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An empirical analysis of environmental externalities incidence on financial performance

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to Fiorella and to mother earth

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Carla Antonini, Barcelona, April 2016

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Chapter 1. Introduction

1.1 Introduction, motivation and research objectives

Due to an increasing deployment of natural resources, improvement in environmental performance has become a major goal for our economies over the past decades. In this quest, the need for reliable information systems for measuring and valuing the environmental impacts from our current production and consumption patterns has proved acute.

A central issue of accounting is to disclose useful information for deciding properly about the administration of scarce resources. Given that, nowadays, natural capital has become a scarce factor (Costanza et al., 1997), accounting needs to update its principles to bring them to line with social and environmental concerns (Mathews, 1995). In this call, accounting needs to start a dialogue with the science of sustainable development to endeavour the integration of environmental impact from economic activities (Bebbington and Larrinaga, 2014). Researchers attempting to succeed in this integration started environmental accounting within the broader area of social accounting see, e.g. (American Accounting Association, 1975; Belkaoui, 1984; Dierkes and Preston, 1977). Since its very origins these attempts had detractors and supporters. On the one hand, it were sceptically received by researchers who doubted about how much emancipating strength can have the integration of environmental impacts before being manipulated by dominant ideology (Cooper, 1992; Maunders and Burritt, 1991; Puxty, 1986). On the other hand, it were supported by researchers who claimed that accounting should include enormous uncounted and/or incorrectly attributed costs to keep externalities within the whole picture and transcend the conventional ethics of accountant to client to that of accountant to the society as a whole (Bainbridge, 2006; Mathews, 1995). In fact, it is claimed that the doubtful potential of this integration depends on how to overcome the extremely challenging transformation of conventional accounting accepted rules regarding measurement and valuation (Gallhofer et al., 2000; Larrinaga, 1999; Schaltegger et al., 2003).

Accepted rules of measurement and valuation revolve around, at least, three accounting principles: (i) capital to maintain, (ii) valuation of assets and liabilities and, (iii) units of measure. Traditional accountants might be well acquainted with these concepts applied to economic capital, however, traditional accounting dismisses natural capital and lacks of established methodologies to measure and value environmental impacts.

On the one hand, the decision to maintain natural capital could be rather straightforward. On the other hand, the process of measurement and valuation of environmental assets and liabilities is challenging given that the process of commensuration requires in all cases vast amounts of resources, organisation and discipline; and it is deeply influenced by social and political stakes (Espeland and Stevens, 1998). In the particular case of the environment, the complexity is not only merely technical but it is also intimately linked with the insoluble dilemma of valuing nature in a homogenized and rational way without valuing it wrongly, or even more concerning, less. Arguably due to lack of awareness regarding the value natural resources, or as vital expressions of core values or at least of political stakes, most environmental impacts remain incommensurable (Espeland, 1998), which in accounting terms equals zero.

Ideally, all, or at least most relevant, true costs and benefits of economic activities should be included to ensure a transparent, reliable, relevant and comparable accounting framework. This concept is not new; it was noted by Pigou (1920) that the market fails unless it includes all costs. Therefore, unless accounting principles take natural capital and environmental costs and/or benefits, called externalities[1] into account, accounting will result in biased information and therefore improper for sound decision making.

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[1] In this thesis the term "externalities" refers exclusively to the environmental impact caused by economic activities which has been excluded in traditional accounts (e.g. air pollution, loss of biodiversity, soil erosion). This thesis excludes other types of externalities such as social externalities and it also leaves out of scope the so-called ecosystems services, which are originated by ecosystems functionality (e.g. bacteria enhancing nitrogen availability; animal pollination; forests stabilization of water flow).

According to standard theory, under certainty, perfect competition, and with a single government, taxation using a "polluter pays" system would include environmental costs (Pigou, 1920). However, whilst classical economics theory can provide useful preliminary insights, there is a much deeper and more complex economic policy problem because in the real world where there is no perfect competition but instead inter-temporal international collective action with major uncertainty. Moreover, measuring natural capital only in price-driven framework is dangerous given that, without proper understanding of main concepts of sustainability, monetary valuation could act even on detriment of the environment. For example if it is accepted that pollution is a by-product of human activities, tools as "polluter pays" would simply start "selling the environment" (Lehman, 1996). The use of indicators is a common practice to overcome this challenging endeavour. "An Indicator is a specific measurement of an individual element, i.e. global warming, that is used to track and demonstrate performance related to the element via recognition and measurement of items, i.e. specific greenhouse gas," (UNCTAD, 2004p.9). The use of multiple indicators to estimate variables that cannot be measured precisely has been well documented through the history of environmental science (Moldan et al., 1997), and is considered appropriate in accounting where variables that are inherently complex cannot be directly observed (Lamberton, 2005). Interest in developing environmental indicators was first promoted by the need of integrating physical and chemical parameters of the environment. The first contributions were mostly related with developing air and water quality indicators for monitoring (Hezri and Dovers, 2006).

A crucial step to use environmental indicators in accounting is to define properly its boundaries from an environmental point of view and merely from a financial perspective. Boundary setting is an important issue in the measurement of environmental impact because (i) it connects the micro perspective of organizations and the macro systemic perspective of sustainability and (ii) different decisions about boundary setting provide completely different pictures about the environmental performance of entities. The purpose of environmental indicators is, arguably, to provide information about the contribution to sustainability of a particular reporting entity. The notion of “entity” draws on conventional financial reporting, where the reporting/accounting entity is defined following the principle of financial control (IFRS Foundation, 2014). Accordingly, an entity (called “parent or investor”) has the obligation of consolidating information when it controls other entities (called “investees”), understanding by control the ability to affect their returns. The rationale being that consolidated financial statements provide more useful, comparable and reliable information to financial stakeholders, because they represent all the transactions made under the control of a single decision maker. In contrast, the financial information of only a part of the same entity (whatever its legal form) is not financially significant. Analogously, accurate sustainability boundaries improve the comparability, completeness and relevance of environmental indicators. For example, in carbon emissions it is necessary to consider *all* the emissions generated by the activity carried out by the company and, consequently, over which it has some control. In this regard, the comparability of sustainability performance among companies with different outsourcing policies or with different energy mixes would demand the inclusion into those sustainability boundaries of supply chain carbon emissions and the emissions produced by the generation of electricity. Otherwise, the carbon indicator would not inform about corporate contribution to sustainability.

Another important step in the application of environmental indicators is related with the data availability. Most of environmental impacts have no available market valuation. A way of assessing the value of environmental impact, being the fact that most of them have no market based price, is the use of relevant proxies. A proxy variable is something that approaches the measurement of unobservable or immeasurable variables. In order for this to be the case, the proxy variable must have a close correlation with the inferred value. As stated, proxies act as a mirror of what needs to be observed, users should never forget that they are in fact working only with a proxy for an estimated measure. Conventional accounting usually takes market-based valuation measures, which act as a proxy for relative value. This makes measurement and valuation relatively easy, herein the use of proxies is widely spread in finance where the real observation would be too costly or timely inefficient. For example, the real quantity of banking services is difficult to define and observe. As a consequence, banking services are estimated by inputs like labour hours in banking and the number of ATM machines. In the case of future-oriented studies for decision support, historical values are proxies for expected future prices (Huppes and Ishikawa, 2005). Some examples of proxies are avoidance costs, subsidies, taxes, treatment costs (e.g. end-of-pipe costs of decreasing the discharge of pollutants in the environment, costs of retrieving recipients, and the cost of cleaning water from polluted sources). Crop diversity has been used as a proxy for biodiversity at the farm level, crop returns as the proxy of the quantity of aggregate marketable output (Sipilainen et al., 2008). Average yield per acre for wheat, barley and canola has been used as a proxy per productivity (Anielski et al., 2001). Energy use is often a good proxy for fuel combustion-related emissions intensity (Pelletier et al., 2008). In this vein, certain expenditures expressed in monetary terms as internal costs can act as proxies of environmental impact.

Finally, it is important to understand that as environmental impact may be related with multiple phenomenon (i.e.: air emission, water pollution, loss of biodiversity) its units of measure tend also to be multiple and complex, to date no single rule is generally accepted. The right selection of weighting system and aggregation of indicators can be a way out to overcome the challenge. Weights are used to allocate different levels of importance to elements according to a certain mindset, they allow to aggregate groups of materials with common characteristics, such as those that contribute to greenhouse effect. If all items have the same importance, they are unweighted. That is why today it is possible to express each greenhouse gas in terms of its warming potential relative to that of carbon dioxide such as in the greenhouse gas protocol (IPCC, 2006). Weighting compress an important amount of information into a single measure without risking that important changes in the individual flows get hidden in the aggregate, i.e. the conversion of sulphur and nitrogen oxides and ammonia into acidification equivalents; the conversion of nitrogen containing residual flows into kilograms of nitrogen; the conversion of phosphorous and nitrogen compounds into phosphorous equivalents according to their contributions to eutrophication potential in inland water bodies (United Nations, 2003). Although aggregation of materials offers a means of avoiding the disadvantages related to use of a single measure, it should be noted that the possibilities for doing so are somewhat limited. The complexity comes from all those materials for which no weighting scheme is yet available.

Despite the vast amount of research devoted to develop standardized environmental indicators (e.g. Alfsen and Greaker, 2007; OECD, 1997; Osberg and Sharpe, 2002; Wackernagel and Rees, 1995; Wiedmann and Minx, 2008) nevertheless, to date no single methodology is accepted to integrate environmental indicators into the accounting framework. This lack of a generally accepted methodology is in itself an obstacle for its use in accounting (Muller and Sturm, 2001). This is arguably due to obstacles on both an institutional and technical level in the design and implementation of information systems taking into account both environmental and economic indicators. On the institutional side, the current accounting normative which regulates biological assets valuation (IASB, 2009) focuses exclusively on the contractual side of this kind of assets, leaving out of consideration all its biological nature and complexities. Furthermore, the statement of financial accounting standards number five follows the conventional rule that things that are not measurable cannot be reflected (FASB, 1975) and therefore they are non-existent, leaving all unmeasured environmental damage, therefore, concealed in traditional accounts. On a technical side, the increasing complexity related with the use of environmental indicators adds confusion to decision-makers and public opinion (Boyd and Banzhaf, 2007). As a consequence the integration of environmental indicators into traditional accounting is still not fully understood. More specifically related with this thesis, despite advances made regarding boundary setting of sustainability indicators (Archel et al., 2008; Global Reporting Initiative (GRI), 2005; Kaspersen and Johansen, 2014; Liesen et al., 2015), nevertheless the exploration of reporting boundaries in the definition of sustainability indicators still requires further attention. Along the same lines, to date there is no system establishing a unique set of proxies to reflect the value of environmental impact in an accounting framework and the exploration of weighting and aggregation of environmental indicators and its use in accounting is still on an exploration stage. Hence, additional research is needed to propose practical solutions to overcome the challenges aroused in the integration of environmental impact into an accounting framework. In this regard, the aim of this thesis is to actively engage in providing fresh answers to the challenges attending to the call of moving academic research towards a more proactive problem solving position (Gray, 2010; Parker, 2012). We argue that accounting and indicators are necessary to measure environmental impact of economic activities and, in doing so, enabling sound decision-making. To this end, this thesis presents three independent papers.

The purpose of the first paper addresses boundary setting of environmental indicators. On the one hand, it aims to foster the understanding of boundaries' role in the definition and measurement of sustainability indicators and reports. More specifically, to explore in which ways reporting boundaries can be expanded to transcend the boundaries of the organisation in the way sustainability concerns do. In this vein, reporting boundaries should include entities beyond financial control, activities across the supply chain and indirect impacts to ensure a reasonable picture of the organisation´s contribution to (un) sustainability. On the other hand, it aims to explore how entities set their boundaries for the construction of sustainability performance indicators and reports.

Subsequently, the second paper aims to engage in the improvement of integration of environmental and accounting analysis exploring the use of proxies of environmental impact. More in detail, it seeks to revisit the evidence that the over-use of certain inputs and intensive industrialization of farming is not only detrimental, as scientific research shows, to environmental sustainability but also to economic sustainability in the long term. Finally, the third article uses weighting and aggregation to calculate environmental impact from own collected data. It seeks to analyse the relationship between economic and environmental performance with the obtained estimated data.

1.2 Structure and contributions of the thesis

The contribution of this thesis is threefold and is presented in three independent papers. Table 1.1 provides an overview of the three papers that constitute this dissertation.

Chapter two presents the first paper. This study explores the setting of boundaries of environmental indicators through a conceptualization of reporting boundaries to explore how entities set their boundaries for the construction of sustainability performance indicators and reports. The paper contends that the boundaries of significant environmental indicators should encompass all entities over which there is sustainability control together with indirect impacts arising from activities across the supply chain, and not merely direct impacts caused by entities within boundaries based on financial control. Adopting a survey methodology, this article performs content analysis to explore how entities set its reporting boundaries for discharging accountability about environmental impacts of its activities. It uses a sample of 92 sustainability reports from companies included in the 2012 Financial Times Global 500 list. Our main contribution in this chapter is to show that in our sample reporting and indicators boundaries are financially restricted and therefore they do not allow disclosing a complete and inclusive view on entities′ environmental performance. Most reporting entities define boundaries restricted to financial control and most indirect environmental impacts are not reported. As a result, the information based on analysed reports is not a trustworthy base for sustainability decision-making.

Chapter three presents the second paper which tests the use of proxies in the measurement of environmental indicators. More specifically, it tests the use of selected financial costs as proxies of environmental costs. This study seeks to revisit the evidence that the over-use of certain inputs and excessive intensive industrialisation of farming is detrimental for both environmental and economic sustainability in the long term. The paper contributes to the literature performing an empirical study of the trends of productivity and environmental costs of farming in the long-term. To this end, it performs a panel data analysis of productivity and environmental costs on a farm accounting database across European regions over the 1989-2009 period. The study considers farm output per hectare as an indicator of productivity and expenditures on energy, pesticides and fertilisers per hectare as proxy indicators of environmental costs. Results show a significant decrease in productivity and a steady increase in environmental costs across time. These results correlate negatively with both, economic and environmental sustainability of farms. Arguably, this is aggravated in the latter due to hidden environmental costs valued at zero in traditional accounting.

Chapter four discloses the third paper which makes an exploration of weighting and aggregation of environmental indicators to analyse empirically the relationship between environmental and economic performance. The empirical approach draws on own collected data from rice farms participating in a LIFE1 project (LIFE09 ENV/ES/000441, 2013) funded by the European Union (EU). We contribute to the field calculating the actual aggregated indicators of GHG emissions and energy consumption of rice farms under analysis, not only resulting from the farm's immediate productive stage, but also those arising in the earlier productive stages of the inputs required by the farm. Subsequently, we analyse the relationship between environmental and economic performance. Results provides evidence that that integrating the analysis of environmental and economic information is not only possible but also useful to provide more accurate information on the overall costs and benefits of farming.

Finally, in Chapter 5, it is presented a summary of the main results of the thesis.

Table 1.1 Overview of the articles included in the chapters of this thesis

	Chapter 2	Chapter 3	Chapter 4
Title of the article	Planetary boundaries and sustainability indicators: a survey of corporate reporting boundaries.	Productivity and environmental costs from intensification of farming. A panel data analysis across EU regions.	The interrelation between economic and environmental performance: empirical study of rice production in Spain.
Purpose	Discussing the importance of boundaries in the definition of sustainability indicators and, on the other hand, exploring how corporations are considering environmental boundaries in practice in their sustainability reports.	Revisiting the evidence that the over-use of certain inputs and intensive industrialisation of farming is not only detrimental, as scientific research shows, to our natural resources but also to farm productivity and environmental costs in the long run.	Revisiting evidence that integrating the analysis of environmental and economic information is not only possible but also necessary to provide more accurate information on the overall costs and benefits of farming.
Research question	How boundaries are set in the sustainability reports published by some of the largest business in the world?	Is farm productivity per hectare decreasing in the long term? Are farm environmental costs per hectare increasing in the long term?	How environmental and economic performance of farming is interrelated?
Theoretical framework	Legitimacy theory versus stakeholder theory. Planetary boundaries.	Law of diminishing marginal returns. Planetary boundaries.	Environmental impact of farming practices. Greenhouse gas protocol.
Methodology	The paper applies this conceptual framework to a content analysis of a sample of 92 sustainability reports from companies included in the 2012 Financial Times Global 500.	This paper performs a panel data analysis of productivity and environmental costs on a farm accounting database across European regions over the 1989-2009 period.	The study uses own collected environmental and economic data from 9 rice farms in Spain and applies the AgriClimateChange Tool software that allows the weighting and aggregation of environmental impact.
Main findings	Results show a lack of ambition in the practice of setting organizational and operational boundaries. Most reporting entities define organisational boundaries restricted to financial control and most indirect environmental impacts are not reported.	Results show a decreasing productivity and significant steady increase in environmental costs across time. These results correlate negatively with farm profitability and sustainability.	Results show that in the farms under study, the achievement of higher yields is attributable to the greater level of GHG emissions GHG and energy consumption.
Outcomes	Second round revision in "Sustainable Development" (ISI JCR: Q2 in Planning & Development).	Accepted for publication the Journal of Cleaner Production (ISI JCR: Q1 in Engineering, Environmental and Environmental Sciences)	Under review in International Journal of Agricultural Resources, Governance and Ecology (Scopus)

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Chapter 2. Planetary boundaries and sustainability indicators: a survey of corporate reporting boundaries

Planetary boundaries and sustainability indicators: a survey of corporate reporting boundaries

2.1 Abstract

This paper addresses the methodological foundations of boundary setting for sustainability reporting. The motivation of this paper is to engage in the development of such methodology in the understanding that improved sustainability reporting is ultimately necessary for making organizations more accountable of their social and environmental impacts. The aim of this research is twofold: (a) to inquire into the methodological foundations of boundary setting for improved sustainability reporting and (b) to explore current corporate practice in this area, with a particular emphasis on environmental indicators. The paper contends that the boundaries of significant sustainability indicators should encompass all entities over which there is sustainability control together with indirect impacts arising from activities across the supply chain, and not merely direct impacts caused by entities within boundaries based on financial control. The paper explores, through an empirical study of the sustainability reports disclosed by some of the top FT500 companies, how corporations are setting environmental boundaries in practice. Results show a lack of ambition in the practice of setting organizational and operational boundaries. Most reporting entities define organisational boundaries restricted to financial control and most of the indirect environmental impacts sought remain undisclosed.

2.2. Introduction

In recent years, an increasing number of organisations started to produce reports attempting to account for their social and environmental responsibility. The number of organisations among the 500 largest companies claiming to produce this kind of reports increased from 52% in 2005 (KPMG, 2008) to 82% in 2011 (KPMG, 2013). Nevertheless, the design and implementation of systems providing such information has often proved difficult on both methodological and institutional levels, leading researchers to question the relevance of such information (Gray and Milne, 2004; Moneva et al., 2006).

On the institutional side, it is argued that the voluntary nature of sustainability reporting erodes its reliability and quality (Dingwerth and Eichinger, 2010), with corporations motivated by reputational concerns, rather than by discharging their accountability with stakeholders (Bebbington, Larrinaga and Moneva, 2008). The increasing complexity of sustainability reporting has not been matched with a comparable level of methodological sophistication. We would argue that the domination of studies focusing on the institutional explanation of sustainability reporting's lack of quality (e.g. Clément and Searcy, 2012; Boiral, 2013), leaves little room to methodological discussions of sustainability reporting and that it is urgent to create spaces for reflection and experimentation (Mitchell et al., 2012) through which organizations and stakeholders can learn how to make corporate accountability operational in a sustainability context.

One specific methodological topic that has not received the attention it deserves is reporting boundary setting. It has been argued that the triple bottom line heuristic, pervasive in sustainability reporting, is actually obscuring the links between the economy, the environment and society (Milne and Byrch, 2011) as well as the interplay between the micro-organizational and the macro-systemic aspects of sustainable development (Gray and Milne, 2004). Sustainability and environmental concerns transcend the boundaries of the organization and it is uncertain how to define the boundaries of indicators and reports to assess corporate contribution to sustainability. For example, Gray and Milne (2004) argue that there is a mismatch between the actual boundaries of ecosystems sustainability and sustainability reporting boundaries (see also Milne, 1996; Gray 2006). According to such explanation, sustainability reports would be problematic since the analysis of sustainable development is only feasible at the ecosystem level of resolution and not within individual organisations (Gray, 2006).

Baker and Schaltegger (2015) contend that this critique of sustainability accounting is important, but critique needs to lead to opening new spaces, new institutional and technical possibilities to address sustainability. In this regard the motivation of this paper is to engage in the development of improved methodologies for sustainability reporting (Parker, 2012), in the understanding that accounting, corporate reporting and indicators are necessary to measure corporate sustainability, which is the purpose of this special issue. Improved sustainability accounting and reporting is ultimately necessary for making organizations more accountable of their social and environmental impacts. Therefore, the aim of this research is twofold: (a) to inquire into the methodological foundations of boundary setting for improved sustainability reporting and (b) to explore current corporate practice in this area. On the one hand, the study seeks to contribute to the theoretical discussion about the methodological issues raised by boundaries setting in the context of sustainability reporting. The paper contends that the boundaries of significant sustainability indicators should encompass all entities over which there is sustainability control together with indirect impacts arising from activities across the supply chain, and not merely direct impacts caused by entities within boundaries based on financial control. On the other hand, the paper also explores, through an empirical study of the sustainability reports disclosed by some of the top FT500 companies, how corporations are setting boundaries in practice, with a particular emphasis on a set of indirect environmental indicators that have received more attention in both reporting guidelines and practice.

Accordingly, this paper is structured as follows. The second section reviews the literature and examines the main issues arising from reporting boundaries. Key to this paper is the interaction between organizations and planetary ecological processes and the importance of rising awareness about corporate environmental impacts through the notion of sustainability boundaries. Section two finishes by outlining the potential and limitations of a boundary heuristic consisting in organizational and operational boundaries. The third section describes an empirical study using this heuristic to investigate how the worldwide largest corporations are considering environmental boundaries in their sustainability reports. The study involves the content analysis of a sample of 92 sustainability reports published by companies included in the 2012 Financial Times Global 500 (FT 500 thereafter) (Financial Times, 2012). Section four presents the results, which suggest that the quality of boundary disclosure is low. Most reporting entities restrict their definition of organisational boundaries to the criterion of financial control and most indirect environmental impacts are not reported. Finally, section five presents some concluding comments.

2.3. From planetary boundaries to corporate sustainability reporting

The purpose of sustainability reports and indicators is, arguably, to provide information about the contribution to sustainability of a particular reporting entity. The notion of "entity" draws on conventional financial reporting, where the reporting/accounting entity is defined following the principle of financial control (IFRS 10, 2014). Accordingly, an entity (called "parent or investor") has the obligation of consolidating information when it controls other entities (called "investees"), understanding by control the ability to affect their returns. The rationale being that consolidated financial statements provide more useful, comparable and reliable information to financial stakeholders, because they represent all the transactions made under the control of a single decision maker. In contrast, the financial information of only a part of the same entity (whatever its legal form) is not financially significant. As an infamous example, Enron deceitfully failed to consolidate some dependent firms that were used to conceal losses. When Enron was forced to retroactively consolidate those entities, the reported losses and debt lead Enron to file for bankruptcy (see Baker, 2003 for more details). As a result, financial stakeholders who trusted Enron financial statements lost their investments. The reporting entity in the context of financial reporting encompasses all the economic activities controlled by a single decision maker. In Enron it should have included the financial operations of the dependent firms.

Analogously to the case of financial reporting, boundary setting is a crucial methodological step in the definition of the reporting entity whose performance is described in the sustainability indicator or report. Accurate sustainability boundaries improve the comparability, completeness and relevance of sustainability indicators. For example, in carbon emissions it is necessary to consider *all* the emissions generated by the activity carried out by the company and, consequently, over which it has some control. In this regard, the comparability of sustainability performance among companies with different outsourcing policies or with different energy mixes would demand the inclusion into those sustainability boundaries of supply chain carbon emissions and the emissions produced by the generation of electricity. Otherwise, the carbon indicator would not inform about corporate contribution to sustainability. Just as in the case of Enron its financial reports were not informing about its debts and losses.

Unlike financial reporting boundaries –based on one dimension (financial control) and mandatory through financial reporting standards–, sustainability reporting boundaries are specific for each environmental/social indicator and not even the voluntary sustainability reporting guidelines clearly prescribe them (Ackers and Eccles, 2015). Nevertheless, any attempt to define sustainability reporting boundaries needs to relax the principle of financial control to allow the inclusion of environmental impacts that are produced beyond the boundaries of financial reporting, but over which the entity has some degree of control/responsibility. Let us call this *sustainability control*.

Among the economic, environmental and social dimensions of the triple bottom line heuristic this paper is emphasizing ecological issues that, arguably, lie at the core of the notion of sustainable development (e.g. greenhouse gas emissions; GHG thereafter). This is not to downplay the importance of the social and economic dimensions of sustainability. For example, despite its sustainability significance, labour practices in the supply chain are not the focus of this study.

Gray (2010) contends that "accounting for sustainability takes the planet as its accounting entity" (p. 55). However, how can the planet be translated into specific boundaries for sustainability indicators at the corporate level is a problematic question that requires a look at the science of sustainable development (Bebbington and Larrinaga, 2014; Schaltegger et al., 2013).

The notion of ecological/planetary boundaries lies at the core of discussions about sustainable development. In the Brundtland Commission's definition of sustainable development (UNWCED, 1987) it was already stated that "growth has no set limits in terms of population or resource use beyond which lies ecological disaster. Different limits hold for the use of energy, materials, water, and land." (p. 42). Such notion of sustainable development is based on two main tenets that illustrate the importance of boundaries: the limits imposed by "the ecological possible" (UNWCED, 1987) and the absence of limits to economic growth. Both tenets are discussed in the following paragraphs.

Scientific research provides evidence that helps to identify some of the limits imposed by "the ecological possible". Rockström et al. (2009) define a set of planetary boundaries that, according to the authors, “define the safe operating space for humanity with respect to the Earth system” (p. 472), in such a way that crossing these thresholds could cause important subsystems to shift into a new state, where the survival of humanity could be jeopardized. Rockström et al. (2009) found nine processes that demand the definition of planetary boundaries, the first of them being climate change. Certain levels of climate change increase ecological risks, including the retreat of mountain glaciers around the world (IPCC, 2007), the loss of mass from Antarctic ice sheets (Cazenave, 2006), the rise of sea-level (Church and White, 2006) or the rise in the number of large floods (MEA, 2005). The boundary proposed by Rockström et al. (2009) is an atmospheric concentration of carbon dioxide of 350 (in parts per million), with current levels beyond this proposed boundary. The rate of biodiversity loss is probably the more unrestrained planetary boundary. Species loss affects both the functioning of ecosystems and their potential to respond and to adapt to changes in physical and biotic conditions (Suding et al., 2008). The boundary proposed by Rockström et al. (2009) is the loss of 10 species per million species per year, with current levels unknown, but well above 100. The anthropogenic interference in the nitrogen cycle with the activation of growing amounts of nitrogen and phosphorus, transforming for example clear-water in oligotrophic state into a turbid-water eutrophic state (Carpenter et al., 2001), is the third process that Rockström et al. (2009) consider that has exceeded the proposed planetary boundary. The proposed boundary in this case is 35 million tonnes of N_2 removed from the atmosphere per year for human use, while the actual figure is 121. The remaining planetary boundaries identified by these authors are ocean acidification, stratospheric ozone depletion, global freshwater use, land-system change, aerosol loading and chemical pollution.

While the planet is characterized by the ecological limits (planetary boundaries) described in the previous paragraph, economic growth (narrowly defined) has no limits. The objective of sustainable development is, therefore, to make economic development compatible with those ecological limits. As regards measuring corporate sustainability, the focus of this special issue, there is evidence that corporations determine a great deal of, for example, global biodiversity (Chaplin-Kramer et al., 2015) and global climate change (Levy and Egan, 2003), through their decisions about the design, sourcing, production and marketing of their products and services. Whiteman et al. (2013) contend that corporations are central within contemporary economies and societies and conceptualize them as playing an important role in some of the planetary processes identified by Rockström et al. (2009). In this regard, it can be argued that keeping the Earth system in the limits of the "safe operating space for humanity" requires developing appropriate sustainability indicators at the corporate level to understand how companies contribute to global ecological processes.

Significant indicators about the corporate contribution to global ecological processes require a precise definition of corporate boundaries, reflecting the degree of corporate responsibility and control over each ecological issue. Reporting boundaries need to be defined in such a way that the indicator reflects the degree of control (and responsibility) a corporation has over the sustainability issue the indicator is providing information about, allowing managers and stakeholders making decisions about the underlying sustainability issues. However, as the Brutland report states, ecological interactions do not respect the boundaries of individual ownership or political jurisdiction (UNWCED, 1987).

This is the reason why sustainability boundary setting needs to refer to the notion of sustainability, in addition to financial, control; while the latter is more amenable to the ideas of financial reporting, the former also has to consider supply chain and lifecycle perspectives, characteristic of environmental analysis, i.e. *sustainability control*. Such notion of sustainability control for boundary setting has been articulated around two different boundaries: organizational and operational boundaries (Archel et al., 2008). Organizational boundaries refer to how boundaries are horizontally set along the continuum of corporate ownership/control to include subsidiaries, concessions or franchises, among other organizations, linked to the reporting entity (see Meyssonnier and Pourtier, 2013). Operational boundaries refer to how reporting boundaries are vertically set along the supply chain and/or the life cycle of products and services to include the direct and indirect impact of energy and material inputs, outsourced activities and products and services (see also Matthews et al., 2008).

Organizational boundaries

The notion of organizational boundaries helps to decide which organizations are to be included in the reporting entity and whose environmental performance is portrayed in the sustainability indicator or report (GRI, 2002, US EPA, 2014). As previously discussed, the notion of entity draws on the principle of financial control (IFRS 10, 2014), where an entity (called “parent or investor”) has the obligation of consolidating information when it controls other entities (called “investees”), understanding by control the ability to affect their returns. Drawing on the principle of financial control, sustainability boundaries should be inclusive of all group-wide activities (e.g. CDP, 2011; Liesen et al; 2015). However, in a sustainability context, the ability to affect returns is not the appropriate benchmark for the definition of organizational boundaries. Instead, it has been proposed (e.g. GRI, 2005) that it is the influence over other entities´ sustainability performance the relevant hallmark of organizational boundaries in this context. In this regard, organizational boundaries should incorporate not only entities wholly or partially owned by the reporting entity, but also other organisations over whose sustainability the reporting entity has significant influence, i.e. does not have financial but sustainability control. For example, provided that an entity has significant influence over the energy consumption of its contractors, failing to include this information in the indicators and reports of that entity might misrepresent its sustainability performance. The current trend of outsourcing different corporate activities makes accurate organizational boundaries more significant than ever.

Operational boundaries

While the organizational boundary refers to the entities considered for the elaboration of sustainability indicators and reports, the operational boundary refers to the notion that sustainability indicators and reports need to embrace two classes of impacts: direct and indirect environmental impacts (US EPA, 1970, title 40). Direct environmental impacts are those directly produced by the operations of the entity (US EPA, 2014; WBCSD, 2004). These impacts are easily noticeable and are more likely to be included in sustainability indicators and reports. For example, most sustainability reports include estimations of energy directly consumed and carbon directly emitted by the entity's operations. In contrast, indirect environmental impacts are produced by the activities that third parties (e.g. suppliers) perform as a consequence of the activities of the reporting organization (WBCSD, 2004). Indirect environmental impacts stem from upstream and downstream activities along the supply chain and/or the life cycle of products and services (GRI, 2002; Soderman, 2003; Wever et al., 2012). The greenhouse gases protocol (World Resources Institute, 2012) provides a well-known set of guidelines for setting the operational boundaries of a particular sustainability indicator: greenhouse gases emissions. The GHG protocol suggests three different operational boundaries for the elaboration of GHG emissions indicators using the term "scope" instead of boundary. In such framework scope 1 covers direct GHG emissions, i.e. stemming from combustion in the operations of the reporting entity. Scope 2 would also consider the GHG emissions produced by the generation of electricity/steam consumed by the reporting entity. Finally, scope 3 would include all other indirect emissions. The importance of indirect GHG emissions is illustrated by the findings of Matthews et al. (2008), who estimate that scope 3 would amount to more than 75% of the carbon footprint for two thirds of the economic sectors.

Significant sustainability indicators require extending operational boundaries to embrace direct and indirect environmental impacts (UN, 2003; World Resources Institute, 2012; GRI, 2006). Extended operational boundaries allow, if not to translate "the ecological possible" to specific corporate sustainability indicators, at least to open new possibilities for the conceptualization of corporate performance with regard to planetary ecological processes. For example, the service sector is at the final end of the supply chain and, although its direct environmental impact is often limited, it causes significant environmental impacts produced by the operations of third parties, often in the primary or secondary sectors (Wiedman et al., 2006), that provide the service sector with resources for their activities (e.g. energy). Disregarding upstream and downstream ecological impacts would leave out of analysis much of the environmental burden of the service industry. For example, according to Matthews et al. (2008) direct carbon emissions amount to 14% of the carbon footprint for the average industry, with vast variation between the power generation industry (92%) and most service industries. Along the same lines, different studies show that the service industry (Rosenblum et al., 2000) and the information and communication technology industry (Malmodin et al., 2010) have significant environmental impacts, even though their direct impacts might be insignificant.

In summary, sustainability indicators are necessary to assess and make decisions in an organizational context, because organizations have a notable influence over sustainability challenges. Boundary setting is an important issue in the elaboration of sustainability indicators because (i) it connects the micro perspective of organizations and the macro systemic perspective of sustainability and (ii) different boundaries provide completely different pictures about the sustainability performance of whole sectors. The next section reports a study that looks at how corporations are considering environmental boundaries in their sustainability reports.

2.4. Methods

To study how corporations are considering environmental boundaries in their sustainability reports, a content analysis was performed to the sustainability reports published by some of the 2012 FT top 500 companies.

Sample

The sample includes the most recent sustainability reports included in the GRI benchmark database[2], submitted by companies included in the 2012 FT 500 ranking (Financial Times, 2012). The GRI benchmark database includes reports applying the G3 sustainability reporting guidelines (GRI, 2011) that went through a GRI application level check between 2012 and 2013 to obtain a certified level of compliance. 105 sustainability reports were initially identified, but thirteen reports were excluded for two reasons: seven reports were in html, which does not allow access to a full version of the report in a single document and six reports were in languages with which the authors are not familiar (German, Korean and Turkish). The final sample was, thus, reduced to 92 sustainability reports for the year ending in 2012 or 2013, representing all six G3 application levels. Table 2.1 displays the names of the 92 companies included in the sample, classified by industry, showing that the basic materials, the financial, the cyclical good and the energy sectors account for 65% of the sample. Additionally, in terms of geographical distribution (not reported in this table), 26 countries were represented in this sample, but five countries accounted to 54% of the sample: 16 reports were published by US companies, 15 by German companies, seven by French companies and six by Brazilian and by Spanish firms.

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[2] Available online at http://database.globalreporting.org/benchmark.

Table 2.1: Companies whose sustainability report is under analysis, by industry (N=92)

Industry (n value)	Firms	Firms	Firms	Firms
Basic Materials (20)	Air products	Antofagasta PLC	ArcelorMittal Brasil	Atlas Sp. z o.o.
	Barrick Argentina	BASF SE	BHP Billiton	CRH
	Dow Chemical	Grupo Mexico	Holcim Spain	Kumba Iron Ore
	Monsanto	Penoles	Praxair	Rio Tinto
	Saint-Gobain	The Mosaic Company	Vale	Xstrata Cooper Peru
Financials (17)	ACE Seguros S.A.	Allianz SE	Banco Santander Brasil	Bank of America
	BBVA Bancomer	China Everbright	Credit Suisse	Deutsche Bank
	Hang Seng Bank	ING Direct	Intesa Sanpaolo	Itau Unibanco S.A.
	Itaúsa	Munich R.E.	Prudential Financial	Unicredit
	Westpack Banking			
Cyclical Goods (12)	BMW Group	Cognizant	Daimler	GM-Chevrolet Argentina
	Inditex	Infosys Limited	MAN Group	PPR S.A.
	Target	Unibail Rodamco SE	Volkswagen	Walmart
Energy (11)	CLP	Duke Energy Perú	Eni S.P.A.	PTT Exploration
	PTT Global Ltd.	PTT Public Company	Repsol-YPF	Shell
	Suncor Energy	TOTAL	Tullow Oil	
Non-Cyclical Goods (7)	FEMSA	Heineken Spain	Kellogg	Kimberly-Clark
	Nestlé	Unilever Brasil	Wesfarmers	
Industrials (6)	Bayer AG	CSX Corporation	ITC Ltd.	Reliance Industries
	Schneider Electric	Siemens		
Health care (5)	Celgene S.L.U.	L´Oreal France	Merck USA	Novartis
	Sanofi			
Telecommunication (5)	Deutsche Telekom	Du (Emirates)	SingTel – Singapore	Telecom Italia
	Vodafone Spain			
Utilities (5)	Enel	GDF Suez	Iberdrola	RWE
	Spectra Energy			
Technology (4)	Dell	Intel Corporation	SAP	Tata Consultancy Services

Notes: Thomson Reuters business classification scheme available at: http://thomsonreuters.com/content/dam/openweb/documents/pdf/tr-com-financial/methodology/trbc-methodology.pdf

As explained in the introduction, previous research has expressed concerns about the relationship between sustainability reporting and sustainable development. These concerns have often focused on GRI (Buhr et al., 2014; Etzion and Ferraro, 2010; Milne et al., 2009; Moneva et al, 2006). However, it is important to make clear that the purpose of this study is not to judge GRI as such, but to inquire into the methodological foundations of boundary setting and to explore current corporate practice in this regard (see above). Moreover, the GRI database and GRI indicators are used instrumentally, as a way to identify the sustainability reports under study and to locate those specific disclosures that are more likely to be found in sustainability reports.

An additional critique to this sample could be that it is skewed towards specific countries, industries or large companies. Although this critique has some ground, it is also the case that those countries, industries and companies arguably present the best sustainability reporting practice, strengthening the conclusions of this investigation, i.e. including second-tier sustainability reports will not improve the results of the boundary reporting analysis.

Content analysis

A content analysis (Abbott and Monsen 1979) was performed to the sample sustainability reports to study how organizational boundaries are set for the whole report and how operational boundaries are set for specific environmental indicators. Groeben and Rustemeyer (1994) define content analysis as “a way of systematising the normal, everyday understanding of texts” (p. 310). Any data using fair standard meanings for a specific group of people can be subjected to content analysis (Krippendorff, 1989). More specifically, a thematic content analysis approach was followed, where the unit of analysis is the “themes” (Beattie et al., 2004; Jones and Shoemaker, 1994), which are usually derived from theory and investigated in the corporate reports. Thematic content analysis has been widely used in environmental accounting research (e.g. Beck et al, 2010; Buhr and Reiter, 2006; Clarkson et al., 2008; Tregidga and Milne, 2006).

An important aspect of this technique, such as reliability, can be enhanced using well-specified decision categories, well-specified rules and multiple coders (Milne and Adler, 1999). In this regard, categories and rules specification lies on the well-defined design of the specific disclosure items that are sought in the sustainability reports. The development of variables for the content analysis (table 2.2) is based on the GRI guidelines, which convey a commonly accepted language about sustainability reporting and reporting boundaries, minimizing the likelihood of disparate interpretation of disclosure. Furthermore, a key factor in reliability is the agreement among independent observers (Hayes and Krippendorff, 2007): 27% of the sustainability reports were analysed by the authors separately to test the research instrument, with any discrepancy about the coding procedure being discussed and agreed.

The first column in table 2.2 shows the fourteen G3 disclosure items considered for this study. Two of them (2.2 and 2.3) disclose information about the reporting organizational profile, four (3.6, 3.7, 3.8 and 3.11) reveal specific boundary issues. Those six indicators reveal different features of organizational boundaries. Eight more disclosure items allow analysing disclosures about indirect environmental impacts. Five of them are G3 core indicators and three are additional indicators.

Content analysis requires developing a set of rules for coding, measuring and recording the analysed data (Milne and Adler, 1999). The research instrument developed (table 2.2) was adapted for that purpose to include G3 disclosure (GRI, 2011), rather than the G2 guidelines (GRI, 2002) used by Archel et al’s (2008). A quantitative scoring method (Al-tuwaijri et al., 2004; Krippendorff, 1989) was used to reduce disclosure to numbers that are considered as commensurate to allow analysis. This method consists in assigning either 1 for the presence or 0 for the absence of each disclosure item in each report. Additionally, an intermediate score (0.5) was used, as explained in table 2.2, when the report provides general descriptions in disclosure items where a precise measurement is required.

Table 2.2: Development of variables for content analysis (adapted from Archel et al 2008)

	Variables						
G3 Disclosures and indicators (GRI 2011)	***ORGB***	***DISB***	***INDI***	***INDC***	***INDA***	***MSIC***	***MSIA***
(3.6) Boundary of the report (e.g., countries, divisions, subsidiaries, leased facilities, etc). See GRI boundary protocol for guidance. (3.7) State any specific limitations on the scope[1] of boundary of the report. (3.8) Basis for reporting on joint ventures, subsidiaries, leased facilities, outsourced operations, and other entities that can significantly affect comparability from period and/or between organization.	Extended (1) financially-restricted (0) boundaries for report	Mentioning companies inside financially restricted boundaries (1)					
(2.3) Operational structure of the organisation, including main divisions, operating companies, and joint ventures.		Disclosure on participation in subsidiaries (1)					
(3.11) Significant changes from previous reporting periods in the scope[1], boundary, or measurement methods applied in the report.		Changes in the definition of boundaries (1)					
(2.2) Major products and/or services (…) degree to which the organisation relies on outsourcing.		Outsourcing information (1)					
Core Indicators							

(EN4) Indirect energy consumption by primary source							
(EN16) Total direct and indirect greenhouse gas emissions by weight.				For each indicator same rule as INDIRECT variable		For each core indicator, direct impact disclosure (1); otherwise (0)	
(EN17) Other relevant indirect greenhouse gas emissions by weight.							
(EN26) Initiatives to mitigate environmental impacts of products and services, and extent of impact mitigation			For each indicator, nondisclosure (0); general description (0.5); description and quantification or detailed information (1)				
(EN27) Percentage of products sold and their packaging materials that are reclaimed by category							
Additional Indicators							
(EN6) Initiatives to provide energy-efficient or renewable energy-based products and services, and reductions in energy requirements as a result of these initiatives.					For each indicator same rule as INDIRECT variable		For each additional indicator, direct impact disclosure (1); otherwise (0)
(EN 7) Initiatives to reduce indirect energy consumption and reductions achieved							
(EN29) Significant environmental impacts of transporting products and other goods and materials used for the organization's operations, and transporting members of the workforce.							
Max. derived from content analysis (min. = 0)	1	4	8	5	3	5	3
Standardized max. For each variable (min. = 0)	1	1	1	1	1	1	

Notes: [1]Scope meaning disambiguation. In this table "scope" refers to issues in sustainability, also denominated aspects in the context of GRI such as energy use, greenhouse gas emissions, etc., covered in a report (GRI, 2011).

As the first row of table 2.2 describes, seven variables were developed to encapsulate the information about organizational and operational boundaries. Two variables account for organizational boundaries and five variables for operational boundaries. First, *ORGB* analyses whether, according to disclosures items 3.6, 3.7 and 3.8, the organizational boundary includes not only entities wholly or partially owned by the reporting entity, but also other organizations over which the reporting entity exerts significant sustainability control. *ORGB* takes the value of 1 if the information about organizations whose sustainability is influenced by the reporting company is consolidated in the sustainability report with information gathered on a strictly financial ownership or control basis. *ORGB* takes the value of 0 if, according to these disclosure items, the organizational boundary of the sustainability report is restricted to the financial control of other companies, as practised in conventional financial reporting.

The second organizational boundaries variable, *DISB*, focuses on two boundary topics. On the one hand, *DISB* measures whether the report discloses those organizations that make up the sustainability reporting entity, considering just a financially restricted boundary. According to their definition, G3 disclosure items 3.6, 3.7 and 3.8 can provide such information. Additionally, disclosure item 2.3 can also provide information about the participation of the reporting entity in subsidiaries and 3.11 can provide information about changes. On the other hand, item 2.2 asks companies to disclose the degree to which they rely on outsourcing, which is a key boundary issue, as was previously discussed. A value of 1 is given if such items are disclosed in the sustainability report and 0 otherwise. Those scores are added and finally standardized to a 0–1 scale ($0 \leq DISB \leq 1$).

Five variables explore operational boundaries. First, *INDI* captures all the information about indirect environmental impacts that can be usually found in a

G3 sustainability report. *INDI* encapsulates disclosure on five G3 core indicators (EN4; EN16; EN17; EN26; EN27) and three G3 additional indicators (EN6; EN7, EN29). Most indirect environmental indicators advocated by the GRI guidelines focus on climate change (EN16 and EN17) and energy (EN4, EN6, EN7). The rest provide information about indirect impacts arising from packaging (EN27), transport (EN29) and products (EN26). As for the coding rules, disclosures were only coded when they provided information about indirect environmental impacts (ignoring additional disclosures included in the definition of the G3 indicator). For example, in EN26 this analysis focuses on the initiatives to mitigate environmental impact in the use phase of products and services, while the G3 definition of such indicator includes environmental impacts *in the production* and/or use phases (GRI, 2011). As previously stated, the aim of this analysis is not to assess GRI, but to explore how boundaries are considered in sustainability reports. Each indicator is given a score of 1 if the reporting organisation fully discloses the required information, 0.5 in case of general disclosures lacking the required detail and 0 for non-disclosure. The addition of the scores given to the eight indicators is standardized to a 0–1 scale ($0 \leq INDI \leq 1$). Subsequently, *INDI* is split into two variables: the first measuring core indicators (*INDC)* and the second additional indicators (*INDA)*. Those two variables are also expressed in a 0–1 scale (see table 2.2).

The last two variables, *MSIC* and *MSIA* measure inaccurate disclosures for core and additional indicators respectively. They account for misleading disclosures of direct impacts as if they were indirect impacts as well as for denials of indirect environmental impact (when a reporting company unsoundly claims that a particular indicator under analysis is irrelevant or not applicable). Those two variables are also standardized to a 0-1 scale. Finally, scores are distributed across industries using the Thomson Reuters 10 sectors business classification scheme.

2.5. Results and Discussion

Descriptive statistics are presented in table 2.3. In essence, the analysis of the sustainability reports submitted to the GRI benchmark database by FT 500 companies shows that, like financial reports, sustainability reports are based on a notion of the entity defined by financial control, not consolidating information about those organizations over which the reporting entity has sustainability control. Along the same lines, the disclosure of indirect environmental impact indicators is far from the disclosure levels required by GRI, even in the case of core indicators.

Table 2.3: Descriptive statistics

Variables	Mean	Max	Min	Std. Dev.
ORGB	0.000	0.000	0.000	0.000
DISB	0.370	0.750	0.000	0.263
***DISB* (2.2)**	0.011	1.000	0.000	0.104
INDI	0.378	0.938	0.000	0.204
INDC	0.457	1.000	0.000	0.240
INDA	0.246	0.833	0.000	0.250
MSIC	0.107	0.800	0.000	0.171
MSIA	0.217	1.000	0.000	0.268

Notes: Mean estimations excluding energy, financials and telecommunication sectors: *INDI*= 0.393; *INDC*= 0.481; *MSIC*=0.159

As regards the definition of organisational boundaries beyond financial control (*ORGB),* 92 out of 92 reports are assigned a 0 score. Despite the previous discussion in GRI (2005) and the possibility of making disclosures in some GRI items, the analysis could not identify in any report a discussion about the consolidation of a single organization on the grounds of influence over their sustainability performance. This seems to confirm that organizational boundaries are, as expected, limited to financial control and, thus, subject to a lack of systemic view as argued in the reviewed literature and in the GRI boundary protocol itself (GRI, 2005; Milne and Byrch, 2011). This approach to the definition of the reporting entity, arguably, limits the usefulness of the sustainability report/indicator as a valid instrument for making decisions concerning broader sustainability.

Disclosing the participation on subsidiaries and the degree of dependence on outsourcing (*DISB*) attains a mean value of 0.37, suggesting that in more than 60% of the cases not even the entities included in the report (within a financial control perspective) are disclosed. Therefore, as it comes to organizational boundaries, the reporting entity seems to be generally defined according to the principle of financial control. But unlike financial reporting, a substantial part of the sustainability reports even fail to disclose enough information for a stakeholder to discern the composition of the reporting entity. Archel et al. (2008) analysed the 2005 reports produced in accordance with G2 and, as organizational boundaries concerns, found similar results (mean *ORGB* = 0.000; mean *DISB* = 0.304). These results suggest that the development of sustainability reporting that has taken place since 2005 has not changed the definition of sustainability boundaries and that, arguably, defining them on sustainability control grounds could be seen as a radical change for corporations. Further, these results show little improvement in disclosing the composition of the reporting entity within a financial control perspective.

It is worth analysing separately disclosure item 2.2 (*DISB* (2.2)), given the importance of outsourcing and the fact that it performs remarkably lower (0.011) than the rest of items included in *DISB* (mean=0.370). According to the GRI definition, companies are requested to disclose in item 2.2 major products and/or services and the degree to which the company relies on outsourcing. However, what *DISB* (2.2) measures is only the disclosure of any information about the degree to which the company relies on outsourcing. Mean *DISB* (2.2) = 0.011

suggests that companies are ignoring environmental impacts produced by outsourced activities. Most companies in the sample merely disclose a list of brands, products and services they provide (first part of indicator 2.2). In fact, only one report (Unilever Brazil) briefly states that the company works with 3,755 outsourced providers. Sustainability reports and indicators ignoring outsourcing can convey a misleading assessment of corporate sustainability performance and obstruct sound decisions: on the one hand, if the reporting entity excludes outsourced activities, the sustainability indicators of companies with and without outsourced activities would not be comparable; on the other hand, to show better environmental indicators, companies could be tempted to outsource those activities with the poorer environmental performance.

Regarding the disclosure of indirect environmental impacts, mean *INDI*=0.378 suggests that, overall, two thirds of such information is missing in some of the, arguably, best sustainability reports worldwide (FT 500 reports submitted to the GRI benchmark database). Archel et al.'s (2008) results for this variable was lower (0.257). This increase can be explained because, unlike Archel et al., the present study focuses on indirect environmental indicators that show higher reporting levels than social indicators, particularly those on energy and GHG emissions. It can be argued that the situation has not improved substantially since 2005, when sustainability reporting was still as its inception.

Table 2.4 displays average *INDI*, *INDC*, *INDA* as well as indirect environmental impact indicators, per industry. The first observation that emerges from table 2.4 is that disclosure scores varies significantly across industries.

Table 2.4: Average indirect environmental indicators, by industry

Industry	*INDI*	*INDC*	*EN4*	*EN16*	*EN17*	*EN26*	*EN27*	*INDA*	*EN6*	*EN7*	*EN29*
Basic Materials	0.403	0.505	0.350	0.850	0.700	0.325	0.300	0.233	0.250	0.150	0.300
Cyclical Goods	0.464	0.567	0.500	0.833	0.667	0.667	0.167	0.292	0.208	0.167	0.500
Energy	0.227	0.309	0.182	0.818	0.364	0.182	0.000	0.091	0.182	0.045	0.045
Financials	0.324	0.382	0.176	0.706	0.706	0.324	0.000	0.225	0.265	0.206	0.206
Health Care	0.350	0.420	0.200	0.600	0.600	0.400	0.300	0.233	0.000	0.200	0.500
Industrials	0.385	0.500	0.167	1.000	0.583	0.667	0.083	0.194	0.333	0.000	0.250
Non-Cyclical Goods	0.527	0.600	0.000	1.000	0.833	0.583	0.917	0.405	0.167	0.167	0.917
Technology	0.484	0.525	0.250	0.750	0.875	0.375	0.375	0.417	0.500	0.000	0.750
Telecommunication	0.363	0.400	0.000	0.600	0.600	0.500	0.300	0.300	0.200	0.300	0.400
Utilities	0.325	0.360	0.000	0.900	0.600	0.300	0.000	0.267	0.200	0.400	0.200
Total	0.378	0.457	0.228	0.799	0.641	0.402	0.212	0.246	0.228	0.158	0.353

Notes: Thomson Reuters business classification scheme available at: http://thomsonreuters.com/content/dam/openweb/documents/pdf/tr-com-financial/methodology/trbc-methodology.pdf

The sector with the best scores is non-cyclical goods (mean *INDI*=0.527, mean *INDC*=0.600 and mean *INDA*=0.405), followed by technology (mean *INDI*=0.484, mean *INDC*=0.525 and mean *INDA*=0.417). In contrast, the energy industry achieves the lowest scores of all sectors (mean *INDI*=0.227, mean *INDC*=0.309 and mean *INDA*=0.091). These low scores in energy could be caused by the fact that direct impacts tend to be the share of the lion of this sector's environmental burden in issues such as energy or GHG emissions. However, it is worth noting that service providers, where indirect impacts entail a particular importance, attain mediocre results. Such is the case of financials (mean *INDI*=0.324, mean *INDC*=0.382 and mean *INDA*=0.225) and telecommunications industries (mean *INDI*=0.363, mean *INDC*=0.400 and mean *INDA*=0.300).
Table 2.4 also shows the mean scores for the different indicators that constitute the variables. Those results indicate that some indicators are disclosed more often than others: means ranging from 0.158 to 0.799. Only two indicators, both core indicators, attain mean scores exceeding 0.5. They are indirect greenhouse gas emissions (EN16) and information about other relevant greenhouse gas emissions (EN17) (0.799 and 0.641, respectively). All the remaining scores are below 0.5: disclosure of initiatives to mitigate environmental impacts of products and services (EN26) achieves a mean of 0.402; disclosure of significant environmental impact of transporting goods, material and staff (EN29) scores a mean of 0.353; indirect energy consumption by primary source (EN4), information about companies initiatives to provide energy efficient products and services (EN6) and reporting the percentage of products sold and their packaging material that are reclaimed by category (EN27) attain means slightly above 20% (0.228, 0.228 and 0.212 respectively); finally, the lowest score is for initiatives to reduce indirect energy consumption and reductions achieved (EN7) with an average of 0.158.

In general, mean *INDC*=0.457 and mean *INDA*=0.246 suggest that companies are focusing on core indicators, something which might be expected. But, more interestingly, the results also show that those indirect impacts over which there is a developed and generally accepted guidance (GHG emissions and the GHG Protocol) are disclosed disproportionately more than those indicators that are more ambiguous and/or poorly defined. The nature of this study does not allow inferring the reasons for a higher level of disclosure in certain indicators rather than others. However, a higher level of disclosure could be due to the existence of official guidelines (e.g GHG protocol; CDP, 2011) perceived as rational and legitimate by reporters (Bebbington et al., 2012) or to the existence of compelling norms to disclose.

Finally, table 2.4 also shows a high dispersion as regards individual indirect impact indicators across industries. In the case of greenhouse gas emissions, EN16 ranges from 0.600 in healthcare and telecommunication services companies to 1.000 in industrial companies, while EN17 disclosure ranged from 0.364 for the energy sector to 0.875 for the technology sector. Sullivan (2009) explains those differences in terms of the existence of differences across sectors in the governance of climate change.

The disclosure of initiatives to mitigate environmental impacts of products and services (EN26) ranged from 0.182 in energy to 0.667 in cyclical goods and industrials. Three indicators ranged from nondisclosure to about 50% of disclosure depending on the sector. Indirect energy consumption by primary source (EN4), initiatives to provide energy efficient products and services (EN6) and initiatives to reduce indirect energy consumption (EN7) were not disclosed at all in non-cyclical goods, telecommunication and utilities; health care sector and industrials. However some of those indicators achieved 50% disclosure in cyclical goods (EN4) and technology (EN6) and 40% in utilities sector (EN7). The sharpest variation occurred in EN29 (transportation impacts) which, on average, ranged from 0.045 in energy providers to 0.917 in companies providing non-cyclical goods. EN27 differences across industries can be explained since this indicator (packaging material reclaimed and/or recycled) could be considered not material for certain industries (in the energy and financial sectors its mean is 0.000).

This study also considers the possibility of misleading disclosure within the reports, i.e. companies could pretend to disclose indirect information when they are really providing direct impact information. Misleading disclosures on core indicators (mean *MSIC*=0.107) and on additional indicators (mean *MSIA*=0.217) suggest that companies are putting more effort in disclosing core indicators accurately. It is interesting to note that these results contrast with Archel et al. (2008), since in the latter study misleading disclosure was more frequent for core indicators. These authors contended that this behaviour could be due to the requirement to disclose core indicators for the "in accordance" label that received all the G2 reports that composed their sample. According to their results, companies could conceal their non-disclosure by disclosing direct impacts in the place of indirect impacts and, thus, fit into the "in accordance" requirements.

Alternative explanations of misleading disclosure would include lack of knowledge, lack of interest or the intention to conceal poor performance. An additional analysis suggests that sustainability illiteracy (which is of course coupled with lack of interest) could play an important role in explaining misleading disclosures. In 4 reports out of the 92 reports we identified cases in which companies openly deny their indirect environmental impacts. In these four reports, companies briefly state that they do not have any indirect energy consumption or impact due to the kind of activities they perform. Considering the previous discussion about the indirect environmental impacts produced by the service industries through the activities of the primary and/or secondary sectors, it is surprising to find such statements in two reports: Ace Seguros (financials) and Celgene (medical research). ACE Seguros states in its sustainability report (p. 93) that EN16 and EN17 are not applicable because their activities do not produce greenhouse gases. Along the same lines, Celgene states for EN16 that Celgene

Spain does not have an industrial plant but only commercialise products and therefore this indicator is irrelevant (p. 53). The two remaining reports are published by two Latin America mining corporations, Peñoles and Xstrata Cooper Peru. Peñoles introduces itself as the major world producer of silver, the biggest producer of bismuth in the Western world and the most important producer of gold and lead in Latin America. In page 42 they declare that, as per their knowledge, transport of staff, products and goods did not cause any significant environmental impact. Similarly, Xstrata, states that EN17, EN26, EN27 are not applicable and, finally, in EN29 they state that there are not significant environmental impacts from transportation because this is appropriately managed.

To confirm results some sensibility analysis were performed: variables measuring core indirect impacts (*INDI; INDC* and *MSIC)* were recalculated considering that EN27, due to its nature, is not applicable to energy, financial and telecommunication sectors. Means calculated along these lines increased from to 0.378 to 0.393 for *INDI* and from 0.457 to 0.481 for *INDC*. Excluding those sectors also produced an increase of misleading disclosure in core indicators (*MSIC)* (from 0.107 to 0.159). The overall conclusions are not affected.

2.6. Concluding comments

This study has explored, at a theoretical level, the importance of boundaries in the definition of sustainability indicators and reports and, at an applied level, how corporations are considering organizational and operational boundaries in their sustainability reports. A review of the literature suggests that the evaluation of the sustainability performance of organizations requires the integration in the reporting entity of organizations over whose sustainability performance the parent company has control or influence. Such is the case of outsourced activities. Along the same lines, previous studies suggest that for most industries, the lion's share of their environmental impact is indirect, taking place upstream in their supply chain or downstream in the lifecycle of their products and services. Addressing planetary boundaries and providing an accurate picture of corporate sustainability performance requires paying attention to indirect environmental impacts.

To ascertain how reporting boundaries are considered in practice in environmental indicators and sustainability reports, the paper reports a content analysis of a sample of 92 sustainability reports published by FT 500 companies and submitted to the GRI benchmark database. The findings are that reporting boundaries are, as expected, limited to the consideration of financial control (characteristic of financial reporting) and, therefore, not aligned with the required systemic view to approach a sustainable use of natural resources.

More in detail, according to our analysis, organizational boundaries are restricted to organizations under financial control and not encompassing all organizations over which the reporting entity generates significant sustainability impacts. Furthermore, in most cases reports do not include environmental impacts from outsourced goods and services. The use of this information for sustainability appraisal and decision making could provide incentives to make unsound decisions from a sustainability perspective, e.g. outsourcing activities with poor sustainability performance in order to disclose a better sustainability performance of the reporting entity.

The analysis of operational boundaries reveals that up to two thirds of the information required by the examined indirect impact indicators is missing in the sustainability reports of some of the largest companies in the world. Considering the importance of indirect environmental impacts and the influence of corporations (especially large corporations) in the major sustainability challenges, the invisibility of this information can again lead to inaccurate sustainability appraisals and to make sustainability-unsound decisions. On a more positive side, certain indicators show a higher level of disclosure than others. This is the case of indirect greenhouse gas emissions, where accepted boundary guidelines exist. This suggests that notable progress on indirect environmental indicators can be made when institutions demand disclosure and reporting guidance is developed and generally accepted.

Additionally, the analysis of misleading disclosure suggests that, despite the development of reporting guidelines, there is room for improvement in terms of raising awareness about corporate responsibility in the current sustainability challenges. Engaging in the design of new accounting methods for environmental disclosure might help to develop more effective disclosure methodologies that should be based on a scientific understanding of the interrelation between organisations and the environment.

The results of this study are relevant for companies, policy makers and researchers alike. To achieve improved disclosure of its environmental impacts, companies and policy makers should take a long-term approach to analyse, align and integrate ecosystems knowledge into reporting boundary setting. More specifically, companies and policy makers need to envisage new approaches to integrate indirect impacts, outsourced activities and entities beyond financial control in their sustainability reports. Although this study cannot conclude about the regulation of sustainability reporting, one of the implications of this study is that more sophisticated guidance on sustainability boundaries is required not only to ensure the quality and quantity of sustainability reporting but also to provide managers and stakeholders with a clear understanding of corporate environmental performance.

This study has focused on GRI sustainability reports published by some of the largest companies in the world and on a selection of a reduced number of indirect environmental impact indicators. In this regard, the disclosure results presented in this paper are positively skewed, as they are gathered from best sustainability reporting practice and from the indirect impact indicators that draw more attention. Although the non-generalizability of the results is a limitation, this approach strengthens the results of the investigation. Nevertheless, future research should focus on other types of organizations and reports, following different guidelines. The focus on a reduced set of environmental indicators is a further limitation of this study. Further research should also look at the disclosure of indirect social and economic impacts.

This paper opens avenues for further research in the alignment of reporting with planetary boundaries in order to achieve meaningful sustainability disclosure. There is evidence that indirect impacts are a big share of the environmental burden of companies. However, there is little empirical research on the different shares of indirect environmental impacts in different countries, economic sectors and environmental issues.

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Chapter 3. Productivity and environmental costs from intensification of farming. A panel data analysis across EU regions

Productivity and environmental costs from intensification of farming. A panel data analysis across EU regions

3.1 Abstract

This paper addresses the need of finding new ways of measuring the environmental and economic consequences of farming. The aim of this study is to inquire into the impacts that excessive intensification has on productivity and environmental costs in the long term and additionally, to explore empirically the trend of these two indicators over time. The contribution of this paper is to perform an empirical study of the trends of productivity and environmental costs of farming in the long-term. To this end, this paper performs a panel data analysis of productivity and environmental costs on a farm accounting database across European regions over the 1989-2009 period. The models proposed take (i) farm output per hectare as indicator of productivity, and (ii) expenditures on energy, pesticides and fertilisers per hectare as proxy indicators of environmental costs. Results provide empirical evidence that the regions under study have a negative trend of productivity and a positive trend of environmental costs over the time frame mentioned. These results correlate negatively with both, economic and environmental sustainability of farms. Arguably, this is aggravated in the latter due to hidden environmental costs valued at zero in traditional accounting.

3.2. Introduction

Agriculture is facing at the very least, a twofold increasing global pressure. On the one hand, an economic pressure due to an increase in global food demand due to population growth and, on the other hand, an environmental pressure to bring economic performance in line with environmental issues (WHO, 2005). In other words, agricultural sustainability revolves around many interconnected topics including but not limited to food security, food quality, environmental concerns and socio-economic issues. Over recent decades, intensive practices (e.g. economies of scale, use of genetically modified seeds, and reliance on external inputs, irrigation and the substitution of land) brought about significant changes in agricultural production. Although intensive practices have resulted in higher yields in the past (de Ponti et al., 2012), they have also led to an undesirable misuse of common resources (Stern, 2006). Research is still inconclusive whether sustainable or alternative agricultural systems, which tend to have a positive or lesser impact of the environment (Pretty and Bharucha, 2014) are able to substitute prevailing intensive practices at a large scale. The main concern is food security given that comparisons among systems demonstrate higher yields in intensive farms (Cisilino and Madau, 2007; Lansink et al., 2002).

The traditional defenders of intensive practices claim increasing average yields (FAO, 2008) that hypothetically lead to an increase in economic growth (de Wit, 1992) as the main advantages over alternative agricultural systems. Nevertheless the reliability of these claims in the long term are contentious on both environmental and economic levels.

On the environmental side, there is plenty of scientific evidence which proves that natural resources essential to sustain agriculture are finite (Rockström, 2009). It is impossible to achieve infinite growth counting on finite resources (Schumacher, 1973). Therefore, an impressive growth of yields is doomed in the long run if it is based on a rapid depletion of resources. In this vein, the undeniable improved efficiency and increased average yields due to intensification (de Ponti et al., 2012) might not be sustainable to resource and environmental constrains caused, in some cases, by its very practices (Ruttan, 2002; Tilman et al., 2001). Among the most representative and environmentally harmful practices are the excessive reliance on costly technology, the heavy dependence on non-renewable resources (Batie and Taylor, 1989), the misuse of direct energy inputs mainly in the form of fuels and oils and indirect energy inputs such as pesticides and fertilisers (Tabatabaeefar et al., 2009). Specifically, only the misuse of energy, pesticides and fertilisers is proved to cause degradation of soil (OECD, 2001), water pollutant runoff and leaching (OECD, 2012), negative effects on human health (Pimentel and Burgess, 2012; Wilson and Tisdell, 2001), loss of biodiversity (Mondelaers et al., 2009) and even a destructive interference with the nitrogen cycle at a global scale (Gruber and Galloway, 2008).

At the economic level, an intensive high-yield form of agriculture is associated with the law of diminishing marginal returns. This is defined by the amount of an external input and yield which levels off requiring ever increasing external inputs (de Wit, 1992). Furthermore, diminishing marginal returns implies increasing marginal costs and rising average costs. These higher costs correlate negative with the income of farmers and in many cases they can even lead to increasing debt per farm (Anielski et al., 2001). In this sense, increasing costs might endanger the potential of agricultural productivity, which is intrinsically linked to the capability of farmers to pay for required inputs to achieve it (Cerutti et al., 2013).

It is generally accepted that a way of improving environmental and economic performance is to start with accurate measurements (Ajani et al., 2013). The use of indicators has proved useful when there is no direct measurement available (Gaudino et al., 2014). Several complex methodologies that encompass multiple indicators have been designed and applied to farming. These include but are not limited to Life cycle Assessment (ISO, 2006), Ecological Footprint (Rees, 2000), DIALECT (Solagro, 2000), and FarmSmart (Tzilivakis and Lewis, 2004). Additionally, several researchers have actively designed frameworks to identify and value the environmental impacts of agriculture in monetary terms (Pretty et al., 2005, 2000; Tegtmeier and Duffy, 2004). However, no measuring system is globally or even nationally accepted and used in a systematic manner. One specific topic that has not received the attention it deserves is the impact that intensive agriculture has on environmental costs and productivity in the long term in monetary terms. This is particularly important if we consider that monetary values hide impacts valued at zero in traditional accounting. Hence, additional research is needed to enlighten this issue. Therefore, the aim of this study is twofold: (a) to inquire on possible impact of intensification on productivity and environmental costs in the long term and, (b) to explore empirically the trend of these two indicators over time. This paper contributes to the literature performing an empirical study of the trends of productivity and environmental costs of farming in the long-term. To this end, it performs a panel data analysis of productivity and environmental costs on a farm accounting database across European regions over the 1989-2009 period. The models proposed take (i) farm output per hectare as indicator of productivity and (ii) expenditures on energy, pesticides and fertilisers per hectare as proxy indicators of environmental costs.

The remainder of this article is organised as follows: Section two discusses the arguments that support our hypotheses of decreasing productivity and increasing environmental costs of intensification of farming in the long-term. Section three explains the methodology adopted in this paper to measure the behaviour of environmental costs and productivity over the analysed period. Section four presents the results and a discussion of these findings and, finally, section five offers some concluding remarks, while identifying some of the limitations of the study and avenues for further research.

3.3. Hypotheses development

The notions of increasing productivity and decreasing costs lie at the core of discussions about intensification of farming. It is often understood that the increasing use of external inputs (e.g. energy, pesticides, fertiliser) boost yields and lower costs. Although this is possible in the short-term, in the long-term, excessive intensification might lead exactly to the opposite direction. Systems that allow a turn towards a more sustainable direction may be considered suboptimal in the short run but nonetheless wiser in the long-term (Dietz et al., 2003).

One of the purposes to increase intensification of farming is, arguably, to increase yields; nevertheless a misuse of resources might lead to a decrease in productivity over time. This is due to the fact that farm productivity does not only depend on the amount of external inputs applied but also on the availability of environmental and economic resources.

It has been already stated that "growth has no set limits in terms of population or resource use beyond which lies ecological disaster. Different limits hold for the use of energy, materials, water, and land" (UNWCED, 1987 p. 42). There is evidence that over time, the excess of intensification impacts negatively on the scarcity of natural resources. For example, an unbalanced application of fertilisers degrades the soil over time and exploits the pools of organic nitrogen in the soil (Robertson and Vitousek, 2009). This degradation of soil fertility is also expected to worsen in coming years due to climate change (Colonna et al., 2010). In a similar manner, water scarcity is also arising due to increasing water demand to ensure food security (Rockström, 2009). Although during the green revolution, irrigated lands allowed a substantial increase in yields, water is becoming scarce and will not be possible to increase these irrigated areas (Postel et al., 1996). On the other hand, if one productive resource remains fixed over time, or even worse becomes scarcer, productivity might be negatively impacted by the economic law of diminishing marginal returns. This microeconomic law holds that an additional unit of input (e.g. fertiliser) keeping constant the other input (e.g. land) although will increase marginal product initially, it will decrease and even cause negative marginal product in the long term. At this point adding additional units of the variable factor decreases the output instead of increasing it (Krugman and Wells, 2009 p. 307). This law is particularly important in agriculture where productive land is, without considering soil degradation, constant.

Based on the above discussion our first hypothesis is:

Hypothesis 1: *Output of farming decreases over time.*

Another purpose of increasing intensification of farming is, arguably, to lower costs of production. Nevertheless, an excessive intensification might lead to an undesirable increase of costs in the long term. This is due to the fact, that being intimately related with productivity, costs also depend on environmental and economic factors.

On the environmental side, the fact that natural resources are becoming scarcer also affects the amounts of inputs required to achieve yields. It is proved that intensive farming requires increasing volumes of direct energy mainly for land preparation, irrigation, harvest, post-harvest processing, transportation and increasing volumes of indirect energy mainly in the form of pesticides and fertilisers (Margaris et al., 1996). For example, increasing pesticide doses will boost yields and lower costs in the short-term. However, in the long term it is demonstrated that the volume and number of pesticides required increase due to herbicide-resistant weeds (Heap, 2014).

On the economic side, "productivism" is defined as "a commitment to an intensive, industrially driven and expansionist agriculture with state support based primarily on output and increased productivity." (Lowe et al., 1993 p.221). Accordingly, farmers will increase the use of external inputs in order to increase yields despite its environmental impacts. There is evidence of increasing costs of energy-based agro-chemicals such as pesticides and fertilisers (Edwards, 1989). Similarly, the vast world energy consumption of farming, calculated in a recent study at an annual 11 exajoules, is forecasted to rise due to increasing mechanisation of farming (Stavi and Lal, 2013). Furthermore, the growing demand for food will force to convert approximately 10^9 hectares of natural ecosystems into agricultural land by 2050, accompanied by comparable increases in fertilisers and pesticide use (Tilman et al., 2001).

The law of diminishing marginal product is also relevant in the analysis of environmental costs in the long term. The relationship between returns and costs of production is inverse. According to this law, decreasing returns imply increasing marginal costs and rising average costs in the long term. More precisely, it claims that the relationship between yields and the amount of an external input levels off requiring ever increasing external inputs (de Wit, 1992). As a consequence, we might already be at the point where it is needed to add increasing amounts of energy, pesticides and fertiliser to merely keep a level of productivity. Moreover, in the case of these particular inputs, an ever increasing use is on detriment of the natural capability of the earth to produce food and therefore it might be even counterproductive. Herein, the assumption that expenditures related with environmental damage would increase over time is therefore a priori not unreasonable. Hence, based on the above discussion our second hypothesis is:

Hypothesis 2: *Environmental costs of farming increase over time.*

3.4. Methodology and sample description

3.4.1 Empirical model

This study analyses the behaviour over time of (i) productivity of farming and (ii) environmental costs of farming using two different equations.

Equation (1) explains the behaviour of productivity of farming over time. A productivity function typically relates output to required production factors or inputs (Coelli et al., 1998). We test our first hypothesis formulating equation (1) where productivity (*OUTPHA*) depends on time (*TIME),* the inputs of environmental costs (*ENVCHA*), labour (*lnAWU*) and capital endowments

(*MACHINERY*) which are two classical inputs in production functions (OECD, 2015; Ruttan, 2002). In addition, control variables of economic size unit (*lnESU*), subsidies (*SUBSIDIES*) and type of farming (*TYPEFARM*) str included in the equation.

$$OUTPHA_{it} = \alpha_0 + \alpha_1 TIME_{it} + \alpha_2 ENVCHA_{it} + \alpha_3 lnAWU_{it} + \alpha_4 MACHINERY_{it} + \alpha_5 lnESU_{it} + \sum \alpha_s SUBSIDIES_{sit} + \sum \alpha_f TYPEFARM_{fit} + \varepsilon_{it} \qquad (1)$$

Equation (2) explains environmental costs depending on time, productivity, capital, size, subsidies and types of farming.

$$ENVCHA_{it} = \beta_0 + \beta_1 TIME_{it} + \beta_2 OUTPHA_{it} + \beta_3 MACHINERY_{it} + \beta_4 lnESU_{it} + \sum \alpha_s SUBSIDIES_{sit} + \sum \alpha_f TYPEFARM_{fit} + \omega_{it} \qquad (2)$$

The variables in both equations refer to a type de farming and European region *i,* and year *t,* α and β are the parameters to be estimated, and *s* and *f* are the subscripts for subsidies and types of farming respectively.

Similarly to previous research (Coelli et al., 1998; Ruttan, 2002), this paper considers output per hectare as a reliable indicator of productivity in agriculture, thus being *OUTPHA* the dependent variable in equation (1).

Our dependent variable in equation (2), *ENVCHA* is the total amount spent on energy, pesticides and fertiliser per hectares. Previous research on environmental management accounting identifies annual expenditure on direct energy (consumed in the form of fuels and oils) as an environmental cost (United Nations, 2001; Jasch, 2003). Nevertheless, agriculture consumes energy also indirectly through the use of pesticides, fertilisers, animal feed and agricultural machinery among others (Eurostat, 2012). We select and include the expenditures on energy, pesticides and fertilisers on the basis of, at least, three reasons. First of all, these three inputs are considered the main forms of energy consumption of agricultural holdings (Tabatabaeefar et al., 2009). Secondly, the monetary measurement of its annual expenditure is available from traditional accounting. Lastly, there is a vast amount of research specifically on the environmental impact of energy, pesticides and fertilisers consumption (Gruber and Galloway, 2008; Pimentel and Burgess, 2012; Wilson and Tisdell, 2001). Overall, we consider that the sum of expenditures on energy, pesticides and fertilisers is a plausible indicator of environmental costs.

Our variable of interest in both equations is *TIME*. This study aims to test the behaviour of productivity and expenditures over time (see sample sub-section). To this end, we use different alternative measures for *TIME*. In the first place, *TIME1* represents the continuous value for each calendar year. Secondly, *TIME3* represents a continuous variable on a three years basis. Therefore, *TIME3* takes values 1 to 7 for the periods 1989-1991 to 2007-2009 respectively. *TIME3* was added to reduce the high variability of farming due to unpredictable and arbitrary market and climate conditions (Pretty et al., 2010). The volatility due to unpredictable outcomes can significantly be reduced over a three year period (Cordts et al., 1984). Afterwards, we include dummy variables of *TIME3* which indicate with value 1 that an observation belongs to a given period and 0 otherwise. We label these variables *TIME8991, TIME9294, TIME9597, TIME9800, TIME0103, TIME0406* and *TIME0709* respectively. The default variable is the first three years period: 1989-1981. According to our hypothesis H1 we hypothesize a negative sign for *TIME* in equation (1), thus indicating that productivity per hectares have decreased along the years under analysis. On the contrary, according to H2, we hypothesize a positive sign for *TIME* in equation (2), thus indicating that expenditures per hectare have increased over the analysed period.

Given that production functions usually assume that productivity increases with inputs endowments, we expect a positive sign for *ENVCHA, lnAWU* and *MACHINERY*. Annual work unit (AWU) approaches labour endowment, and it is defined as the total number of full time workers, (including family work). Given the non-normal distribution for this variable we use its natural logarithm in the equations. *MACHINERY* approaches capital endowment through the ratio of machinery to total assets. Farms with higher machinery intensification are expected to spend more on environmental costs than farms with low machinery use. Therefore a positive sign is also expected for this variable in equation (2).

We use European Size Units (ESU) as a variable representing size. Given the non-normal distribution for this variable we transform it into its natural logarithm, *lnESU*. This measure is commonly used by researchers and institutions in the European Union (EU) as a homogeneous measure of size for comparing heterogeneous types of farming (European Commission, 2013; Reidsma et al., 2010). It is traditionally claimed that economies of scale might decrease unit variable costs when volume increases (Balakrishnan and Labro, 2014). Larger farms are expected to have lower costs per units of production than smaller farms (Valero and Aldanondo-Ochoa, 2014). Herein, farms with larger size arguably benefit from economies of scale with respect to production and external input costs. On the contrary, smaller farms benefit from a different array of advantages such as flexibility (You, 1995); quicker response to changes (Knight and Cavusgil, 2004) and a higher tendency to test creative solutions using and/or reusing constrained resources (Baker and Nelson, 2005). It can be argued that bigger farms benefits for economic of scales in resource consumption as well as that smaller farms use it more efficiently. Therefore, we do not expect any particular sign for size in any of the equations.

Given the importance of subsidies for farmers in the European Union (Olper et al., 2014) and the wide array of aims of the common agricultural policy, we use different measures for subsidies. *INVESUBS, PRODSUBS* and *ENVISUBS* are the ratios of investment subsidies, total production subsidies (excluding environmental payments) and environmental payments to output respectively.

INVESUBS and *PRODSUBS* are not directly linked with environmental concerns or productivity. However both influence agricultural activities and outcomes. Therefore, we do not expect a particular sign for these two variables in equation (1) and (2). In contrast, *ENVISUBS* is linked to specific agricultural outputs which are able to generate positive environmental impacts or mitigate negative ones. These subsidies are designed to compensate farmers for any loss associated with practices that aim to benefit the environment (Kleijn and Sutherland, 2003). Thus, avoiding expenditures on harmful environmental inputs. Accordingly, for this variable, we do not foresee any particular sign in equation (1) and a negative sign is expected in equation (2).

TYPEFARM controls for technical characteristics of types of farming included in our sample which influence both farm productivity and input consumption. We include dummy variables indicating, with value 1 and 0 otherwise, that an observation belongs to a given type of farming. Given the characteristics of the sample and the used database (please see next sub-section), we consider the four types of farming of official EU classification (Reg. 85/377/EEC) which are crop production oriented. These are: field-crops *(FIELDCRO),* wine *(WINE),* and other permanent crops *(OPERCROP)*. The default variable is horticulture, which tends to be particularly intensive in the use of external inputs and more productive in comparison with other crops. Therefore it requires more inputs per hectare. As a consequence, we expect a negative sign for these variables in both equations (1) and (2).

We additionally use *OUTPHA* in equation (2) as a control variable for productivity. From a productivism perspective, most of farmers will try to maximise productivity through the increasing use of inputs despite its environmental impacts. Larger amounts of production attainment require ever increasing environmental costs. Therefore, positive sign is expected for *OUTPHA* in equation (2).

3.4.2 Sample

Research data is obtained from the European farm accountancy data network (FADN). This is an annual survey which was launched in 1965 by the European Commission to collect accountancy data from a sample of farms in the EU. The content and format of FADN reports are essentially similar to standard financial statements. We analyse the 1989–2009 period, which is the longest publicly available database fulfilling our criteria (type of farming-region-year). These 21 years of homogeneous information provide the most suitable data series for our purpose. Due to the change in the methodology (FADN, 2014) there is a break in the time series after 2009[3]. As a consequence, data henceforth is not comparable with the data series used in this study.

Given the panel data structure of the sample we express *OUTPHA* and *ENVCHA,* used as dependent and independent variables in equations (1) and (2), in constant values of 2009.

In order to get more reliable results and ensure comparability, we select only those countries that are present across the years under study. Additionally, given that hectares are used as the measure of standardization, we select only those observations oriented to crop production.

Herein, the final sample for the empirical analysis uses a type of farming-region-year data covering 96 regions of 12 European countries. Table 3.1 shows the detail of regions per country included in the sample.

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[3] FADN database available at <http://ec.europa.eu/agriculture/ricaprod/database/database_en.cfm> contains two datasets. The first one, based on the methodology used until 2009, labelled as SGM (from standard gross margin) provides information from 1989-2009. The second one, with the new methodology applied from 2010 is labelled as SO (from standard output) provides at the moment of writing this research information from 2004 to 2012.

Table 3.1: Sample of country/regions considered (period 1989-2009)

Country	Nº of regions	Region-year observations
Belgium	3	81
Denmark	1	63
France	22	1,477
Germany	14	770
Greece	4	336
Ireland	1	34
Italy	21	1,697
Luxembourg	1	38
Netherlands	1	63
Portugal	6	412
Spain	16	1,061
United Kingdom	6	250
Total	**96**	**6,282**

Although all countries are present in the 21 years, neither all of the regions practice all types of farming, nor are all of the regions present over the whole period under study. The countries most represented are Italy with 1,697 observations, France with 1,477, and Spain with 1,061. The remaining countries have less than 1,000 observations each. This is consistent with the distribution of number of agricultural holdings among included countries (Eurostat, 2015).

Table 3.2 offers the details on the number of observations across the years and type of farming included in our sample. Data tracks farms over 21 years adding up 6,282 observations. Given the sample selection procedure applied, the type of farming-region-year sample is homogeneous and non biased across the whole period.

Table 3.2 Sample: observations per year and type of farming

Year	Field-crops	Horticulture	Wine	Other permanent crops	Total
1989	85	64	61	65	275
1990	83	63	60	67	273
1991	82	66	59	68	275
1992	83	70	58	69	280
1993	83	69	58	67	277
1994	85	71	58	69	283
1995	91	73	56	70	290
1996	90	75	57	73	295
1997	91	73	58	74	296
1998	90	77	60	73	300
1999	91	81	59	74	305
2000	90	79	61	76	306
2001	90	79	61	76	306
2002	90	83	63	74	310
2003	90	82	62	78	312
2004	92	83	63	81	319
2005	92	82	63	80	317
2006	93	82	63	80	318
2007	93	84	62	80	319
2008	91	83	61	78	313
2009	90	83	61	79	313
Total	**1,865**	**1,602**	**1,264**	**1,551**	**6,282**

3.5. Results and Discussion

4.1 Descriptive statistics and univariate analysis

One the one hand, there is a predominant increasing trend in environmental costs. More specifically, there is an increase in 4 out of 7 periods in comparison with its precedent (1992-1994, 1995-1997, 1998-2000 and 2004-2006*).* On the other hand, despite of a steady increasing size in terms of economic size (ESU) and working units (AWU), productivity fluctuates across time. Thus, suggesting that economies of scale are not fully achieved.

Table 3.3 Mean values for continuous variables across 1989-2009 for each period of TIME3

Variables	**1989-1991**	**1992-1994**	**1995-1997**	**1998-2000**	**2001-2003**	**2004-2006**	**2007-2009**
Output per hectare *(OUTPHA)*	13,753.99	13,466.40	15,120.19	15,400.39	15,471.14	16,404.38	14,346.46
Environmental costs per hectare *(ENVCHA)*	1,469.22	1,504.00	1,825.22	1,844.02	1,797.46	1,922.91	1,913.39
Annual work units *(AWU)*	1.82	1.83	2.07	2.12	2.20	2.30	2.36
Machinery to total assets *(MACHINERY)*	0.16	0.16	0.16	0.16	0.17	0.17	0.16
Economic size units *(ESU)*	29.67	38.19	49.17	52.89	61.46	65.22	68.47
Investments subsidies to outputs *(INVESUBS)*	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Production subsidies to output *(PRODSUBS)*	0.01	0.06	0.13	0.14	0.14	0.12	0.12
Agri-environmental payments to outputs *(ENVISUBS)*	0.00	0.00	0.00	0.01	0.01	0.01	0.01

The subsequent multivariate analysis allows a deeper analysis on these issues controlling for the different factors influencing productivity and environmental costs throughout the period. Table 3.4 displays Pearson correlation coefficients between independent variables in equation (1) and (2).

Table 3.4 Pearson correlations for continuous independent variables

	TIME	*OUTPHA*	*ENVCHA*	*lnAWU*	*MACHINERY*	*lnESU*	*INVESUBS*	*PRODSUBS*
Output per hectares *(OUTPHA)*	0.0140	1						
Environmental costs per hectare *(ENVCHA)*	0.0375*	0.5038***	1					
Annual work units *(lnAWU)*	0.1177***	0.4470***	0.4673***	1				
Machinery to total assets *(MACHINERY)*	0.0237*	0.1442***	0.1195***	0.3182***	1			
Economic size units *(lnESU)*	0.2590***	0.2796***	0.3081***	0.7254***	0.4663***	1		
Investments subsidies to outputs *(INVESUBS)*	-0.0554***	-0.0410**	-0-0338*	-0.0598***	-0.0106	-0.1607***	1	
Production subsidies to output *(PRODSUBS)*	0.2192***	-0.2505***	-0.2435***	-0.2557***	0.1584***	-0.0081	0.0068	1
Agri-environmental payments to outputs *(ENVISUBS)*	0.2327***	-0.1333***	-0.1414***	-0.1661***	-0.0870***	-0.1332***	0.0466**	0.2283***

Although the high correlation coefficient between *lnESU* and *lnAWU* (0.7254), however, the highest variance inflation factor 2.79 for variable *lnESU* is clearly under the common rule of thumb is 4 proposed (e.g. Allison, 1999), which indicates that collinearity is unlikely to affect estimations.

4.2 Multivariate analysis

Given that the panel data structure of our sample presents the typical autocorrelation pattern, we perform panel data estimations. The commonly used Hausman test rejects the null hypothesis of no correlation between individual effects and explanatory variables. The random effects estimator is inconsistent, while the fixed effects estimator is consistent, efficient and preferred to random effects in all estimations for both equations (1) and (2). However, fixed effects estimation omits variables that remain unchanged across all periods considered (e.g. *TYPEFARM)*. We believe that technological and specific characteristics of type of farming are important factors influencing our dependent variables, and we additionally perform random effects estimations.

The Breusch-Pagan Lagrange multiplier test for random effects confirms that panel data estimators are more appropriate than common OLS estimators for all estimations for both models. The Breusch-Pagan/Cook-Weisberg test for heteroscedasticity, significant with $p<0.01$ in all estimations, reveals the existence of heteroscedasticity, we herein perform panel data estimations with standard errors adjusted for heteroscedasticity using the Huber–White robust variance estimator (White, 1980).

Table 3.5 and 3.6 display results of panel data estimations for equations (1) and (2) with the following order: results using a continuous variable of calendar years (*TIME1)* are disclosed for fixed (column (A)), and random (column (B)) effects accordingly. Subsequently, the results of the regression with a continuous variable of time as an expression of three years periods (*TIME3)* are disclosed for fixed (column (C)) and random (column (D)) effects accordingly. Column (E) displays results with dummy variables of *TIME3* for the preferred fixed effects estimations.

Table 3.5 shows that all R-squares are around 0.8 and significant with $p<0.01$. With the exception of investment and production subsidies all control variables are significant with $p<0.05$ and present the expected sign. According to our results, increasing amounts of labour and machinery endowments, as well as of environmental inputs, influence higher productivity. The significant negative signs for size (with $p<0.01$ in all estimations) reveal that the advantages of small size prevail over economies of scale. The results are essentially the same with random effects estimations (see columns B, and D) where as expected, all types of farming displayed in the table influence lower productivity than horticulture.

Table 3.5 Fixed and random robust estimations for equation (1) for different specifications of time (1989-2009). Dependent variable: output per hectares. (t-statistics in parentheses)

	(A)	**(B)**	**(C)**	**(D)**	**(E)**
Variables	**Fixed**	**Random**	**Fixed**	**Random**	**Fixed**
Calendar year 1989-2009	-117.51*	-119.90**			
(TIME1)	(-1.89)	(-2.02)			
Periods of three years			-320.19*	-320.92*	
(TIME3)			(-1.80)	(-1.87)	
Period 1992-1994					-84.92
(TIME9294)					(-0.11)
Period 1995-1997					-792.43
(TIME9597)					(-1.31)
Period 1998-2000					-563.50
(TIME9800)					(-0.83)
Period 2001-2003					-722.59
(TIME0103)					(-0.92)
Period 2004-2006					-1380.30*
(TIME0406)					(-1.65)
Period 2007-2009					-1969.27*
(*TIME0709)*					(-1.90)
Environmental costs per hectare	5.66***	6.02***	5.65***	5.18***	5.65***
(ENVCHA)	(9.34)	(8.72)	(9.33)	(7.45)	(9.32)
Annual work units *(lnAWU)*	4,425.87***	4,676.91***	5,117.11***	5,720.34***	5,174.57***
	(2.66)	(2.82)	(2.69)	(2.66)	(2.73)
Machinery to total assets	33,832.48**	33,474.37***	33,658.47**	33,534.5***	33,297.91**
(MACHINERY)	(2.53)	(2.59)	(2.52)	(2.59)	(2.47)
Economic size units *(lnESU)*	-2,237***	-2,302.78***	-2,366.64***	-2,395.75***	-2,432.36***
	(-2.34)	(-2.93)	(-2.82)	(-2.97)	(-2.86)
Investments subsidies to output	-2,169.93	-2,607.27	-2,093.69	-2,856.75	-2,166.49
(INVESUBS)	(-1.22)	(-1.54)	(-1.18)	(-1.60)	(-1.22)
Production subsidies to output	1,344.56	1,465.81	1,173.46	939.94	1151.63
(PRODSUBS)	(0.92)	(0.76)	(1.18)	(0.67)	(0.73)
Agri-environmental payments	22,125.20**	22,724.94**	21,040.42**	21,131.20**	17,433.09**
to output *(ENVISUBS)*	(2.19)	(2.23)	(2.15)	(2.16)	(2.15)
Field-crops *(FIELDCRO)*		-16,813.92***		-16,814.25***	
		(-3.39)		(-3.39)	
Wine *(WINE)*		-1,1291.64**		-1,1352.13**	
		(-2.36)		(-2.36)	
Other permanent crops		-12,312.45***		-12,358.05***	
(OPERCROP)		(-2.59)		(-2.59)	
R-sq: overall	0.80***	0.79***	0.80***	0.79***	0.80***

Notes: *Significant at a 10% level. **Significant at a 5% level. ***Significant at a 1% level.

With respect to our variables of interest, the signs for time calendar (*TIME1*) and for the three-year variable (*TIME3*) are negative and significant (with $p<0.1$) with the preferred fixed effects estimations. This is similar to the results achieved with random effects estimations, thus, persistently provide support for our hypothesis H1. Column E displays results including dummy variables identifying three years periods. All coefficients are negative, and dummies for years 2004-2006 and 2007-2009 significant with $p<0.1$, thus indicating a decrease in productivity with respect to the beginning period of our sample. Results of this last estimation with random effects, not displayed in table 3.5 for simplicity, are very similar. Additionally, we use Wald tests of simple and composite linear hypotheses to test that the coefficients of dummy variables of *TIME3* decrease significantly period after period. These tests provide significant differences in all the combinations of periods *TIME0406* and *TIME0709* with all previous periods. This reinforces the idea that there is a decreasing productivity with its minimum values in the last two periods under study. Overall, these results provide reinforced support for our hypothesis H1.

We rerun fixed effects estimations (not disclosed) for variables included in column C adding squared terms for variables *TIME3* and *ENVCHA*. The non-significant coefficients for these squared variables reject curvilinear relationships with the dependent variable. Therefore, according to our results, despite the extant increasing input expenditure there is a sustained productivity loss of 117.51 and 320.19 € (in constant values of 2009) per hectare every year and three years respectively (see columns A and C). Similarly, measured in constant values of 2009, the attainment of 5.66 and 5.65 € per hectare requires a sustained additional expenditure of 1 € of energy, pesticides and fertilisers per hectare (see columns A and C).

Table 3.6 displays results for equation (2), for different specifications of our variable of interest and panel data estimations.

All R-squares are between 0.79 and 0.83, significant in all cases with $p<0.01$. With the exception of *MACHINERY* all variables present the expected sign. Surprisingly, *MACHINERY* significantly influences lower environmental costs. This could be caused by the fact that farms with higher levels of investment in machinery, endow with more efficient and environmentally friendly equipment (e.g. energy saving equipment; see also United Nations, 2003). However, the nature of this study does not allow to infer the reason of this negative influence. *lnESU, INVESUBS, PRODSUBS* do not result significant in any estimation. The coefficients of environmental subsidies are negative and significant (with $p<0.01$ and $p<0.05$). This suggests that environmental subsidies are achieving more sustainable practices and help farmers to save on environmental costs. Similarly, dummy variables for type of farming have the expected negative sign and are significant with $p < 0.01$ in all estimations. This reveals that all analysed type of farming have lower environmental costs than horticulture, as expected.

Table 3.6: Fixed and random robust estimations for equation (2) for different specifications of time (1989-2009). Dependent variable: environmental costs per hectare. (t-statistics in parentheses)

	(A)	**(B)**	**(C)**	**(D)**	**(E)**
Variables	**Fixed**	**Random**	**Fixed**	**Random**	**Fixed**
Calendar year 1989-2009	23.58**	17.03**			
(TIME1)	(2.49)	(2.11)			
Periods of three years			68.38**	49.65**	
(TIME3)			(2.39)	(2.02)	
Period 1992-1994					11.71
(TIME9294)					(0.12)
Period 1995-1997					147.81
(TIME9597)					(1.43)
Period 1998-2000					216.38*
(TIME9800)					(1.85)
Period 2001-2003					212.70*
(TIME0103)					(1.70)
Period 2004-2006					314.86**
(TIME0406)					(2.29)
Period 2007-2009					406.06**
(*TIME0709)*					(2.48)
Output per hectare *(OUTPHA)*	0.09***	0.09***	0.09***	0.09***	0.09***
	(8.47)	(8.99)	(8.46)	(8.99)	(8.43)
Machinery to total assets	-4772.86***	-3977.87***	-4777.92***	-3984.67***	-4743.13***
(MACHINERY)	(-2.94)	(-2.86)	(-2.94)	(-2.87)	(-2.92)
Economic size units *(lnESU)*	11.84	139.50	23.35	145.17	32.23
	(0.10)	(1.50)	(0.19)	(1.54)	(0.26)
Investments subsidies to output	-166.22	-147.89	-174.15	-152.51	-177.50
(INVESUBS)	(-0.54)	(-0.57)	(-1.23)	(-0.58)	(-0.56)
Production subsidies to output	-249.73	-197.99	-228.49	-182.18	-244.51
(PRODSUBS)	(-1.32)	(-1.11)	(-1.23)	(-1.04)	(-1.04)
Agri-environmental payments to	-3580.47***	-3025.63***	-3476.84***	-2954.72**	-3403.84**
output *(ENVISUBS)*	(-2.66)	(-2.51)	(-2.61)	(-2.46)	(-2.25)
Field-crops *(FIELDCRO)*		-1126.84***		-1129.33***	
		(-3.94)		(-3.95)	
Wine *(WINE)*		-1595.52***		-1593.54***	
		(-6.15)		(-6.13)	
Other permanent crops		-1497.28***		-1497.28***	
(OPERCROP)		(-5.65)		(-5.64)	
R-sq: overall	0.79***	0.83***	0.79***	0.83***	0.79***

Notes: *Significant at a 10% level. **Significant at a 5% level. ***Significant at a 1% level.

With respect to our variables of interest, the signs for time calendar (*TIME1*) and for the three-year variable (*TIME3*) are positive and significant with $p<0.05$ with both the preferred fixed effects and random estimations. Herein, consistently providing support for our H2 hypothesis. Column E displays results including dummy variables identifying three years periods. All coefficients are positive, and dummies for periods starting on 1998 and afterwards are significant. More in detail, the periods 1998-2000 and 2001-2003 are significant with $p<0.05$, and periods 2004-2006 and 2007-2009 are positive and significant with $p<0.01$, thus indicating increasing environmental costs with respect to the beginning period in our sample.

We use Wald tests to test that the coefficients of dummy variables of *TIME3* grow significantly period after period. 14 out of 21 combinations in between periods of three years present significant increasing environmental costs.

We perform random estimation with dummies of *TIME3* and obtain substantially the same results (not displayed in table 3.6). Overall, these results reinforce the support for our hypothesis H2.

We rerun fixed effects estimations (not disclosed) for variables included in column C adding a squared term for variable *TIME3*. The non-significant coefficient for this squared variable rejects curvilinear relationships with the dependent variable. Therefore, according to our results, environmental cost increase steady and linearly across the period under study.

3.6. Conclusions

This study has explored the trends of productivity and environmental costs over time. The methodology uses output as an indicator of productivity and expenditures on energy, pesticides and fertilisers as proxy indicators of environmental costs. On the one hand, the overuse of these three inputs is proved to threaten environmental sustainability of farms. On the other hand, it is usually argued that this increase is for the benefit of economic sustainability. However, the law of diminishing marginal returns claims that an additional unit of input keeping constant the other inputs might even cause negative marginal product in the long term. This law is particularly appropriate for agriculture given that the earth´s amount of land is constant, while fertile soil is diminishing. Addressing economic and ecological sustainability of agriculture requires paying attention to increasing environmental costs required to achieve a hypothetically increasing productivity.

We used a sample of farms across European regions over the years 1989-2009 considering different measures of time. We find that regions under study have a negative trend of productivity and a positive trend of environmental costs in the years under study. Furthermore, the study reveals that the attainment of additional units of output requires a sustained additional expenditure on environmental costs. Alternative estimations to check for the robustness of the results provide with consistent empirical evidence for these findings. These results correlate negatively with both, economic and environmental sustainability of farms.

The results of this study are relevant for farmers, policy makers and researchers alike. This analysis shows that unsustainable practices are not only linked with environmental degradation, but also with decreasing productivity and increasing environmental costs in the long term. This is particularly important if we take into account that accounting information hides many environmental impacts valued at zero.

Paying attention to these two indicators could help to achieve a shift not only in production patterns, but also in consumption habits and in a social awareness of the value of natural resources. These factors are essential in the fight against environmental impact of food production. This study is based on a farm accounting database across European regions over the 1989-2009 period. Future research should focus on other regions and/or periods of time. A limitation of this research is that the used database is mostly representative of intensive farms. It would be interesting for future research to model the difference in the trends of productivity and environmental costs between organic and intensive farming. Additionally, this paper only considers the monetary value of energy, pesticides and fertilisers added at the production stage. Future studies should include expenditures of other indirect energy consumption due to the production and transport of agricultural inputs such as purchased seeds, packaging, oils and lubricants. Additionally, the availability of measurement in physical units of yields and environmental costs could retrieve insightful and complementary results.

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Chapter 4. The interrelation between economic and environmental performance: empirical study of rice production in Spain.

The interrelation between economic and environmental performance: empirical study of rice production in Spain.

4.1 Abstract

We perform a descriptive analysis on the relationship between economic and environmental performance using own collected data from 9 rice farms located in two Spanish natural parks in Valencia and Catalonia. We use yields, revenues and incomes as indicators of economic performance. We use greenhouse gas emissions and energy consumption as indicators of environmental performance. The analysis was carried as a joint effort of the authors and researchers of a European project for assessing the potential of agriculture to combat climate change. We use the AgriClimateChange Tool software that allows the calculation of energy consumption and greenhouse gas emissions. Results show that in the farms under study, the achievement of higher yields is attributable to the greater use of chemical inputs and fossil fuels. We contribute to the field revisiting evidence that integrating the analysis of environmental and economic information is not only possible but also necessary to provide more accurate information on the overall costs and benefits of farming.

4.2. Introduction

An increasing body of scientific evidence continues to fuel concerns regarding the effects of economic human activity on the environment. Agriculture is not an exception, several of its current practices such as overuse of fertilisers, misuse of pesticides, and consumption of non-renewable energy, have been identified as one of the main sources of anthropogenic global warming (Noltze et al., 2013; Stern, 2006). However, there is also evidence that, if well managed, agriculture could also be beneficial to ecosystems services (Tscharntke et al., 2005). In order to improve agricultural management in this sense it is essential to understand the contribution to ecosystems of each agricultural system management type (Pimentel et al., 1992).

On a global scale, this increasing pressure on our natural resources lead to a growing concern on bringing economic performance into line with environmental performance of human activities (Stern, 2006; WHO, 2005). Although there was an important growth in the field of integration between economics and environmental issues in the last years, nonetheless, the association between these two performances is still neither understood nor conclusive (Goyal et al., 2013).

For instance, some authors report a positive influence of a firm's environmental performance on its financial performance (Wahba, 2008), claiming that a sustained improvement in environmental performance enhances financial outcomes. By contrast, others report just the opposite, with a better financial performance being associated with a poorer environmental record (Rassier and Earnhart, 2009). Finally, a third group of researchers argues that no clear pattern emerges in the relationship between economic and environmental performance (Henri and Journeault, 2010; Jacobs et al., 2010; Reilly, 2012). These differences can be attributed to at least three reasons. First, the field lacks a globally accepted system for measuring the interconnection between nature and economics, with previous research relying heavily on firms' financial data and failing to provide a true account of the economic impact of the environmental externalities of their activities. Second, these studies have applied an array of different measures of environmental performance that are prone to give a variety of results and conclusions. Additionally, most use proxies of environmental impact rather than a specific measure. For example, Henri and Journeault (2010) built indicators from firms' survey responses while others constructed them from firms' voluntary disclosures (Déjean and Martinez, 2009; Jacobs et al., 2010), the weakness might be that these disclosure are typically made so as to influence stakeholders via biased information (Cho and Roberts, 2010). Wahba (2008), on the other hand, considered compliance with ISO 14000 or ISO 14001 (environmental certificate) as a proxy for good environmental performance; however, obtaining these certificates does not necessarily reflect the firms' true environmental impact rather they serve only as an indication that they adhere to certain rules of eco-efficiency. Third, the conducting of studies at the macroeconomic scale (Mondelaers et al., 2009) involves a high level of complexity since while environmental impacts are barely comparable at the interregional level they are even less so at that of macroeconomic blocks. Moreover, macroeconomic databases might miss significant regional ecological differences, thus resulting in heterogeneous samples. In spite of these important contributions, and the fact that there is a double relationship of influence and dependence between economic and nature, it remains unclear how economic and environmental performance are interrelated. Herein, additional research is needed to take a wider view on sustainability and clarify this interrelation. A holistic view on sustainability requires taking both direct and indirect environmental impacts into account (World Resources Institute, 2012). Direct environmental impact results from the farm's immediate productive stage (Ranganathan et al., 2004). In contrast, indirect environmental impacts stem from upstream and downstream activities along the supply chain (Wever et al., 2012). Although it is relevant, the information about indirect environmental impacts is not systematically collected. As a consequence, there is no publicly available database. We chose an empirical approach, drawing on own collected data from rice farms participating in a LIFE[4] project (LIFE09 ENV/ES/000441, 2013) funded by the European Union (EU). This particular LIFE project seeks to apply a common evaluation system in the four largest agricultural economies of the EU: France, Germany, Italy and Spain at a farm scale thanks to a conversion of data collected via surveys (European Commission, 2011; Jilg et al., 2014). This study focuses on rice cultivars, identified as one of the main source categories within the agricultural sector for mitigating climate change under the Kyoto

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[4] http://ec.europa.eu/environment/life/

Protocol (United Nations, 1998). We therefore consider that our lessons and conclusions regarding GHG emissions and energy consumption, although specifically for rice in Spain and for one year, are nevertheless valuable for, and can be useful to other regions.

We contribute to this field calculating actual measures of GHG emissions and energy consumption of rice farms under analysis, not only resulting from the farm's immediate productive stage, but also those arising in the earlier productive stages of the inputs required by the farm. Subsequently, we analyse the relationship between environmental and economic performance.

The remainder of this article is organised as follows. Section 2 discusses the main environmental and economic impacts of mainstream agricultural practices. Section 3 explains the methodology. Section 4 presents the results and a discussion of these findings and, finally, section 5 offers some concluding remarks, while identifying some of the limitations of the study and avenues for further research.

4.3. Economic and environmental performance of farming

Agriculture is facing, at least, a twofold increasing global pressure. On the one hand, an economic pressure due to an increasing population with a growing food demand and, on the other hand, an environmental pressure of bringing economic performance into line with environmental issues (WHO, 2005). As a result, a call has been made to shift agricultural patterns in order to achieve economic and environmental sustainability. In other words, it is needed to optimise agricultural production while upholding environmental and social justice (Godfray et al., 2010). In this vein, several studies explored agriculture from a multidisciplinary perspective trying to find holistic solutions.

Certain studies aimed to calculate the economic cost of environmental damage of agriculture. Arguably, it could be possible to place a monetary value on environmental impact (Pretty et al., 2005; Tegtmeier and Duffy, 2004) and therefore make a monetary analysis of both economic and environmental performance. However, the potential role of monetization techniques to solve environmental issues remains unclear (Herbohn, 2005). Probably because nature is considered as incommensurable due to complex ethical concerns and political stakes (Espeland and Stevens, 1998). A second group of studies explored the interconnection between nature and economics indirectly through a comparison of productivity and environmental impact of different agricultural systems. This is the case of research claiming that low chemical inputs lead to environmental benefits (Dima and Odero, 1997; Mondelaers et al., 2009; Pimentel et al., 2005). Furthermore, since 1992 the EU explicitly promotes organic farming on reg. 2078/92 (EU Council regulation, 1992). Thirdly, there are studies proving that win-win strategies are possible. Along these lines, a recent study (Pretty and Bharucha, 2014) discus about finding agricultural systems that can increase yields without causing negative environmental impact. More in detail, there is wide evidence that some agricultural practices not only can enhance the environment, such as GHG mitigation (Smith et al., 2008), but also increase the levels of productivity (Firbank et al., 2013; Whittaker et al., 1995). In particular for rice production, the system of rice intensification is proposed to tackle environmental and economic challenges simultaneously (Noltze et al., 2013).

In practice, although an upward trend in the area and number of organic holdings in the last decade in Europe, nevertheless they still hold only hold a small share of total agricultural land, more in detail only 3% in Europe (European Commission, 2013). In other words, most farms in Europe are still practising traditional intensive farming based on input-intensive agricultural technologies. Over recent decades, these technologies brought about significant changes in agricultural production, especially, for cereal crops. Although increasing use of genetically modified seeds, irrigation, chemical fertilisers, pesticides and mechanisation have, in some cases, resulted in higher yields (de Ponti et al., 2012), they have also resulted in undesirable misuse of common resources that impact negatively both economics and the environment.

Among the most representative and environmentally harmful practices on which the extant intensive and unsustainable modern agriculture relies on, are the excessive reliance on costly technology, the heavy dependence on non renewable resources (Batie and Taylor, 1989) and the misuse of energy, pesticides and fertilisers (Pimentel and Burgess, 2012; Stavi and Lal, 2013). Well researched environmental impact from these practices are the degradation of soil (OECD, 2001), water pollutant runoff and leaching (OECD, 2012), negative effects on human health (Wilson and Tisdell, 2001) and the loss of biodiversity, wildlife habitats and landscapes (Mondelaers et al., 2009). More in detail, the raising use of chemical inputs in agriculture in the last decades is directly associated with a destructive interference with the nitrogen cycle at a global scale (Rockström, 2009). Along the same lines and of particular interest of this study there are two environmental impacts from farm intensification. First, the level of GHG emissions is widely researched to be increasing in the last years due to a growing dependence on scarce fossil fuels (Mekhilef et al., 2013). More specifically, methane is the second most dangerous greenhouse gas, after carbon dioxide, causing global warming (Calpe, 2006). Flooded rice fields, as those analysed in this paper, are a system of rice production that release particular high levels of this gas. Second, agriculture's vast energy consumption, which is estimated at an annual 11 exajoules (EJ), and is setting to rise due to expanding populations and increasing mechanisation of farming (Stavi and Lal, 2013).

In addition to negative impacts from an environmental point of view, there are also studies exploring negative economic impacts. In despite of traditional defenders of intensification claim that higher levels of intensification bring about higher profitability (Crosson and Ostrov, 1988), other authors showed that intensive practices can have negative financial impacts in the long term, e.g. increasing costs of production (McIntyre et al., 2009). Thus, these increasing costs correlate negatively with farmers' incomes and increase their financial pressure (Edwards, 1989). Increasing financial pressure leads, unfortunately often, to an increasing debt per farm (Anielski et al., 2001).

In summary, understanding the interconnectedness between nature and economics is necessary to assess value and make decisions in an agricultural context. Farming practices have an undeniable influence over the environment and simultaneously closely depend on it to subsist. How economic and environmental performances of farming interrelate with each other? The analysis of this double relationship of influence and dependence carried in this case study is important because (i) it connects the micro perspective of rice farms and the macro systemic perspective of sustainability and (ii) it explores the relationship between economic and environmental performance comparing different farm performances while using actual measures of environmental impact. The next section reports the methodology applied in this study.

4.4. Methodology

We perform a comparative analysis that explores the interrelation between economic and environmental performances of farms. We use two environmental indicators: GHG emissions and energy consumption. These indicators have been used in previous studies as environmental indicators in agriculture (Bakam et al., 2012; Stavi and Lal, 2013). Calculations of environmental impact cover both direct and indirect impacts. More in particular, the GHG emissions cover the three scopes of the GHG protocol (World Resources Institute and World Bussiness Council of Sustainable Developemt, 2011). This means that take into account emissions released directly by the organization; plus emissions indirectly caused by the generation of purchased electricity and finally it also includes emissions from suppliers of inputs and downstream emissions from distribution, use and end of product. Therefore, its extends the scope to emissions indirectly attributable to the purchase of all kinds of goods and services such as semi-manufactured goods, transportation services, waste disposal services, outsourced activities, etc. It covers emissions of six different GHGs (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons). Following the guidelines, all emissions are expressed in equivalent tons of carbon dioxide (tCo2) per year. Additionally, we calculate total GHG emissions excluding methane (CH4) given that flooded rice fields release particular high levels this gas. Along the same lines, energy consumption takes into account the same scope. We analyse direct and indirect consumption separated and, afterwards, the addition of these two as the total energy consumption. This paper uses three economic indicators: yields per hectare in kilograms, sales revenues, and income.

We perform the study with farms producing exclusively rice cultivars. Rice was selected due to its importance not only as a vital crop in the nutrition of over half the world (Calpe, 2006) but also as one of the main source categories within the agricultural sector for mitigating climate change under the Kyoto Protocol (United Nations, 1998). More in particular, certain water management practices, such as keeping the soil as dry as possible in the off season and draining the field once or more times during the growing season (Smith and Conen, 2004; Xu et al., 2003) offer an effective solution to reduce methane emissions. Given that all data are collected personally farm by farm, we perform the analysis with a small group of 9 farms participating of a LIFE project (LIFE09 ENV/ES/000441, 2013) funded by the EU for assessing the potential of agriculture to combat climate change (henceforth referred to as LIFE).

The collection and conversion of data is a joint enterprise involving the authors of this paper and the researchers of LIFE. To this end, the generic questionnaire (Solagro, 2013) for LIFE is adjusted to exact requirements of rice production in Spain. Annex 1 displays the shortest form of this adjusted questionnaire. In every farm additional lines are added to match specific data of each farm (i.e. additional lines to include more than one fertiliser, pesticide, energy source, field task, etc). The basic data required to calculate GHG emissions and energy consumption are related to farm information, cultivar, seeds, productivity, fertilisers, phytosanitary treatments, machinery, buildings, fuel, electric energy, water, animals and other synthetic materials. These raw data is then converted by AgriClimateChange Tool (ACCT), a software tool[5] developed by LIFE (Solagro, 2013), into GHG emissions and energy consumption. ACCT follows ISO 14064-1 and the GHG protocol guidelines (ISO, 2006; World Resources Institute, 2012) to select conversion coefficients and make the calculations. The basic data requested to calculate economic indicators are related to outputs, the market prices for their products, wage bills and the cost of each input. We calculate manually yields per hectare in kilograms, sales revenues, and income both before and after wages. Given that western agriculture is still predominantly characterised by family farms (Lueck and Allen, 1998), there is a long established tradition of including family labour in institutional reports and research studies that seek to provide comparable farm incomes (Schmitt, 1997). Some farms under analysis depend exclusively on the family for labour input, while others use hired workers. Therefore, we calculate and add the opportunity cost of family work by applying the average hourly cost of external wages in the farms under study to the number of hours of family work on each farm so as to calculate income before and after wages.

Within the 9 farms, five farms specialise in a variety of rice known by the name of *gleva*, and four specialise in a variety known as *bomba*. Of the nine farms, eight practise the various techniques of intensive farming and one operates as an organic farm specialised in *bomba*. We decided to include the organic farm producing *bomba* to go one step further into the analysis of the relationship between economic and environmental performance given that previous research suggests that organic farming tends to have a lower environmental impact (Mondelaers et al., 2009). Although 9 out of 9 farms lie within natural parks, and

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[5] Further information and access to the software at: http://www.agriclimatechange.eu/index.php?option=com_content&view=article&id=55&Itemid=81&lang=en

are recipients of European environmental subsidies, nevertheless the environmental practices in the intensive farms remain generally poor. Furthermore, the organic farm in this study is the only organic rice farm of the 29 rice farms in the region. Organic rice production in Spain is in its early stages of development and the rice-farming sector continues to be dominated by intensive practices. The varieties of rice produced the size of the farms and the yield productivity per hectare of the farms analysed can be considered representative of rice farms in Spain (MAGRAMA, 2013). All the data collected adhere to the same definitions and were measured applying the same rules. All figures and data correspond to the same year, that of 2011 to ensure comparability.

Table 4.1 displays a summary of collected data per farm classified in two main categories: inputs and outputs. To facilitate the comparison among farms information is expressed in Euros per hectare. In accordance with the ethical agreement governing interviews, the specific identity of the participants cannot be disclosed; therefore farms are coded with a number ranging from 1 to 9 subsequently. Farms 1 to 8 are intensive farm. Farm 9 is the organic farm.

Table 4.1 Farms inputs and outputs expressed in euros per hectare per year (2011)

Data	**Farm 1**	**Farm 2**	**Farm 3**	**Farm 4**	**Farm 5**	**Farm 6**	**Farm 7**	**Farm 8**	**Farm 9**
Cultivars	Bomba	Gleva	Bomba	Bomba	Gleva	Gleva	Gleva	Gleva	Bomba
Size (ha)	39.39	6.28	4.09	26.80	2.60	1.24	5.73	5.75	8.00
Inputs:									
Seeds (€)	312.88	200.64	254.12	312.00	126.00	88.50	201.60	201.60	270.40
Mineral fertiliser (€)	118.61	212.01	165.24	123.31	292.42	292.42	140.49	260.74	
Organic fertiliser (€)									345.00
Pesticides (€)	199.53	213.68	318.63	185.45	203.53	203.53	246.31	208.21	
Pheromones (€)									153.00
Machinery (€)	103.14	116.68	137.68	89.97	87.68	87.70	149.01	162.03	79.02
Paid labor (€)	774.57			746.27					702.00
Family work (€)		2,221.89	3,409.45		10,733.46	22,505.65	4,870.33	4,853.39	1,594.69
Electricity (€)	145.21		137.38	137.38	137.38	137.38			
Water (€)	292.73	261.17	357.14	292.73	292.73	292.73	144.50	144.00	103.50
Outputs:									
Yields (kgs)	5,373.07	9,389.65	4,544.13	4,400.52	9,600.00	9,600.00	8,500.00	10,650.26	3,000.00

Yields (€)	4,298.46	3,098.58	4,089.71	3,828.46	3,456.00	3,456.00	3,060.00	3,200.35	6,000.00
Income before wages (€)	4,374.36	3,558.10	4,414.78	3,657.75	3,766.25	3,803.74	3,641.09	3,713.86	5,469.08
Income after wages (€)	3,599.78	2,797.68	3,654.36	2,911.48	3,005.83	3,043.32	2,880.67	2,953.43	4,006.66

[1] Including the opportunity cost of family work used on the farm

According to the data in Table 4.1, the farms producing *gleva* range from 1.24 to 6.28 ha of utilised agricultural area (UAA). Farms producing *bomba* under intensive farming range from 4.09 to 39.39 ha of UAA. Despite these differences in UAA, data regarding inputs and outputs of the farms producing both rice varieties intensively are fairly similar. More in detail, within inputs, planted seeds range from 122.00 to 150.00 kilograms per hectare in the case of *bomba* and from 230.00 to 240.00 in the case of *gleva*. This is the only variable in which intensive and organic farms are aligned. Other inputs such as fertiliser, pesticides and machinery display greater variations between organic and intensive practices. More in detail, in the case of intensive farms, expenditures on mineral fertiliser range from 118.61 to 165.24 Euros per hectares and from 140.49 to 292.42 Euros per hectare for *bomba* and *gleva* respectively. The organic farm applies exclusively an organic fertilizer, bokashi, with a cost of 345 Euros per hectare. Expenditure on pesticides per hectare ranges from 185.45 to 318.63 Euros in the case of intensive *bomba* producers and from 203.53 to 246.31 Euros for farms producing *gleva*. The organic farm control pests with pheromones traps applied under a partially subsidised local scheme that cost to this farm per year 153 Euros per hectare. The annual expenditure on machinery represents litres of gas-oil and kerosene required to fulfil different field work over the year (e.g. land preparation, plantation, nutrient control, etc). Among *bomba* producers, the farm with a minimum input in machinery is the organic farm with 79.02 Euros per hectare, the maximum expenditure is 137.68 Euros per hectare and occurs in an intensive farm. Among *gleva* producers the range goes from 87.68 to 162.03 Euros per hectare. The use of kerosene in intensive farms is originated in a highly controversial practice: the aerial application of pesticides using a helicopter to spread pesticides through all the 8 farms together in the same flight.

Table 4.1 also displays the distribution of family work and paid labour. The two largest intensive farms depend exclusively of hired workers, while the other intensive farms are all run exclusively by family members. The organic farm is the only one that has a mix of family work and hired workers. The annual expenses on electricity in the case of intensive farmers range from 137.38 to 145.21. Farms without electricity expenses are those that do not have any building and therefore do not consume electricity from the grid. Regarding annual expenditures on water supply, the 8 intensive farms are part of a specific water system denominated “tancat”. It consists of a community of farmers that use the same water canal; they specify irrigation allocation rules and share the supply water payment. It ranges from 292.73 to 357.14 Euros per hectare among intensive producers of *bomba* and from 144.5 to 292.73 Euros per hectare in the case of farms producing *gleva*. The organic farm annual expenditures on water is 103.50 Euros per hectare.

Regarding outputs, in the case of the intensive farms, the highest yield of *gleva* and *bomba* farms are 10,650.26 and 5,373.07 kg/ha respectively while the minimum figures are 8,500.00 and 4,400.52 kg/ha respectively. The deviations for the other economic indicators are not as great. The intensive farms can be considered largely homogeneous in terms of the economic indicators selected for analysis. However, substantial differences are found with respect to the sub-groups of intensive and organic *bomba*-producing farms. The organic farm in the study reports yields of 3000 kg/ha compared to an average yield on intensive farms of 4772.57 kg/ha: i.e., 1772.57 kg/ha less or 37% less. While sales revenue and income are also homogeneous across intensive farms, they are substantially higher in the case of the organic farm. It reports revenue of 6000 Euros/ha compared to a mean of 4072.21 on intensive *bomba*-producing farms and an income after wages of 4006.66 Euros/ha compared with a mean of 3389.36 Euros/ha on intensive *bomba*-producing farms: i.e., 1927.79 and 617.3 Euros/ha more, respectively. Clearly, despite lower yields, organic production currently boasts a special market share of customers able to pay a higher price per kilogram of rice.

4.5 Results and Discussion

Table 4.2 shows the results when relating the environmental indicators to the economic variables under analysis. Intensive farms are shown separated between farms above and farms below the mean of economic indicators. All economic indicators lead to the same distribution displayed on columns A to D. Column A and C displays the mean values above mean economic performance for farms producing *gleva* (farms 5, 6 & 8) and *bomba* (farms 1 & 3) respectively. Column B and D display the mean values below mean economic performance for farms producing gleva (farms 2 & 7), and *bomba* (farm 4), respectively. Given that the organic farm presents substantially different characteristics, its results are shown separately in column E.

Table 4.2. Economic and environmental performance relationship (year 2011)

Data	Intensive*				Organic
	Gleva (5 farms)		Bomba (3 farms)		Bomba
	(A) Above (3 farms)	(B) Below (2 farms)	(C) Above (2 farms)	(D) Below (1 farm)	(E) 1 farm
Panel A: Economic Indicators					
Yields (kg/ha)	9950.09	8944.83	4958.60	4400.52	3000.00
Revenue (€/ha)	3370.78	3079.29	4194.08	3828.46	6000.00
Income before wages (€/ha)	3761.28	3599.60	4394.57	3657.75	5427.48
Income after wages (€/ha)	3000.86	2839.17	3628.29	2911.48	4006.66
Panel B: Environmental indicators (externalities)					
1. Direct energy (GJ/year/ha)	4.17	4.55	6.15	4.60	2.90
2. Indirect energy (GJ/year/ha)	16.07	12.15	7.60	5.20	1.40
Total energy=1+2 (GJ/year/ha)	20.23	16.70	13.75	9.80	4.30
Ratio indirect/direct energy	3.86	2.67	1.24	1.13	0.48
Total emissions (tCo2/year/ha)	7.17	6.23	5.61	5.49	4.36
Emissions excluding CH4 (tCo2/year/ha)	1.39	0.91	0.55	0.45	0.11
Panel C: Ratios externalities/economic indicators					
Total energy/yields (MJ/year/kg)	2.03	1.87	2.77	2.23	1.43
Total energy/ income after wages (MJ/year/€)	6.74	5.88	3.79	3.37	1.07
Total emissions/yields (tCo2/year/kg)	0.72	0.70	1.13	1.25	1.45
Emissions excluding CH4/yields (tCo2/year/kg)	0.14	0.10	0.11	0.10	0.04
Total emissions/ income after wages (tCo2/year/€)	2.39	2.19	1.55	1.88	1.09
Emissions excluding CH4/ income after wages (tCo2/year/€)	0.46	0.32	0.15	0.15	0.03

Notes: *All four economic indicators included in this table split the sample with the same intensive farms above the mean/median of economic performance, and the same farms below the mean/median of economic performance.

Kg is kilograms; ha is hectare; GJ is gigajoules per year per hectare; MJ is megajoules; tCo2 is tons of carbon dioxide.

Data on economic performance are displayed in panel A. All intensive farms above the mean of economic performance present higher production, revenue and income results than their counterparts below the mean, for both rice varieties. The sales price of *bomba* rice is higher than that of the *gleva* variety, but the costs associated with this first variety are also higher, and so income levels are similar if we compare the two rice varieties for the same group of performers.

While yield per hectare of the organic farm producing *bomba* falls well below that of intensive farms, its revenue and income per hectare are much higher. The organic farm under study is one the few organic rice farms operating in Spain and, therefore, it benefits from a highly atypical, yet extremely profitable, business plan. It produces relatively small quantities of high value-added outputs and undertakes direct selling of most of its production to high profile restaurants and distribution channels.

Data on environmental performance and the interrelation between economic and environmental performances are displayed in panel B and C accordingly. The ratios in panel B are expressed in gigajoules per year per hectare (GJ/year/ha). To facilitate comprehension, the ratios in panel C are expressed in megajoules (MJ) per year per euro of income after wages (MJ/year/€).

Panel B displays the environmental performance for both rice varieties. Direct energy consumption is higher for the sub-group of *bomba* producers with an above mean economic performance than that of below mean producers: 6.15 vs. 4.60 GJ/year/ha, respectively. However, the same relationship does not hold for the sub-group of *gleva* producers. Here, farms with an above mean economic performance consume less direct energy (4.17 GJ/year/ha) than that consumed by their below mean counterparts (4.55 GJ/year/ha). Note, however, that direct energy consumption represented a small share of the overall environmental impact attributable to energy consumption.

The measures of indirect energy consumption offer an appraisal of the accumulated energy consumption from previous productive stages. According to the results in panel B, this consumption is substantially higher than that of direct energy in all the intensive farms, and substantially higher for the sub-group of more (as opposed to less) productive and profitable farms: 16.07 GJ/year/ha vs. 12.15 for *gleva* producers and 7.60 vs. 5.20 for *bomba*, respectively.

The ratio between indirect and direct energy consumption increase with the intensification of farming practices. According to our data, indirect energy consumption is 3.86 times greater than that of direct energy in the sub-group of more productive *gleva* rice farms, while it is only 2.67 times greater in the less productive farms of this rice variety. While the ratios are lower for intensive farms producing *bomba* rice, the indirect energy required is also greater than the direct energy consumed in the productive stage on these farms. Indeed, the ratio also increases with productivity on the *bomba* rice farms: a ratio of 1.24 for the more productive vs. 1.13 for the less productive farms. This means that for the attainment of higher levels of productivity and profitability it is required to purchase and use more inputs that have previously consumed large amounts of energy, inputs that have consequently damaged the environment, depleted the earth's natural resources and overloaded the planet with an increasing ecological footprint. Total energy consumption (direct plus indirect) is consequently higher for intensive farms with an above mean economic performance compared to that of less productive farms, as can be seen in Table 4.2: 20.23 GJ/year/ha vs. 16.70 for *gleva* rice farms and 13.75 vs. 9.80 for *bomba*, respectively.

Our indicator of direct energy only captures the impact of electricity and fuels used on the farms, but does not take into account the energy required for the production and transport of various farming inputs, including, fertilisers, seeds bought from outside the farm, pesticides, herbicides and fungicides, packaging plastics, oil, infrastructure and machinery, among other major inputs in industrial agriculture that are included in our indicator of indirect energy consumption. In classic intensive agriculture, increased productivity is achieved by implementing intensive crop techniques that require preliminary extractive and manufacturing activities that have a high impact on the environment. These impacts are triggered in the early stages of a farm's productive activity when the inputs that are required are being produced and transported to the farm.

The equivalent data for the organic farm describe the profile of a more environmentally friendly farming practice. Direct energy consumption on this farm (2.90 GJ/year/ha) is substantially lower than for any other group of rice producers under study. More in detail, it is below the lowest rate of direct energy consumed by *bomba* rice producers (4.55 GJ/year/ha consumed by the low *bomba* economic performers). Its indirect energy consumption is more than 50% lower than its direct consumption. In contrast to intensive farms, it does not produce prior high-level environmental impacts. Its total energy consumption (4.30 GJ/year/ha) was well below that of any other sub-group (9.8 being the next lowest figure recorded by the less productive *bomba* rice farms). The organic farm not only consumes less energy in the final stage of agricultural production, but also in prior stages. It is environmentally friendly in its dealings and requirements across the whole agribusiness cycle. As such, it provides a remarkable example that a sustainable, and at the same time highly profitable, farming system is feasible. However, according to results, it does not appear that a similar performance could be attained within the boundaries of intensive farming, where increased productivity requires increasing the use of chemical inputs and fossil fuels and, therefore, greater environmental damage. No economies of scope are to be found in this instance. On the contrary, there is an exponential relationship between productivity and environmental damage when we compare organic and intensive rice farms. These results are consistent with previous studies with other crops in terms of the increasing environmental damage caused by increasing the use of external inputs (Mondelaers et al., 2009).

GHG emissions per hectare are higher for the sub-group of intensive farms with an above mean economic performance, 7.17 and 5.61 tons of carbon dioxide per year per hectare (tCo2/year/ha) for *gleva* and *bomba* rice farms, respectively, than those with a lower economic performance (6.23 and 5.49 tCo2/year/ha, respectively), while they are substantially lower for the organic farm (4.36 tCo2/year/ha).

It should perhaps be stressed that our results might be influenced by the fact that rice farms´ main emission is methane, which does not in fact depend so much on output as on the size and flooding cycles of the field. Emissions per hectare excluding CH4 are also higher for the sub-group of intensive farms with an above mean economic performance, 1.39 and 0.55 tons of carbon dioxide per year per hectare (tCo2/year/ha) for *gleva* and *bomba* rice farms, respectively, than those with a lower economic performance (0.91 and 0.45 tCo2/year/ha, respectively), while they are substantially lower for the organic farm (4.36 tCo2/year/ha). Therefore, our results suggest that the higher economic performance of rice farms is attained at the expense of greater air pollution.

Panel C provides data on the environmental impact needed to produce a physical unit of output and to obtain a monetary unit of income. As such, it relates the economic performance data in panel A to the environmental performance data in panel B.

Overall, the data in panel C confirm previous results regarding the existence of a positive relationship (albeit negative in terms of sustainability) between environmental performance and economic performance. While this relationship is strong with respect to energy consumption, it is weaker for GHG emissions.

According to our results, the less productive *gleva* rice farms consume 1.87 MJ of total energy in producing one kilogram of rice, while the more productive farms require 2.03 MJ for one kilogram of output. The same increasing relationship is observed for *bomba* rice farms: the group of less productive farms needs 2.23 MJ, while the more upper productive requires 2.77 MJ. Likewise, 5.88 MJ is required to generate 1 € of income after wages in the less profitable group of *gleva* rice producers, while the more profitable group required 6.74 MJ. The same trend is found in intensive farms producing *bomba* rice (3.37 MJ vs. 3.79 MJ for lower and higher performers, respectively).

The results for GHG emissions are not conclusive. While *gleva* rice producers adhere to the aforementioned trend of increasing productivity resulting in a greater environmental impact: increasing emissions per kg of rice, as well as per € of income, with increasing economic performance, the intensive *bomba* rice producers adhere to a declining trend: less productive farms require more emissions per kg of output (1.25 tCo2/kg), or per € of income (1.88 tCo2/€ income after wages) than their more productive counterparts (1.13 and 1.55, respectively). Although methane does not depend largely on productivity, nevertheless emissions of nitrous oxide and carbon dioxide (see emissions excluding CH4) are more closely related to it. High *gleva* economic performers release 0.14 and 0.46 tCo2 per kg and per € of income after wages respectively compared to 0.10 and 0.32, respectively, in the case of low performers. The emissions of the *bomba* producers are virtually the same for producers above and below the mean.

The data in panel C also confirm our previous findings with respect to the organic farm. This farm requires much less energy consumption per kilogram of output and per € of income than did their counterparts. Likewise, it produces lower field emissions than those of intensive farms per € of income (1.09 tCo2). However, it produces more field emissions per kilogram of rice cropped (1.45 tCo2), a fact that can be explained in terms of its lower productivity in physical units per UAA; nonetheless, it is more environmentally friendly when methane is excluded from the analysis (0.04 tCo2/kg and 0.03 tCo2/€ of income). In summary, organic rice farming is found to be more respectful of the environment, albeit at the expense of lower yields in the short term. Nevertheless, in our study, these practices ensure higher financial profits, even in the short term.

This study finds that enhanced economic performance is attained at the expense of increasing environmental damage. Intensive farming is concerned above all with achieving short-term economic targets with the use of environmentally aggressive inputs across the whole agribusiness cycle to enhance economic performance.

4.6 Conclusions

This study seeks to analyse the relationship between GHG emissions and energy consumption on the one hand, and the yields, revenues and incomes on the other. It uses own collected data and calculations for 9 rice farms producing two cultivars: *gleva* and *bomba*. Our results reinforce the idea that the higher productivity and higher revenues per hectare achieved thanks to the intensive use of fossil fuels and chemical inputs are closely linked with a higher impact on the environment.

More in detail, GHG emissions per hectare are consistently higher in the case of farms above mean economic indicators for both rice varieties farmed intensively, while they were substantially lower in the case of the organic farm. As such, our results suggest that a better economic performance in intensive farming is achieved at the expense of a greater impact on our ecosystem. Total energy consumption is analysed considering both direct and indirect energy consumption. The latter enables us to assess the energy accumulated in the stages prior to actual rice production. It is found to be substantially higher than direct energy consumption in all intensive farms, and it is also higher for farms with an above mean economic performance. Here again the organic farm presents more environmentally friendly results with lower energy consumption values. This means that intensive farms achieve higher productivity and profitability at the cost of overusing energy sources and, therefore, of an increased ecological footprint.

The ratios between environmental and economic performance confirm that a higher environmental impact in terms of climate change is associated with a better economic performance in the short term. In producing one kilogram of rice, the less productive farms require less energy and are responsible for lower rates of emissions, a relationship that is stronger in the case of energy consumption than it was for GHG emissions. This might be attributable to the fact that methane emissions are unrelated to output but are rather determined by the size and flooding cycles of rice fields. Increasing impacts are recorded in the case of the intensification of the use of chemical inputs, fossil fuels and land.

We find some evidence that software applications like ACCT may well be useful to fill some of the gaps in the traditional accounting framework regarding the transparency while reporting the environmental impact of farming. Indeed, environmental impacts and, more importantly, indirect environmental impacts are not captured by traditional accounting methods. The latter only take into consideration certain outputs that can be measured in monetary terms, overlooking those outcomes that cannot be measured and valued by the market and, thus, considered ‘externalities’. If forms of capital that include clean air, clean water and jobs are valued as zero, a decision based on this information is unlikely to consider them important capital to be maintained. As such, traditional financial accounting does not provide a full view to stakeholders, consumers, citizens or policy makers on their choices about food production and consumption. Although identifying best practises is not a linear process and involves the complexity of considering multiple factors and stakeholder’s point of view, nevertheless, it is important because a more holistic approach could help to achieve a shift in patterns and in social awareness of the value of natural resources.

Unfortunately, this study covers only GHG emissions and energy consumption, other positive and negative environmental impacts, such as loss of biodiversity, wildlife and landscape degradation, water filtering or the substitution of natural wetlands regrettably lie outside the scope of this study. Additionally, even though we estimate emissions and energy consumption of outputs, however, do not analyse all subsequent stages after production, most notably that of transportation. A further limitation is the fact that we take only rice crops and we only make the analysis with one year data. To be able to identify further implications and draw additional inferences, we would need to perform similar analyses taking into account additional environmental impacts, taking farms producing a range of different crops and over longer periods of time so as to analyse the evolution of this relationship in the long term.

4.7 References

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Annex 1: List of data collection

Place and date of data collection:

Data needed for the evaluation of energy consumption, GHG emissions and the correlation between environmental and financial performance in paddy fields.

AGROCLIMATECHANGE TOOL DATA (ACCT):

Farm information:
Name of the farmer:
Location:
Agricultural area (UAA):
Cultivar (specify amount of seeds needed per hectare):
Productivity (total tones in UAA):

Fertilisers:
Nitrogen fertiliser units:
Phosphorus fertiliser units::
Potassium fertiliser units:

Phytosanitary treatment (pesticides, herbicides and fungicides):
Name of pesticide / herbicide / fungicide:
Total quantity used:
Pest:
Application:
Size (volume, kg) of containers:
* (Add as many lines as necessary)

Machinery:
Tractor model, tractor year, hours of actual field time, others.

	Land preparation	**Plantation**	**Nutrient control**	**Disease control**	**Harvest**	**Others**
Approximate gas oil consumption						

Energy consumption: please detail annual consumption of other energy sources and equipments

Water consumption (annual):

Others:
Buildings, fuels, electric energy, animals and other synthetic materials.

DATA ANALYSIS OF FINANCIAL EFFICIENCY:

Accounting system:
Does the farm presents financial statements? When? In which format?

Income:
Sales revenue:
Cash/accrual basis:
Comments:

Current subsidies:
Investment subsidies:
Produce subsidies:
Environmental subsidies:

Expenses:
Wages:
Unit of family farm work:
Drying and storage costs:
Water canons expenses:
Purchase price of external inputs:

Chapter 5. Conclusions

5. Conclusions

5.1 Concluding remarks

Since a financial point of view, accounting must provide with useful information for decision-making. If environmental impact from economic activities is left out of traditional accounts we are endangering the most essential capital for human survival, which is natural capital.

This thesis sought to engage in providing fresh innovative solutions to endeavour the integration of environmental impact into the accounting framework using indicators, in the understanding that accounting and indicators are necessary to measure environmental impact of economic activities and, in doing so, enabling sound decision-making.

First, one crucial methodological step in the definition of environmental indicators is boundary setting. Accurate sustainability boundaries improve the comparability, completeness and relevance of environmental indicators. For example, the comparability of sustainability performance among companies with different outsourcing policies or with different energy mixes would demand the inclusion into those sustainability boundaries of supply chain carbon emissions and the emissions produced by the generation of electricity. Chapter 2 approached indicator boundary setting exploring at a theoretical level, the importance of boundaries in the definition of sustainability indicators and reports and, at an applied level, how corporations are considering organizational and operational boundaries in their sustainability reports. Results show that environmental indicators and sustainability reporting boundaries disclosed by all 92 analysed firms in the sample are limited to the consideration of financial control and, therefore, not aligned with the required systemic view to approach a sustainable use of natural resources. Furthermore, in most cases reports do not include environmental impacts from outsourced goods and services. Finally, up to two thirds of the information required by the examined indirect impact indicators is missing. Companies and policy makers should take a long-term approach to analyse, align and integrate ecosystems knowledge into indicators and reporting boundary setting. More specifically, they both need to envisage new approaches to integrate indirect impacts, outsourced activities and entities beyond financial control in their sustainability reports. The use of a reduced number of indirect environmental impact indicators may limit the application of the results to other environmental indicators. The use of reports from large corporations might not be comparable to practices of small companies or non for profit organisations. Future avenues of research in this line should include the analysis of boundary setting of social indicators, a wider array of environmental indicators and/or a more diverse sample of reporting companies. Analysing the reasons of restricted boundary setting could retrieve insightful and fruitful results.

Second, clearly the applicability of different methodologies using environmental indicators is limited by the data already available, on one hand, and on the opportunity cost of obtaining not available measurement, on the other. In this regard, the use of proxies is extremely important. Conventional accounting often takes market-based valuation measures, which act as a proxy for relative value. This makes measurement and valuation relatively easy, herein the use of proxies is widely spread in finance where the real observation would be too costly or timely inefficient. Under the same logic, certain expenditures can act as proxies of environmental costs. Chapter 3 tested the use of selected financial costs as proxies of environmental costs. In this chapter it was performed a panel data analysis of environmental costs and productivity on a farm accounting database across European regions over the 1989-2009 period. Results expose that European regions under study have a negative trend of productivity and a positive trend of environmental costs over 1989-2009. Furthermore, the study reveals that the attainment of additional units of output requires a sustained additional expenditure on environmental costs. These results correlate negatively with both, economic and environmental sustainability of farms. These results have implications for farmers, policy makers and researchers alike, who should pay attention to these two indicators. In doing so they could help to achieve a shift not only in production patterns, but also in consumption habits and in a social awareness of the value of natural resources. These factors are essential in the fight against environmental impact of food production. Our database is limited by the fact that is mostly representative of intensive farms. Additionally, the sample covers exclusively regions across Europe over 1989-2009. This can limit the applicability of results to different types of production, regions or periods of time. Additionally, this paper only considers the monetary value of environmental costs while other measurement could also act as valid proxies. These results open avenues for researchers interested in modelling the difference in the trends of productivity and environmental costs between organic and intensive farming. Integrating measurement in physical units of yields and environmental costs when they become available could retrieve meaningful results.

Third, given the complexity of environmental processes, weighting and aggregation are also relevant in the definition of environmental indicators. Chapter 4 made an exploration of using weighting and aggregation to account for environmental impact expressed in multiple units of measure. More specifically, it performed and empirical analysis on the relationship between environmental and economic performance. Our calculations resulted in GHG emissions and energy consumption per hectare consistently higher in the case of farms above mean economic indicators for both rice varieties farmed intensively, while they were substantially lower in the case of the organic farm. As such, our results suggest that a better economic performance in intensive farming is achieved at the expense of a greater impact on our ecosystem. Farmers should use these results to identify best farming practices from both environmental and economic point of view. Researchers should include applications like ACCT to fill some of the gaps in the traditional accounting framework regarding the transparency while reporting the environmental impact of farming. The use of a reduced number of 9 farms over only one year of production may limit the application of the results to larger agricultural samples. This study covers only GHG emissions and energy consumption, this neglect to some extent the impact of other negative and positive environmental impacts of farming. Analysing larger samples, over longer periods of time could be interesting avenues of future research. As well as including additional environmental impact measurements in the analysis while those become available.

Finally, overall results in the three papers included in this thesis suggest that although it is undoubted that companies would not function without the support and infrastructure of the environment in which they exist, unfortunately, there is still often a disjunctive between corporation and environmental perspective. The integration of environmental indicators into the accounting framework could help to overcome the challenges of measuring, valuing and discharging accountability for the environmental burden of economic activities. Furthermore, it could help to increase accounting transparency regarding the use of natural capital and therefore improve the quality of accounting information for environmentally sound decision-making. As environmental resources are on one had limited, and on the other, indispensable for the normal course of companies operations, by behaving in a non-sustainable way, companies are not only jeopardizing other areas and interests of society but are also jeopardizing the very same source of its operations and therefore the source of their own profits and survival in the long term.

To be able to draw further implications about the use of indicators to integrate environmental and accounting information, it would be of interest of academic researchers and practitioners to apply and test the different approaches used in this thesis on wider empirical basis, whether following the evolution of one single company through a period of time, or choosing as a benchmark different companies, industrial sector or desired targets. This thesis has focused exclusively on environmental indicators, it would be fruitful to integrate also social indicators to measure not only environmental but also social impact of human activities into the accounting framework. Second, convinced of the benefits of using indicators to integrate environmental and accounting information, an interesting additional research opportunity could be to extend the analysis about indicators to measure the strong co-benefits companies can obtained from reduced environmental impact. Finally, this paper opens avenue for further research in the relationship between environmental indicators, environmental accounting and sustainable development.

Annex: Outcomes of the Ph.D. dissertation

FIRST ARTICLE: **Planetary boundaries and sustainability indicators: a survey of corporate reporting boundaries**

Journal papers in second round review

Title: Planetary boundaries and sustainability indicators: a survey of corporate reporting boundaries

Authors: Antonini, Carla; Larrinaga, Carlos

Source: Sustainable Development

Indexed in: Journal Citation Report/Social Sciences Edition.

International conferences

Title: Revisiting boundaries of sustainability reports: A survey on disclosures made by companies included in the Financial Times Global 500 list

Authors: Antonini, Carla; Larrinaga, Carlos

Conference: X CSEAR Spain Conference

Venue: Carmona, Spain

Year: 2015

Title: Planetary boundaries and sustainability indicators: a survey of corporate reporting boundaries

Authors: Antonini, Carla; Larrinaga, Carlos

Conference: Accepted for presentation in 39th European Accounting Association, 2016

Venue: Maastricht, Netherlands

Year: 2016

Title: Planetary boundaries and sustainability indicators: a survey of corporate reporting boundaries

Authors: Antonini, Carla; Larrinaga, Carlos

Conference: Accepted for presentation in 6th CSEAR North America Conference

Venue: Illinois, United States

Year: 2016

SECOND ARTICLE: **Productivity and environmental costs from intensification of farming. A panel data analysis across EU regions**

Journal papers

Title: Productivity and environmental costs from intensification of farming. A panel data analysis across EU regions

Authors: Antonini, Carla; Argilés-Bosch, Josep Maria

Source: Journal of Cleaner Production

Indexed in: Journal Citation Report/Sciences Edition.

International conferences

Title: Does it pay to go on further with intensification of farming? A panel data analysis across EU regions

Authors: Antonini, Carla; Argilés-Bosch, Josep Maria

Conference: X CSEAR Spain Conference

Venue: Carmona, Spain

Year: 2015

Title: Productivity and environmental costs from intensification of farming. A panel data analysis across EU regions

Authors: Antonini, Carla; Argilés-Bosch, Josep Maria

Conference: Accepted for presentation in 6th CSEAR North America Conference

Venue: Illinois, United States

Year: 2016

THIRD ARTICLE: **The interrelation between economic and environmental performance: empirical study of rice production in Spain.**

Working papers

Title: Rice farming, profitability and climate change. Can accounting help to identify best practices? Empirical case study in Spain

Authors: Antonini, Carla; Argilés-Bosch, Josep Maria

Source: Universitat de Barcelona Business papers. Business collection B15/1

Journal papers currently under review

Title: The interrelation between economic and environmental performance: empirical study of rice production in Spain.

Authors: Antonini, Carla; Argilés-Bosch, Josep Maria

Source: International Journal of Agricultural Resources, Governance and Ecology

Indexed at: Scopus (Elsevier)

International conferences

Title: The impact of environmental behaviour on the economic performance of rice farms.

Authors: Antonini, Carla

Conference: International Conference on Accounting and Finance 2013

Venue: Copenhagen, Denmark

Year: 2013

Title: Relation between economic and environmental performance of rice farms: an empirical study in Spain

Authors: Antonini, Carla; Argilés-Bosch, Josep Maria

Conference: IX CSEAR Spain Conference

Venue: Burgos, Spain

Year: 2014