in the accounting rules after 2020. For example, the overall *R* for Spain in 2014 would drop from 30.8% to 19.5% if biostabilised materials were subtracted. This issue points to the need for solid accounting rules in the context of monitoring compliance with the EU WFD (Eunomia Research and Consulting *et al*. 2017).

Finally, attention should be paid to the state of waste treatment technology in Spain since in several regions, treatment facilities show low performance levels in comparison to the BAT, hence, there might be some lessons learnt by the best performing regions that might be worth broadcasting to other regions.

4.6.4 The policy gap

It is the view of the authors, that there is a policy gap between the national and the regional administrative levels. As noted by the European Commission, this policy gap is related to a lack of coordination and enforcement, which explains the diversity of MSW management strategies and the differing levels of compliance across regions (European Commission 2015b).

One example is the lack of enforcement mechanisms cascading downwards, in the implementation of the measures that are included in national waste management plans, to the regions. Although the Organic Law 2/2012 foresees the possibility of transferring the EU penalties that are received at the national level to the ACs, due to the non-compliance with the European legislation, these penalties could only be transferred once the EU had imposed them in Spain. Therefore, the lapse of time between the non-fulfilment at national level and the execution of penalties at regional level could be a varying number of years, which prevents this mechanism from being sufficiently dissuasive.

A second example is the lack of a nationwide harmonised framework on landfill taxes. In 2019, only four AC had regional landfill taxes in place for MSW (Ministerio de Hacienda y Administraciones Públicas, 2017). Nonetheless, tax rates on MSW were low (i.e. 12 €/t in Extremadura, 7 €/t in Castile Leon) in comparison to other European countries (Watkins *et al*., 2012). In Cataluña, an escalated increase in tax rates from 30 €/t in 2017 to 47.10 €/t by 2020 was adopted (Ministerio de Hacienda y Adminitraciones Públicas 2017).

A third example would be the uneven deployment of the separate collection of *FGW*, described above.

Covering this gap would require setting a common ground for the most relevant points in order to ensure WFD compliance. Among others, making the separate collection of *FGW* compulsory across all AC, plus minimum tax rates across all regions, with the intention of preventing landfilling and incineration would help significantly.

4.6.5 Contribution to policy-making

In this study, the formalisation of the WFD might be relevant to policy making in several forms. The most obvious is in providing the calculation and representation of the gap between the aforementioned EU recycling targets and current performance (i.e. the distance between the dot and the compliance areas) for any system through three relevant variables under alternative technological assumptions. The said gap can be analysed in terms of the limits of a given system (e.g. the minimum separate collection rates and maximum landfilling and incineration rates that are required in order to achieve a particular target). This in turn serves to identify cases of treatment overcapacity: target compliance entails M-BT overcapacity in five Spanish regions, unless significant technological improvements beyond the state-of-the-art occur before 2020. In Baleares, there is no combination of variables that reach 50% recycling with the current incineration rates. Therefore, there will be incineration overcapacity in Baleares before the end of 2020.

Furthermore, it allows exploring trade-offs between alternative strategies to achieve management goals in a visual manner. These trade-offs also occur between alternatives to reach subsequent targets, unveiling how certain strategies to comply in 2020 might compromise, or be contradictory with, long-term strategies. For example, one region could reach 50% recycling by increasing *MBT*, although the current *MBT* levels might be over those making compliance possible in 2035, which is relevant when increasing M-BT capacity means building new infrastructure. This is the case in Asturias. In this sense, the model in this study can serve to explore the possibility of "minimum regret" paths to the target, avoiding large investments in infrastructure that might later become unnecessary.

Additionally, the model contributes to the debate on the accounting framework stemming from the implementation of new waste legislation (e.g. the amendments to the WFD) (Eunomia Research and Consulting and Resource media 2017, Eunomia Research and Consulting *et al*. 2017) supporting the calculation of the recycling rates in the EU by highlighting three aspects. Firstly, the definition of W currently depends on the accounting method chosen by the MS. In the view of the authors, this is a significant flaw since the overall recycling rate resulting from alternative definitions of W has different reference systems; hence, the recycling rates arising from different definitions of W are not comparable among them. Although MS could choose any of the four reporting methods, a 50% recycling will have a different meaning under each of the definitions. Insofar as the recycling rate is not calculated under a common definition of *W* (i.e. a common definition of which waste streams comprise MSW), the figures at the EU level will be inconsistent. This point has already been addressed in the amended version of the WFD (European Union 2018a) by proposing a common definition of MSW. Having a common and stable definition of MSW will ensure the comparability of results over time and across systems (i.e. Member States, regions, etc.).

Secondly, the model reveals the relevance of defining the conditions under which each waste stream comprising *W* is "recycled". To this end, the focus should be on reintroducing waste materials as inputs into the economy (Ghisellini *et al*. 2016, Iacovidou *et al*. 2017, Lee *et al*. 2017). Thus far, materials can be considered as recycled once these are sorted out after treatment (e.g. metals recovered from mechanical biological treatment or plastic sorted out from packaging sorting treatment plants) (European Union 2018a). Therefore, material losses related to the process of converting recovered waste materials into raw or secondary materials are not accounted for, thus missing a crucial dimension of recovered materials, which is quality (Roithner and Rechberger 2020). High quality outputs from sorting processes (e.g. packaging waste sorting plants) lead to reduced material loses in the process of converting waste into new materials. This point is particularly relevant for the organic outputs from M-BT plants, but also for those waste streams for which 100% recycling is currently being assumed[16] (e.g. paper and glass).

A third issue is related to the effect of MSW composition. The relative abundance of each waste stream makes an overall target easier to reach for those systems with a higher relative abundance of those streams having higher waste stream-specific efficiencies (e.g. paper and glass). In order to avoid such effects, the recycling rate should set common waste stream-specific targets, resulting in different overall recycling targets for each system (i.e. Member State-specific overall recycling rates). Otherwise, the accounting framework would implicitly encourage the separate collection of those fractions with the highest waste stream-specific recycling rates. Thus far, specific targets have been set for packaging waste materials and WEEE, although these targets are set as a share of what producers, distributors and importers declare to have placed in the market, instead of abundance found in MSW composition (European Union 1994, 2012, 2018b, 2018c). Notwithstanding, the relevance of MSW composition demands a common and continuous monitoring scheme for this variable.

4.6.6 Methodological issues and limitations

The model in this study formalises the recycling rate, as defined in the EU WFD. It integrates MSW composition, treatment efficiency and MSW management strategies that are understood as the combination of *SC*, *MBT* and *D*. The visualisation of results through ternary plots facilitates an intuitive representation.

From a methodological point of view, several issues should be borne in mind when it comes to interpreting the results. First, the definition of the three main variables (i.e. *SC*, *MBT* and *D*) in order to explore possible combinations is an a priori methodological decision grounded in its relevance for the MS (i.e. a significant number of policies are focused on these three variables). However, it frames the discussion around a limited set of possibilities which express only a part of the complexity derived from waste management systems, e.g. it skips the trade-offs between landfilling and incineration (Cherubini *et al*. 2009, Assamoi and Lawryshyn 2012).

Regarding *SC*, in the case of Spain it is comprised by the sum of 13 different waste streams. Therefore, the minimum value for *SC* that is calculated by the model might be achieved by a limited number of combinations of values for these 13 waste streams. For example, in the case of Andalusia (Table 4.8), two combinations of the variables comprising the minimum *SC* (0.3551) comply with R=0.5. If these combinations are analysed, it can be observed that the values for several variables (e.g. *PC*) correspond to the maximum value for the variable according to its abundance in waste composition (see Table 4.3). This implies that, for example, all paper and cardboard waste that is generated should be collected separately. This result is mathematically coherent since the minimum value of *SC* that is required to obtain a given R is achieved by maximising the collection rate of those waste streams with higher waste stream-specific efficiencies. However, in practice, collecting the totality of a single waste stream might be non-feasible. Consequently, feasible *SC* figures to comply with R=0.5 will likely be over the minimum as calculated by the model in a real management context. This issue makes the contours, somehow, "optimistic" and reinforces the need for increasing *SC* in most Spanish AC. From a more general perspective, this means that since the cost efficiency of the complying combinations is not considered, the number of feasible combinations might be even narrower in a real management context (Kinnaman 2017).

[16] According to recent waste characterisations made by the Catalan Waste Agency (Agència de Residus de Catalunya 2020), about 15% of paper and cardboard and 5% of glass packaging separately collected might be unsolicited materials. Therefore, equalling separate collection and recycling of these flows implies an over estimation of the overall recycling rate.

Table 4.8 **Example of combinations of variables for the minimum SC (0.3551) required to reach R=0.5 in Andalusia under the current technology**

Variable	Combination 1	Combination 2
PC_c	0.1900	0.1900
GP_c	0.0700	0.0700
FGWc	0	0
LP_c	0	0
G_c	0.0022	0.0022
MET_c	0.0055	0.0055
PLA_c	0	0
WD_c	0.0067	0.0135
TEX_c	0.0037	0
$WEEE_c$	0.0075	0.0038
BA_c	0.0003	0.0009
BK_c	0.0692	0.0692
Total (*SC*)	**0.3551**	**0.3551**

Source: own elaboration.
Notes: PC_c is the separate collection of paper and cardboard; GP_c is the separate collection of glass packaging; FGW_c is the separate collection of food and garden waste; LP_c is the separate collection of light packaging; G_c is the separate collection of non-packaging glass; MET_c is the separate collection of non packaging metals; PLA_c is the separate collection of non-packaging plastic; WD_c is the separate collection of wood; TEX_c is the separate collection of textiles; $WEEE_c$ is the separate collection of waste electrical and electronic equipment; BA_c is the separate collection of waste batteries and accumulators; BK_c is the separate collection of bulky waste.

Regarding the mathematical formulation, it is a straightforward linear formalisation of the WFD recycling rate as constants and variables. This implies that the contours comprising compliant combinations of *SC*, *MBT*, and *D* for a given technology mix do not capture potential feedbacks between variables. For example, the overall treatment efficiency of a system might increase as *SC* grows (e.g. waste stream-specific recycling efficiencies could be modelled as functions that are dependent on collection rates instead of as constants). This hypothesis could also be tested in time series of individual regions and facilities in order to have further insight, however, such data are not available at regional level.

Furthermore, it is assumed that technology (i.e. type of treatment facilities and its treatment efficiency) and waste composition remain constant; hence, the aforementioned gap has to be interpreted as “the gap between the EU recycling targets and the performance of each AC in year 2014”. This is particularly relevant for those regions where there is no separate collection of FGW, since the adoption of this strategy has not been modelled; hence, the range of possibilities for compliance explicitly excludes it. However, the model could be programmed to calculate how this strategy would change the results for a given technology (e.g. the Spanish average efficiency).

Data availability is limited when it comes to subnational analyses. For example, the model does not integrate other targets on waste management, as required by further EU legislation. While the model is able to include such constraints, the lack of data has prevented the authors from undertaking such an analysis. Furthermore, there were no available data on the recycling efficiency of 8 out of 14 waste streams (17.57% of waste composition) at regional level; hence, national figures were used instead. In response to this limitation, the model was built so that data inputs can be easily updated in the event that new information is made available.

4.7 Conclusions

The recycling rates, as defined by the WFD, can be formulated as a numerical model in order to explore the distance between the current situation of a given system (i.e. Member States, regions, etc.) and the combination of variables that allow compliance with a condition (e.g. recycling targets). In this work, the conditions are the WFD recycling target set by the EU for 2020 and 2035 and the systems analysed are the Spanish regions. The results are summarised and visualised in ternary plots that represent the combination of three variables that allow for accomplishment of the WFD target for alternative scenarios regarding treatment efficiency. These variables are: 1) separate collection rates, 2) the direct disposal of unsorted waste in landfills and incinerators, and 3) the rate of unsorted waste treated at mechanical-biological treatment plants, which are typically of interest for policy-makers.

By applying this model to the Spanish regions, compliance with the WFD target has been shown to be uneven across regions, as a result of differing waste management strategies implemented thus far (e.g. significant investment in mechanical-biological treatment plants, improving separate collection, prioritising disposal facilities such as incinerators). Consequently, the aforementioned gap within each region has different traits, such as the need for expanding source segregation, improving technology or limiting direct disposal. Given the current legal framework in Spain, compliance at national level will rely on the coordination between the State and the regions to make those changes happen in a timely manner.

The model can be of interest for policy-making, since it calculates the gap with respect to the WFD target in a straightforward manner and identifies trade-offs between management strategies in the short- and midterm. Furthermore, the model foresees treatment overcapacity. From an EU-level perspective, the model contributes to the debate on the need for a waste-stream-specific definition of "recycling" and the influence of waste composition over the definition of targets.

Further research should focus on modelling feedbacks between variables, while improved data inputs could enrich the analytical capacity of the model. Moreover, integrating the requirements of other regulation on waste (e.g. target on the landfilling of biodegradable waste, specific targets on packaging and waste electrical and electronic equipment), and representing a subset of more realistic values for *SC*, would also make the model more appealing to policy-makers. Finally, the combinations obtained from the model are calculated regardless of their cost-efficiency. Significant insights could be gained by adding cost functions to the model, so that the different combinations of *SC*, *MBT* and *D* could be appraised in terms of cost-efficiency.

Chapter 5

Conclusions

5.1 Summary of conclusions

Derived from the work carried out in this thesis, several conclusions can be drawn. Specific conclusions have been already exposed in the context of each chapter and are next summarised.

A first conclusion is that **the calculation of EW-MFA at regional level is methodologically possible and analytically profitable**. Further methodological refinement and harmonisation would be required in order to make these accounts comparable to nation-wide studies, though. In this sense, the main challenges have been identified and considering that the methodological decisions made for this work require further discussion for a more general application, these have contributed to understanding the scope of the efforts required.

Chapter two materialises the calculation of the main EW-MFA input indicators for Spain at regional level. These confirm that **economic growth led by the construction sector**, as is the case for the period 1996-2007 in Spain, **has a strong influence on the regional metabolic pattern of a country**. In contrast with other developed economies, a loss of material productivity and an increase in CO_2 emissions accompanied economic growth in Spain. The housing bubble also exacerbated the share of non-renewable materials within material consumption across all the Spanish regions.

These results are unsurprising given the material intensity of the construction sector, particularly regarding construction minerals. Furthermore, evidence from the Spanish case has shown how **very differing metabolic patterns coexists within a country**, and that these **differences in material extraction and consumption were amplified during the economic growth period** between 1996 and 2007.

Interregional trade, i.e. between subnational units, is confirmed to be larger in size and different in its composition in comparison with international trade. This implies that **trade between regions of a country might be a major mechanism of environmental burden shifting**, as it occurs with international trade.

In chapter three, where interregional and international trade flows are analysed on a material-per-material basis, it is found that **the Spanish regions play different commercial roles at interregional and international level**, and according to the type of material considered. It is found that Spain is completely dependent on the international imports of metals and fossil fuels. Therefore, all the Spanish regions would be shifting the environmental burdens related to the extraction of these materials towards other countries.

Despite the methodological uncertainties related to working with direct flows only (e.g. mixing raw and processed materials in the same trade accounts, assuming certain homogeneity within material categories) a profiling of the commercial roles of the Spanish regions is proposed. Derived from this profiling it is found that **the Spanish regions can play different roles** (net importers/net exporters) **for different materials and that this role might be different at regional and international level for the same material** (i.e. one region might be a net regional importer and a net international exporter of biomass).

One of the most striking results is the consistent role of Madrid as a net importer for all types of materials in both the interregional and international context. Plus, it is confirmed that, considering its magnitude at regional level, **the trade of non-metallic minerals deserves further attention and analysis.**

Although the original intention of this thesis was carrying out a proper analysis of the output flows at regional level, the lack of data availability at regional level (a conclusion in itself, see below) prevented the author from developing such a study. Instead, a narrower focus on municipal solid waste was applied.

Chapter four reveals that, in parallel with extraction and trade patterns, **municipal solid waste management policies and recycling largely differ across the Spanish regions** and that all of them were far from accomplishing the EU target on recycling for 2020.

According to these results, three main municipal solid waste management strategies can be identified across the Spanish AC: a first set of regions focused on maximising separate collection while minimising mixed waste; a second set of regions focused on maximising the recovery of materials from mixed waste; and a third set of regions that were not taking any steps towards achieving the 50% recycling target keeping the landfilling of waste (i.e. with no previous treatment) as the main management option.

A set of three main barriers to achieve the recycling targets common to all the regions were found: the lack of a proper strategy for the separate collection of biowaste; the low efficiency of waste treatment technologies (i.e. material recovery for both mixed and separately collected waste); and the lack of a consistent policy framework in key areas such as waste taxes.

Next, two additional conclusions stemming from an integrated view of the thesis are provided.

5.1.1 The data gap: managing the environment blindly?

A first overall conclusion of this work is methodological. EW-MFA at subnational level is still struggling with data unavailability compared to EW-MFA at national and international level. Whereas items such as domestic extraction are easier to compile at regional level, international trade may not be available (Kovanda *et al.* 2009) and interregional trade requires additional hypothesis and discretional normalisation (Carpintero, Sastre, Lomas, Arto, Bellver, *et al.* 2014, Sastre *et al.* 2015). This challenge enlarges when it comes to calculating advanced models based on input-output tables, such as material footprints (Piñero *et al.* 2020).

The fact that it has not been possible to compile a full database on the output side of material flows at regional level for Spain reinforces this conclusion. Greenhouse gases emissions are readily available given that the ACs are responsible for the reporting to the national authorities, and these are in turn committed to EU-wide and global agreements. However, when it comes to, for example solid waste, data is scarce and contradictory when several sources are compared (i.e. national vs. regional). Only municipal waste could be addressed in a comprehensive way at regional level and only for years well after 2010.

So, we can conclude that regional environmental management in Spain (as it may be the case for most countries) has occurred in the context of a worrying lack of data. This fact alone might help understand where Spain stands in terms of environmental policies in 2021 (e.g. far from reaching the EU's legal binding targets).

In the light of the current resource efficiency policies in the EU (e.g. circular economy policies), subnational material flow accounts could provide a better resolution and policy targeting. As far as this thesis lets me envision how such an endeavour might occur, coordinated and targeted actions would be necessary, in the vein of those from the late 90's and early 2000, when the first Eurostat manual came up. In this sense, I find the differing weight subnational administrative unit have across EU countries to be a barrier for such coordinated effort. In contrast, the more evident the relevance of regional socioeconomic metabolism is shown in the literature, the more appealing the subnational approaches becomes (Delgado *et al.* 2014, Christis *et al.* 2017, Naredo 2017, Bianchi *et al.* 2020, 2021, Piñero *et al.* 2020).

5.1.2 A country made of differing metabolic profiles

A second conclusion stemming from the results of this thesis is that the socioeconomic metabolism of Spain is quite diverse on the inside, and values twice/half the average for the main EW-MFA indicators can be found across regions. EW-MFA performed at a single scale might therefore be analytically misleading if the realities enclosed within a country are different enough for the average to explain nothing relevant in environmental terms: a given reference value might seem relatively low whereas it might be hiding the complete resource/ecosystem exhaustion of a region.

Trade between subnational regions has been shown to be intense whereas specialisation patterns also play a role at subnational level. The construction bubble exerted environmental extraction burdens on all the regions, but also increased the trade of construction materials with clear net importers and exporters so confirming a pattern of environmental burden shifting between the Spanish regions.

Regional heterogeneity is also observed in the field of municipal solid waste management. Performance across regions reaches differing results both in quantitative and qualitative terms because of the different (some of them antagonist) approaches deployed.

Besides the patterns observed during the 1996-2007 economic cycle, further questions arise: how has Madrid become a blackhole of materials and energy? why hasn't any region claimed for an "interregional ecological debt" so far? Also, how are regional extraction and trade patterns interacting with issues such as depopulation of rural areas? Why are environmental issues not considered in welfare distribution debates at national level? Although this thesis has covered the most relevant EW-MFA indicators for Spain, these issues call for further analysis with more sophisticated tools such as raw material equivalents and advanced statistical analysis. Furthermore, the results enclosed in this thesis should lead to further reflection on environmental governance issues in Spain, particularly regarding the role of the national government in monitoring and correcting the observed regional imbalances. The economic, social and environmental imbalances between the Spanish regions is a well-known issue (Delgado and Sánchez 1999, Delgado *et al.* 2014, Naredo 2017) and EW-MFA can serve as a quantitative support for the environmental side of this debate.

Finally, according to the yet scarce results for other countries (Kovanda *et al.* 2009, Wang *et al.* 2019), the phenomena observed in Spain, i.e. regional polarisation in environmental terms, does not seem to be uncommon. This is an important point since improving the resolution of EW-MFA might lead to a better screening of material extraction/consumption/disposal hotspots. Such an exercise might be particularly relevant for countries with a extractive profile such as India or Brazil.

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