

Modelling Barriers to the Adoption of Industrial Sustainability Measures

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Please cite as:

Trianni, A., Cagno, E., Neri, A. (2017). *Modelling Barriers to the Adoption of Industrial Sustainability Measures*. *Journal of Cleaner Production*, 168, 1482–1504.
doi:10.1016/j.jclepro.2017.07.244.

Abstract

Sustainability is constantly gaining relevance among industrial decision makers, policy makers and scholars. In order to be sustainable, firms need to implement industrial sustainability measures, however there are many barriers to doing this. This work is based on a review of literature on barriers to the areas of occupational health and safety, eco efficiency, energy efficiency and to sustainability and contributes to industrial sustainability research by presenting a novel, integrated theoretical model of barriers to implementation of sustainability measures. The model encompasses previous literature review contributions and is intended to characterize and evaluate barriers to the adoption of industrial sustainability measures in all its areas. We have conducted a preliminary validation of the model investigating eight northern Italian manufacturing firms, looking at its ability to represent barriers to sustainability, usefulness and ease of use. We conducted semi-structured interviews to people responsible of the different areas of industrial sustainability, complemented by questionnaires and secondary materials. Results show a positive overall judgment of the model by all the interviewees. Moreover, the model was able to be applied to issues deriving from different perspectives and different areas of industrial sustainability. The findings can help firms and policy makers overcome barriers and they also provide insight into the different perspectives on the adoption of industrial sustainability measures than can be used to promote their adoption.

Keywords: Industrial Sustainability, Barriers, Measures, Energy efficiency, Eco efficiency, Occupational Health and Safety

1 Introduction

In recent years, the interest of policy-makers and industrial decision-makers in the sustainability of industrial activities has dramatically grown. The industrial sector is a domain in which there is real need to improve sustainability (Rademaekers et al., 2011): current modes of production are unsustainable and substantial technological, managerial, organizational and behavioral changes are required to make them more sustainable (Blok et al., 2015).

The Triple Bottom Line model (TBL) proposed by Elkington (1998) identifies sustainability as the intersection of three different pillars, namely economic, environmental and social. In the industrial context we can refer to corporate sustainability (CS), industrial sustainability (IS) and manufacturing sustainability (MS). CS usually relates to the strategic level (Lozano et al., 2015) and MS to the production system level (Garetti and Taisch, 2012), however IS relates to the industrial plant level. Indeed, IS accounts for all the actions that are referred to production plant (and not just the production

line), i.e. requiring actions at the levels of material, product, process, plant and systems of production (Tonelli et al., 2013), as well as integration into normal operations (Evans et al., 2009), and it has been considered as the research domain of the present study. IS has been often identified in literature with the areas of occupational health and safety (OHS) (Pagell and Gobeli, 2009), and eco efficiency (EE) (Gimenez et al., 2012), with a growing relevance of energy efficiency (EnEff) issue within EE (Pehlken et al., 2015). OHS and EnEff can be identified using the TBL model as the intersections of social and economic pillars, and environmental and economic pillars respectively.

To improve their sustainability, firms have to implement measures in all IS areas. Although there is good evidence that such measures are effective and have a positive impact on firms' performance, e.g. (Fleiter et al., 2012a) for EnEff, (Hami et al., 2015) for sustainable practices, (Tompa et al., 2006) for OHS, many firms still struggle to implement them. OHS continues to be one of the major challenges for companies and policy-makers (Cagno et al., 2016), and there is general recognition that "the need to improve working conditions is a collective concern, prompted by both humanitarian and economic considerations" (Eurostat, 2016). The situation is also quite serious in relation to EE: industrial production is one of the biggest consumers of resources and one of the largest sources of waste (Eurostat, 2016), however adoption of measures has been very slow and more and faster actions are needed (Vermeulen and Witjes, 2016). Sustainability measures have been shown to have positive effects on economic and financial performance (Ambec and Lanoie, 2008), and it costs surprisingly little to implement cost-effective EnEff measures in firms (Fleiter et al., 2012a). However, less than 50% of manufacturing firms have adopted such measures due mainly to the long payback times and high costs (Anderson and Newell, 2004). There is often more emphasis on the economic impact of sustainability measures than on the social or environmental one. Authors show trade-offs (Salzmann et al., 2005) both between economic and environmental goals and between economic and social ones (Beckmann et al., 2014; Haffar and Searcy, 2017), and most firms will prioritize financial goals (Fennema, 2000), particularly in the short term (Van Der Byl and Slawinski, 2015). However, pursuing only economic goals is not enough to deliver long-term sustainability (Dyllick and Hockerts, 2002). Nevertheless it has been shown that implementing measures able to improve social and/or environmental performances can also have significant economic benefits (Henri and Journeault, 2009; Tanzil and Beloff, 2006).

This gap is due to the presence of barriers, so that sustainability measures are perceived as burdensome or unprofitable, e.g. (Cherniack and Lahiri, 2010) for OHS, (Vieira and Amaral, 2015) for EE, (Walsh and Thornley, 2012) for EnEff, or requiring too much organizational changes, e.g. (Smith and Carayon, 2009) for OHS, (Martín-Peña et al., 2014) for EE, (Liu et al., 2014) for EnEff. Barriers to single different areas of IS have been largely discussed in literature, focusing on specific industrial sector, geographical areas or firm's dimensions, e.g. (Whysall et al., 2006) for OHS, (Zhang et al., 2009) for EE, (Venmans, 2014) for EnEff, but none of these contributions has offered a comprehensive overview on barriers to IS. Indeed, hitherto research on barriers to IS as we intended it has been quite limited. There have been some studies of CS, but they have either not used formal measures (Lozano, 2013), or were based on empirical case studies and lacked a theoretical underpinning (Paramanathan et al., 2004). Summing up, there is thus no single, comprehensive model of barriers to the implementation of industrial sustainability measures (ISMs). Such a model would be of considerable interest as it would underline possible interdependences among the different IS areas and highlight similarities and differences, developing an effective strategy for tackling barriers to implementation of ISMs.

The remainder of the paper is structured as follows: in Section 2, literature review is conducted; in Section 3 research methods used for the development of the research are reported; in Section 4, the new model is introduced; in Section 5, the procedure for the evaluation of the validity of the model is presented; in Section 6 the results obtained are reported. Lastly, discussion and conclusion are provided in Section 7, along with limitations of the study and possible further research.

2 Literature review

We carried out a background analysis of IS and of the different IS areas, so to obtain an understanding of the barriers affecting them. We focused both on IS and on CS because the two concepts are often misled – being to some extent interconnected – . For this reason, despite our research is focused on IS, including also CS offers a larger and more detailed analysis of existing contributions. We searched for relevant literature by querying the international databases SCOPUS, Google Scholar and ISI Web of Knowledge and also used the snowball method. Regarding keywords, we use *barrier* and similar terms, e.g. *obstacle*, combined with the terms related to the different level and areas considered, i.e. *IS*, *CS*, *OHS*, *EE*, *EnEff*. We limited our review to work published in the last 20 years. Following, for each area of IS the relevant contributions have been analyzed according to: *i*) how the barriers have been presented in the study, i.e. namely by examples of barriers (single ones or a list of them), classification or taxonomy; *ii*) type of study, i.e. theoretical, empirical, or both; *iii*) whether the barriers were identified as internal or external in origin; and *iv*) nature of barriers such as, e.g. economic, organization or information-related.

2.1 Industrial Sustainability and Corporate Sustainability

Our analysis of barriers to IS and CS raised some interesting issues. Firstly, research has already observed a dearth of research on barriers to IS (Paramanathan et al., 2004), and CS, e.g. (Chowdhury et al., 2015). Additionally, IS and CS are often confused with or treated as overlapping with Corporate Social Responsibility (Arevalo and Aravind, 2011; Frankental, 2001) or environmental sustainability (Lodhia, 2003; Setthasakko, 2009). Focusing on CS, that presents a more developed literature than IS, two main general barriers to the implementation of measures emerge: the lack of understanding of the concept of CS, e.g. (Belal and Owen, 2007) and the difficulty of implementing CS measures in an integrated fashion, e.g. (Dyllick and Hockerts, 2002) and (Van Marrewijk, 2003). More specific barriers have been identified, such as *resistance to change*, e.g. (De Paiva Duarte, 2015), *culture*, e.g. (Doppelt, 2003), *lack of awareness/ knowledge*, e.g. (Lo and Sheu, 2007), *human barriers* relating to both *employees*, e.g. (Maximiano, 2005), and *management*, e.g. (Collins et al., 2010), *lack of written internal policy*, e.g. (Naeem and Welford, 2009), *lack of resources*, e.g. (Maximiano, 2005), *lack of information*, e.g. (Doppelt, 2003) and *cost*. The importance of *regulatory* barriers has also been underlined, e.g. (Hossain et al., 2010).

Two contributions emerged as of particular interest from our review. Firstly, Lozano (2013) reviewed organizational systems analyzing how they are influenced by attitudes. Lozano noted that most companies having implemented sustainable practices did it mainly as a result of upper management initiatives, and that, hitherto, firms have been treated as black boxes, thus not accounting for subcultures and intra-organizational differences. Lozano provided a very interesting contribution regarding barriers faced by an organization, distinguishing between barriers at individual-level, group level and organization level. Secondly, Collins et al., (2010) empirically analysed barriers to implementation of specific CS measures, evaluating barriers to measures related to different areas of CS, i.e. environmental, social and economic. This research offers a valuable contribution for a first identification of differences among the areas.

2.2 Occupational Health and Safety

We analyzed 17 publications dealing with OHS, reported in Table 1.

Organization barriers emerged as an important category of barrier to the implementation of OHS measures. Among them we can find barriers related to organizational structure, lack of resources (time and staff), or to the prioritizing of other activities, such as production, e.g. (Cunningham and Sinclair, 2015). Barriers related to *human factors* are also important. These are barriers related to the management, in particular its approach towards OHS, and to staff who may adopt inappropriate

behaviors or may not be involved in OHS initiatives, e.g. (Barbeau et al., 2004). Literature shows that *lack of knowledge and competence* represents a very important barrier, e.g. (EASHW, 2010). Further, *economic* barriers, mainly related to cost, e.g. (Quinlan and Mayhew, 2000), and to *technological* barriers, e.g. (Smith and Carayon, 2009) may be relevant. *Regulatory* barriers may also be a hindering factor, either through over-bureaucracy, e.g. (Champoux and Brun, 2003), or inadequate legislation, e.g. (Masi et al., 2014). There is a smaller number of publications dealing with barriers related to *lack of external support*, such a lack of technical support or guidelines, e.g. (Masi and Cagno, 2015). For the complete picture of the literature review regarding OHS, please refer to Table 1.

2.3 Eco efficiency

We included in our analysis of EE literature some publications dealing with closely related concepts, (Glavič and Lukman, 2007; Van Berkel, 2007), e.g., cleaner production (WBCSD and UNEP, 1998) and green manufacturing (Manzan and Miyake, 2013). We analyzed 30 publications on EE, reported in Table 2.

Discussion over *economic* barriers is large, pointing out the relevance of, e.g. high cost of investments, lack of financial resources, overly long payback time and the implementation risks, e.g. (Murillo-Luna et al., 2011). *Organization* barriers included other priorities over EE, lack of resources and the internal structure of the firm, e.g. (Hillary, 2004). *Lack of awareness* within an organization can also act as a barrier, e.g. (Biondi et al., 1998). Both these factors may apply to an organization generally or to the workers or management specifically. *Human-related* barriers such as inappropriate staff behavior, e.g. (Matus et al., 2012), and low management commitment, e.g. (Studer et al., 2006) are also important. *Information-related* barriers, e.g. (Côté et al., 2006) and *technology-related* barriers such as technological risk or lock-in can occur, e.g. (Ministerie Van Vrom, 2004). Further, we can find *regulatory* barriers, such as legal requirements and legislation, e.g. (Moors et al., 2005). Moreover, *lack of external market pressure* to implement measures is deemed as a very important barrier, e.g. (Zilahy, 2004). The importance of *external support* has been also recognized, e.g. (Shi et al., 2008). For the complete picture of the literature review regarding EE, please refer to Table 2.

2.4 Energy efficiency

We analyzed 38 publications related to EnEff, reported in Table 3.

The *economic* barriers such as high initial cost, lack of capital, payback time and hidden costs have a serious impact on implementation of measures, e.g. (Harris et al., 2000). *Organization* barriers include other issues taking priority over EnEff measures, inertia and internal structural problems, e.g. (Rohdin and Thollander, 2006). *Lack of awareness* (general, worker-specific or management-specific) is also an important barrier as is *lack of competence/knowledge* at all levels, e.g. (Cooremans, 2012). *Human behavior* can represent a barrier, e.g. (Hasanbeigi et al., 2010): indeed, workers can adopt an incorrect behaviour, e.g. (Nagesha and Balachandra, 2006), or there may be a lack of management support, e.g. (Blass et al., 2014). *Information-related* barriers are those relating to lack of information and the trustworthiness of sources, e.g. (Kostka et al., 2013). *Regulatory* barriers may include bureaucracy and policy inconsistency or distortion, e.g. (Weber, 1997). *Technology-related* barriers are important, e.g. (De Groot et al., 2001), as is *lack of market demand* or *external pressure*, e.g. (Venmans, 2014), and problems related to *market dynamics*, such as uncertainties about energy prices or price distortions, e.g. (Worrell and Price, 2001). Lastly, the importance of *external support* has been also recognized, e.g. (Cagno et al., 2013). Finally, two major taxonomies for barriers can be observed in most recent literature contributions. First Sorrell et al. (2010), revising (Sorrell et al., 2000), identified six main barriers as follows: Risk, Imperfect information, Hidden costs, Access to capital, Split incentives, and Bounded rationality. Then, Cagno et al. (2013) developed a theoretical

model of barriers to industrial energy efficiency based on an industrial decision-making empirical perspective, identifying the following categories, namely: Technology –related barriers, Information barriers, Economic, Behavioral, Organizational, Barriers related to competences, Awareness. A broad set of empirical studies based on those taxonomies can be found, e.g. (Schleich and Gruber, 2008) for the former, (Catarino et al., 2015) for the latter. For the complete picture of the literature review regarding EnEff, please refer to Table 3.

2.5 Emerging gaps

Some gaps were identified during the literature review:

- Authors have investigated barriers to IS and CS as a whole, nevertheless they had underlined difficulties in the integration of all the areas;
- The frameworks and models used in research on barriers to IS and CS are less structured than those applied to specific IS areas;
- To date research has evaluated barriers to IS by considering one area of IS at a time, rather than taking a holistic perspective and thus has failed to take account of possible interdependencies. Indeed, theoretical studies, e.g. (Hasle and Limborg, 2006) for OHS, (Silva Lopes et al., 2013) for EE, (Cagno et al., 2013) for EnEff, and empirical studies, e.g. (Mellor et al., 2011) for OHS, (Dobes, 2013) for EE, (Schleich, 2009) for EnEff, focusing on specific industrial sectors, e.g. (Whysall et al., 2006) for OHS, (Chan, 2008) for EE, (Okazaki and Yamaguchi, 2011) for EnEff, on specific geographical areas and countries, e.g. (EASHW, 2010) for OHS, (Murillo-Luna et al., 2011) for EE, (Venmans, 2014) for EnEff, or on small and medium-sized enterprises, e.g. (Lamm, 1999) for OHS, (Zhang et al., 2009) for EE, (Kostka et al., 2013) for EnEff, but, so far, no study has offered a comprehensive overview;
- previous research did not consider barriers to specific measure of IS as a whole, addressing them only at a general level. Collins et al. (2010) and Cagno and Trianni (2014) started evaluating barriers to specific measures, but they focused on a specific IS area, respectively the different areas of CS and EnEff without an integrated approach.

To conclude, an integrated approach accounting for potential similarities and differences among the measures in different areas is effectively required.

					<i>Nature</i>							
	<i>Type</i>	<i>Theoretical</i>	<i>Empirical</i>	<i>Internal/ External</i>	Management	Staff	Organisation	Knowledge	Support	Regulatory	Technology	Economic
Rubenowitz, 1997	<i>E</i>		x		x	x	x					
Lamm, 1999	<i>E</i>					x	x	x (<i>W</i>)	x			x
Quinlan and Mayhew, 2000	<i>E</i>						x					x
Champoux and Brun, 2003	<i>C</i>		x		x	x				x		x
Barbeau et al., 2004	<i>E</i>		x		x	x	x					
Walker and Tait, 2004	<i>E</i>		x				x					
Hasle and Limborg, 2006	<i>E</i>	x					x		x	x		x
Whysall et al., 2006	<i>E</i>		x		x	x	x		x			
Smith and Carayon, 2009	<i>C</i>	x				x	x				x	
Cherniack and Lahiri, 2010	<i>C</i>	x	x				x					x
EASHW, 2010	<i>E</i>		x				x	x	x			x
Hale et al., 2010	<i>E</i>		x		x	x	x					
Theberge and Neumann, 2010	<i>E</i>		x				x					
Mellor et al., 2011	<i>C</i>		x		x	x	x		x			
Masi et al., 2014	<i>E</i>		x		x	x	x			x		
Cunningham and Sinclair, 2015	<i>E</i>		x				x	x				
Masi and Cagno, 2015	<i>C</i>	x	x	x	x	x	x		x	x	x	

Table 1: Occupational Health and Safety Literature Review. The table categorized the contributions according to their Type (E= examples, C=classification, T= taxonomy), whether they are Theoretical, Empirical or both, whether their distinguish between Internal and External barriers and the Nature of the barriers considered (W= referred only to workers; M= referred only to Management; G= General)

	<i>Nature</i>														
	<i>Type</i>	<i>Theoretical</i>	<i>Empirical</i>	<i>Int/Ext</i>	Information	Management	Staff	Organisational	Competence/ Knowledge	Awareness/ Culture	Support	External Market	Regulatory	Technology	Economic
Gunningham and Sinclair, 1997	<i>E</i>	<i>x</i>		<i>x</i>	<i>x</i>		<i>x</i>	<i>x</i>	<i>x (G)</i>			<i>x</i>	<i>x</i>		<i>x</i>
Biondi et al., 1998	<i>E</i>	<i>x</i>	<i>x</i>					<i>x</i>		<i>x (G)</i>					<i>x</i>
Bianchi and Noci, 1998	<i>E</i>	<i>x</i>						<i>x</i>				<i>x</i>			
Gombault and Versteeg, 1999	<i>E</i>		<i>x</i>					<i>x</i>	<i>x (G)</i>				<i>x</i>		<i>x</i>
Doniec et al., 2002	<i>C</i>		<i>x</i>		<i>x</i>		<i>x</i>			<i>x (G)</i>	<i>x</i>			<i>x</i>	<i>x</i>
Van Hemel and Cramer, 2002	<i>E</i>	<i>x</i>						<i>x</i>	<i>x (G)</i>	<i>x (G)</i>		<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>
Vernon et al., 2003	<i>C</i>		<i>x</i>	<i>x</i>	<i>x</i>			<i>x</i>		<i>x (G)</i>	<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>
Ministerie Van Vrom, 2004	<i>C</i>	<i>x</i>		<i>x</i>	<i>x</i>			<i>x</i>					<i>x</i>	<i>x</i>	<i>x</i>
Zilahy, 2004	<i>E</i>	<i>x</i>	<i>x</i>				<i>x</i>	<i>x</i>		<i>x (G)</i>		<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>
Hillary, 2004	<i>C</i>	<i>x</i>		<i>x</i>			<i>x</i>	<i>x</i>	<i>x (G)</i>	<i>x (G)</i>	<i>x</i>		<i>x</i>		<i>x</i>
Moors et al., 2005	<i>C</i>		<i>x</i>					<i>x</i>	<i>x</i>	<i>x (G)</i>				<i>x</i>	<i>x</i>
Siaminwe et al., 2005	<i>C</i>		<i>x</i>		<i>x</i>				<i>x (G)</i>	<i>x (G)</i>			<i>x</i>		<i>x</i>
Côté et al., 2006	<i>E</i>	<i>x</i>			<i>x</i>			<i>x</i>	<i>x</i>	<i>x (G+M)</i>			<i>x</i>		<i>x</i>
Studer et al., 2006	<i>E</i>	<i>x</i>	<i>x</i>				<i>x</i>	<i>x</i>	<i>x (G)</i>	<i>x (W)</i>		<i>x</i>	<i>x</i>		<i>x</i>
Dieleman, 2007	<i>E</i>		<i>x</i>					<i>x</i>	<i>x (G)</i>				<i>x</i>		
Chan, 2008	<i>C</i>	<i>x</i>	<i>x</i>		<i>x</i>		<i>x</i>	<i>x</i>	<i>x (G)</i>		<i>x</i>		<i>x</i>		<i>x</i>
Shi et al., 2008	<i>C</i>	<i>x</i>	<i>x</i>		<i>x</i>		<i>x</i>	<i>x</i>	<i>x (G+W)</i>	<i>x (G)</i>	<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>
Zhang et al., 2009	<i>E</i>	<i>x</i>	<i>x</i>				<i>x</i>				<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>
Fernández-Viñé et al., 2010	<i>E</i>		<i>x</i>					<i>x</i>		<i>x (G)</i>				<i>x</i>	<i>x</i>
Massoud et al., 2010	<i>E</i>	<i>x</i>	<i>x</i>					<i>x</i>	<i>x (G)</i>			<i>x</i>	<i>x</i>		<i>x</i>
Murillo-Luna et al., 2011	<i>C</i>	<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>		<i>x</i>	<i>x</i>	<i>x (W)</i>	<i>x (W)</i>		<i>x</i>	<i>x</i>		<i>x</i>
Matus et al., 2012	<i>C</i>		<i>x</i>						<i>x (G)</i>			<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>
Daddi et al., 2013	<i>E</i>		<i>x</i>												<i>x</i>
Dobes, 2013	<i>E</i>		<i>x</i>					<i>x</i>							
Fernández-Viñé et al., 2013	<i>E</i>	<i>x</i>			<i>x</i>		<i>x</i>		<i>x (W)</i>	<i>x (G)</i>		<i>x</i>	<i>x</i>		
Mittal et al., 2013	<i>E</i>	<i>x</i>	<i>x</i>		<i>x</i>		<i>x</i>			<i>x (G)</i>		<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>
Silva Lopes et al., 2013	<i>C</i>	<i>x</i>			<i>x</i>		<i>x</i>						<i>x</i>		<i>x</i>
Martín-Peña et al., 2014	<i>C</i>	<i>x</i>	<i>x</i>				<i>x</i>	<i>x</i>							<i>x</i>
Mittal and Sangwan, 2014	<i>E</i>	<i>x</i>	<i>x</i>		<i>x</i>		<i>x</i>			<i>x (G)</i>		<i>x</i>	<i>x</i>	<i>x</i>	<i>x</i>
Vieira and Amaral, 2015	<i>E</i>	<i>x</i>		<i>x</i>			<i>x</i>	<i>x</i>	<i>x (W)</i>				<i>x</i>		<i>x</i>

Table 2: Eco efficiency Literature Review. The table categories the contributions according to their Type (E= examples, C=classification, T= taxonomy), whether they are Theoretical, Empirical or both, whether they distinguish between Internal and the Nature of the barriers considered (W= referred only to workers; M= referred only to Management; G= General)

					Nature											
	Type	Theoretical	Empirical	Int/Ext	Information	Management	Staff	Organisation	Competence/ knowledge	Awareness	Behaviour	Support	External Market	Regulatory	Technology	Economic
Weber, 1997	C	x			x			x		x (G)			x	x		
Reddy and Shrestha, 1998	E		x		x								x			x
Harris et al., 2000	C	x	x						x (G+W)							x
Sorrell et al., 2000	T	x			x			x		x (G)	x				x	x
De Groot et al., 2001	C	x	x					x							x	x
Worrell and Price, 2001	C	x			x			x	x (W)						x	x
Anderson and Newell, 2004	E		x		x								X			x
Sorrell et al., 2004	T	x			x			x		x (G)	x				x	x
Nagesha and Balachandra, 2006	C	x	x		x			x		x (G)	x			X		x
Rohdin and Thollander, 2006	E	x	x		x		x	x	x (G)	x (W)					x	x
Rohdin et al., 2007	E	x	x		x	x		x	x	x (G+W)		x (G)			x	x
Thollander et al., 2007	E	x	x		x	x		x	x	x (W)		x (G)			x	x
Sardianou, 2008	C	x	x					x	x (W+M)				x			x
Schleich and Gruber, 2008	C	x	x		x			x								x
Thollander and Ottosson, 2008	E	x	x		x	x		x	x	x (W)		x (G)			x	x
Schleich, 2009	C		x		x			x					x			
Hasanbeigi et al., 2010	E				x	x		x						X	x	x
Sorrell et al., 2010	T	x	x		x			x		X (G)	x		x		x	x
Okazaki and Yamaguchi, 2011	C		x					x	x (G)					x	x	x
Cooremans, 2012	E	x				x		x								x
Fleiter et al., 2012b	C	x	x					x	x (G)				x		x	x
Trianni and Cagno, 2012	C	x	x					x			x		x			x
Walsh and Thornley, 2012	E		x					x					x	x	x	x
Apeaning and Thollander, 2013	E	x	x		x	x		x		x (W)					x	x
Cagno et al., 2013	T	x		x	x			x	x	x	x	x	x	x	x	x
Kostka et al., 2013	C	x	x	x	x			x								x
Trianni et al., 2013a	T	x	x		x	x		x	x (G)	x	x				x	x
Trianni et al., 2013b	T	x	x	x	x			x	x		x				x	x
Trianni et al., 2013c	T	x	x	x	x			x	x	x	x				x	x
Blass et al., 2014	C		x			x										
Brunke et al., 2014	C	x	x	x				x	x	x	x		x	x		x
Cagno and Trianni, 2014	C	x	x	x	x			x		x					x	x
Liu et al., 2014	C	x	x	x				x	x	x		x		x		
Venmans, 2014	C	x	x		x			x							x	x

Table 3: Energy efficiency Literature Review. The table categorizes the contributions according to their Type (E= examples, C=classification, T= taxonomy), whether they are Theoretical, Empirical or both, whether their distinguish between Internal and the Nature of the barriers considered (W= referred only to workers; M= referred only to Management; G= General)

3 Research methods

Stemming from the literature review, the new model for barriers to IS has been developed. Indeed, after the analysis, the need for a new model was even more evident: contributions related to the different areas of IS presented several commonalities, such as the distinction between external and internal barriers in origin, and the further distinction into categories. We tried to create categories able to comprehend and represent all barriers. Barriers affecting the three IS areas present a considerable overlap; however, some differences are worth noting. We extended or modified some barrier's definition provided in literature, so to fit barriers referred in literature to one or two areas, to all the three areas. Stemming from the theoretical model proposed, we then developed a model for the empirical investigation, trying to understand how internal stakeholders perceive external barriers as internal ones. This has been done through the reconstruction of linkages with a logical approach supported, when available, by literature.

The validity of the model was assessed through case studies. We conducted a preliminary validation study in which we evaluated three performances: ability to represent, usefulness and ease of use. Each performance was evaluated using different questions. We investigated *ability to represent* considering the capability of the proposed model to represent the full set of barriers to IS, whether the barriers were sufficiently distinct and whether they had the same level of detail. We investigated *usefulness* by understanding, from the interviews, whether the model allowed pointing out barriers that to interviewees were not hitherto aware. Finally, the model would be useful if allows interviewees to better structure what they had already in mind, or for designing and implementation of measures, and whether the model would provide a valid and quick help for the identification of barriers. We assessed *ease of use* by understanding whether the model was easy to be used and if it was worth the effort.

The reason for our choice to focus on northern Italian manufacturing firms was two-fold: first, the undoubted importance of the manufacturing sector to Europe generally and Italy in particular. Second, despite the primary role, there is still, indeed, ample room for improvement in all areas of IS (ILO, 2011; INAIL, 2014; Eurostat, 2016). Our company sample includes eight manufacturing firms differing in activity, size and turnover. Investigating a heterogeneous sample of companies provides evidence of the generalizability of an emerging theory (Eisenhardt, 1989). As case study research is judged on its theoretical generalizability rather than on its statistical generalizability (Hillebrand et al., 2001; Stuart et al., 2002), we decided that a sample of eight firms was adequate for validate the initial set of propositions, basing also on previous research (Eisenhardt, 1989; Pagell and Wu, 2009), according to which a set from 6 up to 10 cases would be a proper one. We chose to perform investigation with people in charge of EE, EnEff and OHS, so to collect the most appropriate information and data. We interviewed thirteen people in relevant leadership positions in eight firms, with details reported in Table 4.

	ATECO	Sector	Employees	Turnover	Persons interviewed
Company 1	C 28.10	Manufacture of general — purpose machinery	370	50.000 k€	Health Safety and Environment Manager 1 Health Safety and Environment Manager 2 Maintenance Manager
Company 2	C 21	Manufacture of basic pharmaceutical products	130 (in the plant)	200.000 k€	Health Safety and Environment Manager
Company 3	C 28.30	Manufacture of agricultural and forestry machinery	47	20.000 k€	OHS Manager Energy and Environmental Manager
Company 4	C 20.15	Manufacture of fertilizers and nitrogen compounds	35	15.000 k€	OHS Manager Quality Manager
Company 5	C 17.22	Manufacture of household and sanitary goods	250	75.000 k€	OHS Manager Technical Director
Company 6	C 25.40	Manufacture of weapons and ammunition	About 500	80.000 k€	Health Safety and Environment Manager
Company 7	C 28.20	Manufacture of other general-purpose machinery	184	50.000 k€	Health Safety and Environment Manager
Company 8	C 21.20	Manufacture of biotech pharmaceuticals	21	500 k €	CEO

Table 4: Main information of the companies in the selected sample

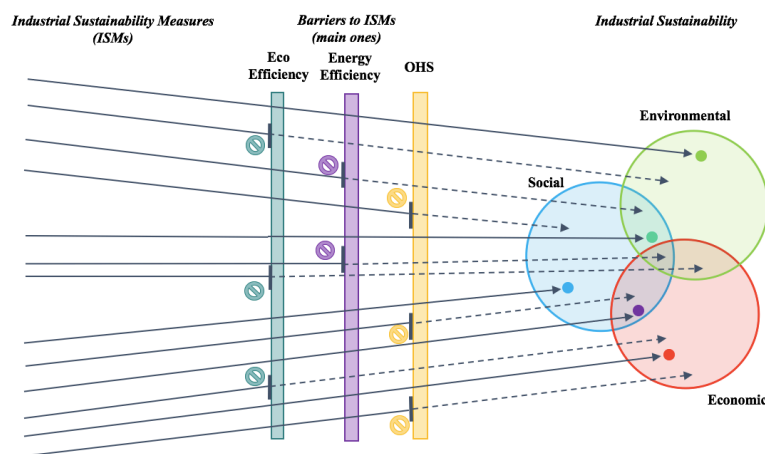
4 Development of a new model for barriers to industrial sustainability measures

Taking inspiration by previous literature, barriers have been reorganized into internal and external, as well as in categories, trying to comprehend and represent all barriers previously identified by scholars. The external barrier categories were: *regulatory, support* and *market barriers* and the internal barrier categories were: *organization, management behavior, worker behavior, information, technology/service* and *economic barriers*.

The model of barriers is represented in Figure 1 and detailed in Table 5. Origin, categories and barriers are presented, as well as a description of each barrier and references.

Figure 1: The model of barriers to industrial sustainability.

The arrows indicate different industrial sustainability measures. Measures pass through three different lenses, i.e. barriers related to the different areas of industrial sustainability, namely eco-efficiency, energy-efficiency and occupational health and safety (OHS), without any prioritization order. Passing through these lenses, measures can be stopped by barriers (solid vertical bars) related to the different areas. If they are stopped (dashed arrows), they are not able to reach the target, i.e. positively impact on industrial sustainability.



Origin	Category	Barrier	Definition	Literature references
External	Regulatory	Legal requirements	Legal requirements are excessive or not effective with respect to the real needs of the company related to sustainability	OHS: <u>Hasle and Limborg, 2006</u> ; Masi et al., 2014; Masi and Cagno, 2015 EE: Côté et al., 2006; Dieleman, 2007; Fernández-Viñé et al., 2013; Gombault and Verstege, 1999; Gunningham and Sinclair, 1997; Hillary, 2004; Massoud et al., 2010; Matus et al., 2012; Ministerie Van Vrom, 2004; Mittal et al., 2013; Mittal and Sangwan, 2014; Moors et al., 2005; Murillo-Luna et al., 2011; Shi et al., 2008; Silva Lopes et al., 2013; Studer et al., 2006; Van Hemel and Cramer, 2002; Vernon et al., 2003; Vieira and Amaral, 2015; Zilahy, 2004 EnEff: Hasanbeigi et al., 2010; Liu et al., 2014; Nagesha and Balachandra, 2006; Okazaki and Yamaguchi, 2011; Walsh and Thornley, 2012; Weber, 1997
		Bureaucracy	Excessive amount of paperwork necessary to be compliant with legal requirements, which is not tailored with respect to the capabilities of the company.	OHS: <u>Champoux and Brun, 2003</u> ; Masi et al., 2014; Masi and Cagno, 2015 EE: Matus et al., 2012; Murillo-Luna et al., 2011 EnEff: Anderson and Newell, 2004; Sardanou, 2008
		Lack of incentives	No economic incentives such as tax exemptions and grants for the implementation of measures.	EE: Massoud et al., 2010; <u>Shi et al., 2008</u> ; Studer et al., 2006 EnEff: De Groot et al., 2001; Hasanbeigi et al., 2010; Nagesha and Balachandra, 2006; Okazaki and Yamaguchi, 2011; Walsh and Thornley, 2012
		Policy distortion	Taxes, subsidies or other policy that discourage measure's implementation	EnEff: <u>Cagno et al., 2013</u> ; Walsh and Thornley, 2012
Support	Lack of external	Firm does not receive a technical support suitable to its needs	OHS: EASHW, 2010; Masi and Cagno, 2015 EE: Hillary, 2004; Mittal and Sangwan, 2014; <u>Shi et al.,</u>	

	technical support		2008 EnEff: Cagno et al., 2013; Trianni and Cagno, 2012
	Lack of consultancy	There is not an adequate consultancy (from services, insurance companies, accounts, public authorities) that can help firm in the different phases of the decision making	OHS: <i>Hasle and Limborg, 2006</i> ; Masi and Cagno, 2015 EE: Chan, 2008; Hillary, 2004 EnEff: Trianni and Cagno, 2012
Market	Customer not ready /Lack of demand	Customers are not sensible to the issue thus not requiring a minimum level of performance e.g. not demanding green products/not demanding specific safety requirements	EE: Bianchi and Noci, 1998; <i>Fernández-Viñé et al., 2013</i> ; Massoud et al., 2010; Mittal et al., 2013; Shi et al., 2008; Studer et al., 2006; Van Hemel and Cramer, 2002; Zhang et al., 2009; Zilahy, 2004 EnEff: Nagesha and Balachandra, 2006; Reddy and Shrestha, 1998; Venmans, 2014; Walsh and Thornley, 2012
	Uncertainty of future trend	Without guidance on the future trend e.g. the prices of energy, natural resources or fines lower of sustainability, measures may be avoided	EE: Mittal et al., 2013; Mittal and Sangwan, 2014; Studer et al., 2006 EnEff: Brunke et al., 2014; Hasanbeigi et al., 2010; Nagesha and Balachandra, 2006; <i>Sardianou, 2008</i> ; Schleich and Gruber, 2008
	Distortion of price	Prices do not reflect all the externalities (that can be related for example to environment or to social costs).	EE: Gunningham and Sinclair, 1997; Ministerie Van Vrom, 2004; Moors et al., 2005 EnEff: <i>Cagno et al., 2013</i> ; Walsh and Thornley, 2012; Worrell and Price, 2001
Internal	Organization	Lack of time	Firm has not enough time for the implementation of the measure
		Lack of staff	Firm has not enough staff for the implementation of the measure
		Resistance to change/Inertia	Organization can be against the change since it leads to a modification in ways of working and in habits
		Attitude/ Other priorities	The culture and the values of the firm inhibit the implementation of the measures. Moreover, the decision making might be focus almost uniquely on core the business activity, thus focused mainly on productivity related measures.
			OHS: Barbeau et al., 2004; Champoux and Brun, 2003; EASHW, 2010; Hasle and Limborg, 2006; Masi et al., 2014; Masi and Cagno, 2015; Whysall et al., 2006 EE: Biondi et al., 1998; Chan, 2008; Côté et al., 2006; Dieleman, 2007; <i>Dobes, 2013</i> ; Fernández-Viñé et al., 2010; Gombault and Versteeg, 1999; Hillary, 2004; Martín-Peña et al., 2014; Massoud et al., 2010; Matus et al., 2012; Mittal et al., 2013; Mittal and Sangwan, 2014; Studer et al., 2006; Van Hemel and Cramer, 2002; Vernon et al., 2003; Vieira and Amaral, 2015 EnEff: Apeaning and Thollander, 2013; Brunke et al., 2014; Fleiter et al., 2012b; Rohdin et al., 2007; Rohdin and Thollander, 2006; Schleich and Gruber, 2008; Thollander et al., 2007; Thollander and Ottosson, 2008
			OHS: Champoux and Brun, 2003; Cunningham and Sinclair, 2015; EASHW, 2010; Hasle and Limborg, 2006; Masi et al., 2014; Mellor et al., 2011; Whysall et al., 2006 EE: Bianchi and Noci, 1998; Biondi et al., 1998; Chan, 2008; Côté et al., 2006; Dieleman, 2007; Dobes, 2013; Gunningham and Sinclair, 1997; Hillary, 2004; Matus et al., 2012; <i>Ministerie Van Vrom, 2004</i> ; Mittal et al., 2013; Mittal and Sangwan, 2014; Studer et al., 2006; Vernon et al., 2003 EnEff: Kostka et al., 2013; Sardianou, 2008
			OHS: Matus et al., 2012; <i>Rubenowitz, 1997</i> EE: Dobes, 2013; Fernández-Viñé et al., 2010; Gunningham and Sinclair, 1997; Moors et al., 2005; Murillo-Luna et al., 2011; Shi et al., 2008; Silva Lopes et al., 2013; Studer et al., 2006; Vieira and Amaral, 2015 EnEff: Cagno et al., 2013; Nagesha and Balachandra, 2006; Sorrell et al., 2000; Thollander et al., 2007
			OHS: Barbeau et al., 2004; Champoux and Brun, 2003; EASHW, 2010; Hasle and Limborg, 2006; <i>Masi and Cagno, 2015</i> ; Quinlan and Mayhew, 2000; Whysall et al., 2006 EE: Doniec et al., 2002; Gombault and Versteeg, 1999; Massoud et al., 2010; Murillo-Luna et al., 2011; Shi et al., 2008; Studer et al., 2006; Vernon et al., 2003 EnEff: Apeaning and Thollander, 2013; Brunke et al., 2014; De Groot et al., 2001; Fleiter et al., 2012b; Hasanbeigi et al., 2010; Okazaki and Yamaguchi, 2011; Rohdin et al., 2007; Rohdin and Thollander, 2006; Schleich, 2009; Schleich and Gruber, 2008; Thollander

			et al., 2007; Thollander and Ottosson, 2008; Venmans, 2014; Weber, 1997
	Communication	Lack of communication or the inadequacy of communication between management and workers or between the workers themselves	OHS: Masi and Cagno, 2015; Mellor et al., 2011 EE: Gunningham and Sinclair, 1997; Silva Lopes et al., 2013; <i>Vieira and Amaral, 2015</i> EnEff: Walsh and Thornley, 2012
	Workplace and task	Not taking into account the workplace (analysis of the workplace, like hazard exposures) and the tasks (design, pace, repetition, pressure and psychosocial issues) during the implementation of a measure may have inhibitory consequences	OHS: Rubenowitz, 1997; <i>Smith and Carayon, 2009</i>
	Organizational system	The firm is a social system influenced by goals, routine, organizational structure and dominated by the decision making. There are several factors related to the company's structure that can hinder measures.	OHS: Champoux and Brun, 2003; Cherniack and Lahiri, 2010; Hale et al., 2010; Hasle and Limborg, 2006; Lamm, 1999; Masi and Cagno, 2015; Mellor et al., 2011; Rubenowitz, 1997; Smith and Carayon, 2009 EE: Hillary, 2004; Martín-Peña et al., 2014; Moors et al., 2005; Murillo-Luna et al., 2011; Vieira and Amaral, 2015 EnEff: Apeaning and Thollander, 2013; Brunke et al., 2014; De Groot et al., 2001; Fleiter et al., 2012b; Hasanbeigi et al., 2010; Liu et al., 2014; Rohdin et al., 2007; Schleich, 2009; Schleich and Gruber, 2008; Sorrell et al., 2000; Thollander et al., 2007; Thollander and Ottosson, 2008; Venmans, 2014; Walsh and Thornley, 2012; <i>Weber, 1997</i>
Management behavior	Commitment/Awareness	Manager has no awareness and/or commitment.	OHS: Hale et al., 2010; Masi et al., 2014; Masi and Cagno, 2015; Mellor et al., 2011; Rubenowitz, 1997; Walker and Tait, 2004; Whysall et al., 2006 EE: Dieleman, 2007; Martín-Peña et al., 2014; Mittal et al., 2013; Mittal and Sangwan, 2014; Shi et al., 2008; Silva Lopes et al., 2013; Studer et al., 2006 EnEff: Blass et al., 2014; Brunke et al., 2014; Cagno et al., 2013; <i>Liu et al., 2014</i> ; Sardianou, 2008; Schleich, 2009
	Expertise	Manager lacks of adequate management skills with respect to the issue or have limited expertise.	OHS: Hale et al., 2010; <i>Masi and Cagno, 2015</i> EE: Côté et al., 2006; Dieleman, 2007; Gombault and Versteeg, 1999; Gunningham and Sinclair, 1997; Shi et al., 2008; Silva Lopes et al., 2013 EnEff: Sardianou, 2008
Workers behaviour	Not trained/skilled	Lack of adequate skill or training of the personnel, with respect to a specific measure area, can hinder the implementation of measure.	OHS: Lamm, 1999; Masi and Cagno, 2015; Smith and Carayon, 2009; Theberge and Neumann, 2010; Walker and Tait, 2004 EE: Chan, 2008; Côté et al., 2006; Dieleman, 2007; Fernández-Viñé et al., 2013; Gombault and Versteeg, 1999; Gunningham and Sinclair, 1997; Hillary, 2004; Matus et al., 2012; Moors et al., 2005; Shi et al., 2008; <i>Silva Lopes et al., 2013</i> ; Vieira and Amaral, 2015 EnEff: Apeaning and Thollander, 2013; Brunke et al., 2014; Liu et al., 2014; Rohdin et al., 2007; Rohdin and Thollander, 2006; Sardianou, 2008; Thollander and Ottosson, 2008; Venmans, 2014; Worrell and Price, 2001
	Awareness	Staff lacks of awareness on the issue and ignores which are the criticalities of the firm with respect to the issue	OHS: Masi and Cagno, 2015; Rubenowitz, 1997; <i>Smith and Carayon, 2009</i> EE: Fernández-Viñé et al., 2013; Martín-Peña et al., 2014; Silva Lopes et al., 2013; Studer et al., 2006; Zhang et al., 2009; Zilahy, 2004 EnEff: Apeaning and Thollander, 2013; Brunke et al., 2014; Cagno et al., 2013; Liu et al., 2014; Rohdin et al., 2007; Rohdin and Thollander, 2006; Sardianou, 2008; Thollander et al., 2007; Thollander and Ottosson, 2008; Venmans, 2014
	Not involved	Employees not involved are given a fair opportunity to take	OHS: Hale et al., 2010; Masi and Cagno, 2015; Mellor et al., 2011; Rubenowitz, 1997; Walker and Tait, 2004

		an active part in the decision-making and realization process.	EE: Silva Lopes et al., 2013 EnEff: Sardianou, 2008
	Incorrect behaviour	The adoption of wrong behaviors by the personnel can hinder the implementation of sustainability measures in case in which an active participation of the personnel is required	OHS: Champoux and Brun, 2003; Masi et al., 2014; <i>Masi and Cagno, 2015</i> ; Whysall et al., 2006
Information	Lack of information	Lack of information or inadequacy of the information owned by the firm with reference to all the aspects related to measure implementation	OHS: Barbeau et al., 2004; Cherniack and Lahiri, 2010; Masi and Cagno, 2015; Walker and Tait, 2004 EE: Côté et al., 2006; Doniec et al., 2002; Fernández-Viñé et al., 2013; Gunningham and Sinclair, 1997; Ministerie Van Vrom, 2004; <i>Mittal et al., 2013</i> ; Mittal and Sangwan, 2014; Murillo-Luna et al., 2011; Shi et al., 2008 EnEff: Anderson and Newell, 2004; Apeaning and Thollander, 2013; Brunke et al., 2014; Cagno et al., 2013; Hasanbeigi et al., 2010; Kostka et al., 2013; Okazaki and Yamaguchi, 2011; Reddy and Shrestha, 1998; Rohdin et al., 2007; Rohdin and Thollander, 2006; Sardianou, 2008; Schleich, 2009; Schleich and Gruber, 2008; Sorrell et al., 2000; Thollander et al., 2007; Thollander and Ottosson, 2008; Venmans, 2014; Weber, 1997; Worrell and Price, 2001
	Trustworthiness of information	Problems with trustworthiness of the information sources, the sources are not adequate.	EnEff: Cagno et al., 2013; Rohdin and Thollander, 2006; Sardianou, 2008; <i>Sorrell et al., 2000</i> ; Venmans, 2014; Worrell and Price, 2001
Technology/ Service	Lock in	Solution is incompatible with the current status of the system.	EE: Ministerie Van Vrom, 2004; Mittal et al., 2013; Mittal and Sangwan, 2014 EnEff: Apeaning and Thollander, 2013; Okazaki and Yamaguchi, 2011; Rohdin et al., 2007; Rohdin and Thollander, 2006; Sardianou, 2008; Thollander et al., 2007; Thollander and Ottosson, 2008; <i>Venmans, 2014</i>
Economic	Limited access to capital	Firm does not have sufficient capital for the implementation	OHS: Barbeau et al., 2004; Cherniack and Lahiri, 2010; EASHW, 2010; Hasle and Limborg, 2006; Masi et al., 2014; Masi and Cagno, 2015 EE: Biondi et al., 1998; Côté et al., 2006; Doniec et al., 2002; Gombault and Versteeg, 1999; Gunningham and Sinclair, 1997; Matus et al., 2012; Moors et al., 2005; Shi et al., 2008; Siaminwe et al., 2005; Silva Lopes et al., 2013; Studer et al., 2006; Vernon et al., 2003; Vieira and Amaral, 2015; Zilahy, 2004 EnEff: Apeaning and Thollander, 2013; Brunke et al., 2014; <i>Cagno et al., 2013</i> ; De Groot et al., 2001; Fleiter et al., 2012b; Hasanbeigi et al., 2010; Kostka et al., 2013; Nagesha and Balachandra, 2006; Okazaki and Yamaguchi, 2011; Rohdin et al., 2007; Rohdin and Thollander, 2006; Sardianou, 2008; Schleich, 2009; Schleich and Gruber, 2008; Sorrell et al., 2000; Thollander et al., 2007; Thollander and Ottosson, 2008; Trianni and Cagno, 2012; Venmans, 2014; Walsh and Thornley, 2012; Worrell and Price, 2001
	Hidden costs	Investment entails extra costs or loss of benefits that are no properly estimate in investments analysis.	EnEff: Brunke et al., 2014; Cagno et al., 2013; Kostka et al., 2013; Rohdin et al., 2007; Rohdin and Thollander, 2006; <i>Sorrell et al., 2000</i>
	Risk	Risk related to the success of the measures e.g. interruption of production, losses in quality.	EE: Gunningham and Sinclair, 1997; Moors et al., 2005 EnEff: <i>Apeaning and Thollander, 2013</i> ; Brunke et al., 2014; Cagno et al., 2013; De Groot et al., 2001; Fleiter et al., 2012b; Hasanbeigi et al., 2010; Okazaki and Yamaguchi, 2011; Rohdin et al., 2007; Rohdin and Thollander, 2006; Schleich, 2009; Sorrell et al., 2000; Thollander et al., 2007; Thollander and Ottosson, 2008; Venmans, 2014; Walsh and Thornley, 2012; Worrell and Price, 2001
	Investment cost	High investments costs prevent firms from implementing sustainability measures.	OHS: Champoux and Brun, 2003; Cherniack and Lahiri, 2010; Hasle and Limborg, 2006 EE: Chan, 2008; Daddi et al., 2013; Doniec et al., 2002;

		Martín-Peña et al., 2014; Massoud et al., 2010; Matus et al., 2012; Ministerie Van Vrom, 2004; Mittal and Sangwan, 2014; Murillo-Luna et al., 2011; <u>Shi et al., 2008</u> ; Silva Lopes et al., 2013; Studer et al., 2006; Vernon et al., 2003; Vieira and Amaral, 2015; Zhang et al., 2009; Zilahy, 2004 EnEff : Cagno et al., 2013; Fleiter et al., 2012b; Nagesha and Balachandra, 2006; Reddy and Shrestha, 1998
Pay back time	Measure not sufficiently profitable such as low returns and long period of time required.	OHS : Champoux and Brun, 2003; Cherniack and Lahiri, 2010 EE : Chan, 2008; Côté et al., 2006; Daddi et al., 2013; Gunningham and Sinclair, 1997; Massoud et al., 2010; Matus et al., 2012; Mittal et al., 2013; Mittal and Sangwan, 2014; Shi et al., 2008; Siaminwe et al., 2005; Silva Lopes et al., 2013; Vieira and Amaral, 2015; Zilahy, 2004 EnEff : Fleiter et al., 2012b; Nagesha and Balachandra, 2006; Reddy and Shrestha, 1998; Sardianou, 2008; Schleich, 2009; Schleich and Gruber, 2008; Sorrell et al., 2000; Trianni and Cagno, 2012; Walsh and Thornley, 2012; Worrell and Price, 2001

Table 5: The new model for barriers to the adoption of Industrial Sustainability Measures. Categories are divided, according to their Origin, in Internal and External. For each barrier, definition and references are provided for each of the three areas on Industrial Sustainability. The main reference, on which the definition is based, is underlined.

This operation allowed us to point out several elements of novelty. First, we found that many barriers could also apply to areas other than those cited. For instance, *lack of incentives* is reported as a barrier to EE (Massoud et al., 2010) and EnEff (Walsh and Thornley, 2012), but not within OHS; however, lack of incentives for firms that would like to go beyond the legal requirements' targets can be perceived as a barrier. *Policy distortion* was identified as a barrier to EnEff (Walsh and Thornley, 2012) but not OHS and EE, but the existence of taxes and disincentive policies, discouraging the implementation of measures could be a barrier. *Market-related* barriers affecting EE (Fernández-Viñé et al., 2010) and EnEff (Venmans, 2014) were reported, but may also apply to OHS. Here, *lack of demand* may be seen as analogous to lack of a requirement for a certain level of safety, *uncertainty about future trends* could apply to fines and *price distortion* can result in an economic advantage deriving from not fulfilling the legal requirements. *Workplace and task-related* barriers to OHS (Smith and Carayon, 2009) may also be relevant to EE and EnEff, as EE and EnEff measures may affect the workplace or workers' tasks. *Incorrect behavior of workers*, identified as a barrier to OHS is also relevant to EE and EnEff because it may cause the failure of measures. *Trustworthiness of information*, identified as a barrier to EnEff (Worrell and Price, 2001) is also relevant to OHS and EE. *Technological lock-in*, identified for EE (Mittal and Sangwan, 2014) and EnEff (Okazaki and Yamaguchi, 2011), can represent a barrier also for OHS when the new technological solution is in contrast with the actual one. *Economic barriers* identified only for EnEff, i.e. *hidden costs* or for EE (Sorrell et al., 2000), i.e. *risk*, for EE (Moors et al., 2005) and EnEff (Fleiter et al., 2012b), can be relevant barrier also for the other areas, when the measures have costs not adequately identified or loss of benefits (e.g. production) not properly analyzed before the implementation.

After developing the theoretical framework, we adapted it for the empirical investigation. In fact, firms are only able to perceive internal barriers for what they really are; perception of external barriers is based on the effect that they have on the firm and on the internal barriers (Cagno et al., 2013). To deal with this, we tried to identify the perception of internal stakeholders about barriers arising externally from the firm (as reported Table 6).

Two example could help understand how we came up with the model for the empirical investigation.

- *Lack of incentive*: the presence of incentives would reduce the cost to the firm of implementing a measure and thus reduce the payback time; correspondingly, without incentives investing in sustainability would be more expensive and/or less profitable, with a likely influence on the

organizational attitude;

- *Uncertainty about future trends*: with uncertainty on e.g. energy prices trend, the cost of natural resources or level of fines has a negative impact on organizations' attitude, increasing the risk to implement measures, due to the increased difficulty of identifying hidden costs and evaluating payback time.

		External barriers									
		<i>Regulatory</i>				<i>Support</i>		<i>Market</i>			
		Legal requirements	Bureaucracy	Lack of incentives	Policy distortion	Lack of external technical support	Lack of consultancy	Customer not ready/ Lack of demand	Uncertainty of future trend	Distortion inn price	
Category	Internal Barriers										Reference (only linkage between external and internal)
<i>Organization</i>	Lack of time		*								* Masi and Cagno, 2015
	Lack of staff		*								*Masi and Cagno, 2015
	Resistance to change/ Inertia										
	Attitude /Other priorities	*	*	*	*	*	*	*	*	*	*Cagno et al., 2013; Fernández-Viñé et al., 2013; Hasle and Limborg, 2006; Masi and Cagno, 2015; Theberge and Neumann, 2010; Whysall et al., 2006
	Communication										
	Workplace and task										
	Organizational system							*			*Fernández-Viñé et al., 2013
<i>Management behavior</i>	Commitment/ Awareness										
	Expertise										
<i>Workers behavior</i>	Not trained/skilled										
	Awareness										
	Involvement										
	Incorrect behavior										
<i>Information</i>	Lack of information	*				*	*				*Cagno et al., 2013; Hasle and Limborg, 2006; Theberge and Neumann, 2010
	Trustworthiness of the info. sources					*	*				*Hasle and Limborg, 2006; Theberge and Neumann, 2010
<i>Technology/ Service</i>	Lock in					*					*Hasle and Limborg, 2006
<i>Economic</i>	Limited access to capital										
	Hidden cost								*		
	Risk										
	Investments cost			*							
	PBT			*					*		*Cagno et al., 2013; Shi et al., 2008

Table 6: Model for the empirical investigation. For each external barrier, it has been tried to understand how internal stakeholders perceive external barriers as internal ones. This linkage is identified by a black box; the white “*” indicates the existence of related literature references (only the boxes with the star have reference).

5 Validation of the model

We decided to perform the investigation using semi-structured case studies with interviews, questionnaires and secondary material. This study fulfils the criteria by Yin (2009), as well as Meredith (1998), Voss et al. (2002) and Zorzini et al. (2008) for case study research: i.e. a situation in which “why”, “how” and “what” questions are asked, the investigator has little or no control over events and contemporary events are investigated. Using a semi-structured format allows researchers to structure interviews and ensure that they follow a logical order. We based the interviews around a series of open-ended questions, which were supplemented by questions emerging from the dialogue between interviewer and interviewee, and we also collected free comments, in line with the procedure described by Diccio-Bloom and Crabtree (2006). We also used multiple sources of evidence (Voss et al., 2002; Yin, 2009) to ensure that findings were corroborated and to increase the validity of the analysis. In particular, our findings were corroborated by collecting and analyzing secondary data, i.e. company websites, reports and direct observations. Interviewees were asked to arrange a tour of their organization’s plant for the interviewer to facilitate the collection of secondary data.

According to Yin (2009), four requirements must be met to guarantee the methodological rigor. First, *external validity*, i.e. the extent to which results can be generalized; this was assessed by defining the domain to which study findings can be generalized. Second, *internal validity*, i.e. the extent to which casual relationships can be established; this was assessed through pattern matching during data collection. Third, *construct validity*, i.e. the establishment of operational measures; this was achieved by using multiple sources of evidence (Voss et al., 2002), i.e. semi-structured interviews, questionnaires, direct observations, company website and reports. Fourth, *reliability*, was addressed with the use of a protocol.

5.1 Data collection

The data collection has been organized in three parts. In the first part, we have identified our research sample. More specifically, through the use of a database (AIDA) containing relevant industrial information, we preliminarily identified possible firms for our investigation, selecting them on the basis of their sector, number of employees, turnover and geographical location. We contacted firms by e-mail or phone call. For all those firms that accepted to participate to the research, we looked for secondary company data (company websites, reports, newspapers) regarding companies organization, production processes, as well as material describing (where available) projects, initiatives and similar, towards increased IS.

The second part corresponded to the investigation within the sampled firms where, beyond a tour of the plant, we had a semi-structured face to face interview, supported by a questionnaire as a guide, so to standardize the sequence in which the questions were asked and minimize the impact of contextual effects (Patton, 1990). Finally, we made some concluding questions on the evaluation of the model after having used it. Each interview was audio-recorded and transcribed for analysis. In detail, to start, interviewees were asked to introduce the firm to the interviewer, in terms of sector, production process, number of employees, turnover and attitude toward sustainability. In this way we double-checked public data found in the web, but also explored possible misalignments, in particular regarding interviewees’ attitude toward sustainability. Then, through the plant tour we could directly observe and evaluate how the plant worked, and identify possible issues related to IS areas. After the tour, the interview took place. We presented the model of barriers to interviewees, describing every single barrier. Then, we provided interviewees with the list of ISMs, asking them to identify, among the measures, those considered for adoption within their firm. The procedure for the development of the list of measures is provided in 5.2. We enquired interviewees to identify, using the model proposed, the main barriers to the adoption of each selected ISMs. Further, interviewees could discuss possible additional measures missed from the list. The identification of a barrier was followed by a depth analysis. Indeed, for each measure we asked interviewees to recount us the whole steps followed, contextualizing the situation in which the adoption of measure was taken in consideration.

Then, for each barrier identified, interviewees were asked to explain in detail the impact of that barrier in the specific situation. Main insights and issues emerged from the evaluation of barriers were further investigated. Following, after the evaluation of the barriers, interviewees were asked to rate the relevance of barriers using a four-point Likert scale, where 1 is “not relevant”, 2 is “low-medium relevance”, 3 is “medium-high relevance” and 4 is “high-very high relevance”. Using a Likert scale to collect data on the relevance of barriers enabled us to synthesize the data from all interviewees and provide a quantitative measure, thus supplementing the comments and evaluations. Moreover, a pairwise Likert scale forces the respondent to take a position as there is no neutral position (Cagno and Trianni, 2014). At the end, we asked interviewees to evaluate the novel model of barriers. The evaluation was performed at the end of the interview according to the three performances previously identified, since we considered necessary to make interviewees use the model before asking them to evaluate it.

The third part of the data collection corresponded to the transcription and coding of the interviews and to the identification of possible misalignments emerged. In three out of eight companies investigated, we called back the interviewees, asking for a second face-to-face or phone meeting, for further clarification.

5.2 Selection of industrial sustainability measures

The provided list was intended to include the most frequently implemented and most important measures in each area of IS as well as to provide a short list of measures with different impacts on the different areas of IS. The list represents a common basis for evaluating barriers in the different firms. Taking inspiration from Klewitz and Hansen (2014), but limiting their proposed compensation trade-off effect, we defined an ISM as a *technical or organizational measure tailored to a firm's characteristics that is intended to improve a firm's overall sustainability performances or practices related to a specific sustainability pillar, whilst having no impact or a positive impact on the others*. To produce the list of ISMs, we analyzed 43 contributions (scientific articles; reports; books; company reports; organizational reports and publications; government publications). This resulted in the identification of 52 measures based on data availability and applicability in an industrial context. We classified measures according to their impact on the different IS areas (OHS; EE; EnEff; OHS + EE; OHS + EnEff; EE +EnEff; OEE (i.e. the measure has impact on OHS + EE+ EnEff)). Complete details regarding the classification of the selected measures, descriptions and references, are reported in Annex (Table A1).

6 Results

The results of our validation study are divided in two parts. In Section 6.1, we report three out of the eight cases in detail; in Section 6.2 we summarized the results of the full set of sampled firms.

6.1 Results by single companies.

6.1.1 Company 1

Company 1 is a large firm manufacturing steam engines and power generation boilers focused on the production of turbines (steam and hydraulic), aggregate plant supply (steam and hydraulic), service activities and third party operations. The critical financial position of the company negatively affects the implementation of IS measures: priority is exclusively given to measures able to guarantee the minimum safety requirements, thus overlooking any other thorough change of existing production assets, even with potential relevant benefits in economic and environmental performance. As shown by interviewees, e.g. a re-roofing the whole plant for improved energy efficiency is extremely needed. Nevertheless, this measure is not considered for adoption, because of minimum lighting requirements already satisfied by the existing roof. The firm holds ISO 9001 and ISO 3834-2 certification and it is on its way to re-certificating ISO 14001 and certifying its safety management system.

We have interviewed two members of the health safety and environment (HSE) leadership team and

a member of the maintenance leadership team, as a representative of the plant management. All the interviewees have judged the model very positively with respect to all three criteria.

One of the two HSE interviewees stated: “*This model contains all the things that we need [...] it takes into consideration all the factors that need to be evaluated in a business risk situation, it also covers the legislation: organizational, technical and procedural measures*”, then adding: “*We are aware of our problems and limitations, but having such a model would be very helpful to us in improving our management system.*”

The second HSE interviewee stated that the model “*considers all the aspects in which we are interested.*” Both the second HSE interviewee and the maintenance interviewee affirmed that having such a ready-made checklist would have been very useful for their firm.

All the interviewees recognized that the main barriers for their firm are related to *management* and *lack of capital*. *Economic* barriers and barriers relating to *managerial commitment/awareness* mainly affect the implementation of EE and EnEff measures, whilst *organization* barriers mainly affect OHS measures. Further, *lock-in* is recognized as critical in almost all the areas of IS. The results are reported in Table 7.

<< *Insert Table 7 around here* >>

6.1.2 Company 2

Company 2 is a large firm manufacturing basic pharmaceutical products and pharmaceutical preparations, with focus on active pharmaceutical ingredients, custom synthesis and fine chemicals. It has several plants in Italy and each plant is autonomous, despite general guidelines on sustainability offered by the firm, and implements several quality management systems and environmental sustainability programs, with a focus on environmental safety, health and green chemical processes. In this study we considered one of firm’s plant, which can be considered as a medium enterprise.

The interviewee, chief of engineering, with responsibility over HSE issues at plant level, deemed to be able to understand and use the model properly. He has judged it very positively, adding that it is complete, well-structured and offers a comprehensive picture of the issue. In particular, he describes the model as “*well structured*”, also noting that “*it could be very useful during the implementation of measures, because it gives one have a comprehensive picture of potentially related problems.*” He also considers the model “*very useful for evaluating an investment or a suggested measure, as it would give you advance warning of the problems you would be likely to face.*”

The interviewee identified *investment cost* and *payback time* as the main barriers to OHS measures, *investment cost* as the main barrier to EE and EnEff measures, and *lack of time* and *lack of staff* as the main barriers for the firm in general. When asked to evaluate barriers to implementation of specific measures, *economic* and *organization* barriers were mentioned in relation to OHS measures, whilst *economic* barriers were cited in relation to EnEff measures. The main barriers related to implementation of specific EE measures were *economic* and *organization*. The results are reported in Table 8.

<< *Insert Table 8 around here* >>

6.1.3 Company 3

Company 3 is a small energy-intensive manufacturer of agricultural machineries, founded in 1983 and with steady and rapid growth. The firm is a member of a Quality Assurance Service, with also ISO 9001 certification. We interviewed two members of the leadership team, respectively the energy and environment manager and the OHS manager.

Both interviewees judged the ability to represent and ease of use of the model very positively, but, interestingly, they had different opinions on its usefulness in the specific context. The first interviewee considered that only some of the IS barriers’ categories (i.e. *information*, *technology* and *economic barriers*) would effectively describe the barrier, asserting that the firm does not face any relevant internal barriers related to *organization*, *management behavior* and *workers behavior*.

Nevertheless, he pointed out that “*my observations are related to our business context, that of a small-medium enterprise that operates globally [...] You will find that other firms give different answers because of their different characteristics*”. The OHS interviewee, on the other hand, said the model could be useful for understanding the different types of ISMs and that it had helped him to identify a previously unrecognized barrier. According to him, the model “*describes the set of problems well*”, and noted that “*yes, I would have not considered the training...we should give serious thought to worker training.*”

Barriers identified at a general level are *lack of awareness, low worker involvement, lock-in* and *economic* barriers. The main barriers to implementation of specific OHS measures are *lock-in* and *wrong behavior of workers*, whilst the main barriers to implementation of specific EE and EnEff measures are *economic*. The results are reported in Table 9.

<< *Insert Table 9 around here* >>

Despite it does not specifically fall under the scope of the present research, it is really important to note that the application of a model in a context where multiple decision-makers on IS are involved, showed the capability of our innovative model to gather different perspectives regarding IS within the same company, thus pinpointing possible mismatches, conflicts etc. regarding decision-making over the adoption of ISMs.

		OHS - Guards	OHS - Safety sheets	EnEff - Detection /elimination of leaks	EnEff - More efficient lamps/ light sources (not done)	EnEff - Solar panels installation (not done)	OHS + EnEff - Preventive Maintenance	EnEff + EE - More efficient type of motor	EnEff + EE - Inverter
	Lack of time	●	●●●	●	●	●	●	●	●
	Lack of staff	●	●●●	●	●	●	●●●●	●	●
	Resistance to change/ Inertia	●	●	●	●	●	●	●	●
Organization	Attitude /Other priorities	●	●	●	●	●	●	●	●
	Communication	●	●	●	●	●	●	●	●
	Workplace and task	●	●	●	●	●	●	●	●
	Organizational system	●	●	●	●	●	●	●	●
Management behavior	Commitment/ Awareness	●	●	●	●●●●	●●●●	●	●	●●
	Expertise	●	●	●	●	●	●	●	●
	Not trained/skilled	●	●	●	●	●	●	●	●
Workers behavior	Awareness	●	●	●	●	●	●	●	●
	Involvement	●	●	●	●	●	●	●	●
	Incorrect behavior	●	●	●	●	●	●	●	●
Information	Lack of information	●	●	●	●	●	●	●	●
	Trustworthiness of info. source	●	●	●	●	●	●	●	●
Technology/ Service	Lock in	●●●●	●	●●●●	●	●	●	●●●●	●
	Limited access to capital	●	●	●	●	●	●	●	●
	Hidden cost	●	●	●	●	●	●	●	●
Economic	Risk	●	●	●	●	●	●	●●●	●
	Investments cost	●	●	●●●●	●●●●	●●●●	●	●●●●	●●●
	PBT	●	●	●	●●●●	●●●●	●	●●●●	●

Table 7: Company 1's results. Detail of the barriers identified. Measures have been categorized according to their impact on IS's areas. The number of the points corresponds to the identified value of the Likert-like scale (one point, light green: value 1, "not relevant"; two point, dark green: value 2, "low-medium relevance"; three points, orange: value 3, "medium-high relevance"; four points, red: value 4, "high-very high relevance").

		OHS - PPE	OHS - Emergency Buttons	OHS - Replacement of machine	OHS - Training on safety procedures	OHS- Hazards/ accidents record	EE - Environmental performance	EE - Modify the process to reduce the use of water	EnEff - More efficient lamps/ light sources	EnEff+EE - More efficient type of motors + Right size of motoris	EnEff + EE - Inverter	EnEff+EE - Modify the process to reduce material use/cost	OHS + EnEff - Preventive Maintenance	OHS + EE - Hazardous substances register	OHS + EE - Replace toxic/ dangerous material	OHS - Pollution/ contaminant reduction
	Lack of time	●	●	●	●●	●●	●●	●	●	●	●	●●	●	●●	●	●
	Lack of staff	●	●	●	●●	●●	●●	●	●	●	●	●●	●●	●●	●	●
	Resistance to change/ Inertia	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Organization	Attitude /Other priorities	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Communication	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Workplace and task	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Organizational system	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Management behavior	Commitment/ Awareness	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Expertise	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Not trained/skilled	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Workers behavior	Awareness	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Involvement	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Incorrect behavior	●●	●	●	●●	●	●	●●	●	●	●	●	●	●	●	●
Information	Lack of information	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Trustworthiness of info. source	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Technology/ Service	Lock in	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Limited access to capital	●	●●	●●●	●	●	●	●●	●●	●●	●	●	●●●	●	●	●●●●
Economic	Hidden cost	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Risk	●	●	●●●	●	●	●	●	●	●●	●	●	●	●	●●	●
	Investments cost	●	●●	●●●	●	●	●	●●	●●	●●	●	●	●●	●	●	●●●●
	PBT	●	●●●●	●	●	●	●	●	●●	●●	●●	●	●	●	●	●●●●

Table 8: Company 2's results. Detail of the barriers identified. Measures have been categorized according to their impact on IS's areas. The number of the points corresponds to the identified value of the Likert-like scale (one point, light green: value 1, "not relevant"; two point, dark green: value 2, "low-medium relevance"; three points, orange: value 3, "medium-high relevance"; four points, red: value 4, "high-very high relevance").

		OHS - Lifting System	OHS - Guards	OHS - Safety sheets	OHS - PPE	EE - Modify the process for use different raw material	EnEff - Solar panel installation	EnEff - More efficient lamps/ light source	EnEff - Detection/ elimination of leaksZ	OEE - Performance (environment)	OHS + EnEff - Preventive Maintenance	OHS + EE - Replace toxic/ dangerous material
	Lack of time	●	●	●	●	●	●	●	●	●	●●	●
	Lack of staff	●	●	●	●	●	●	●	●	●	●●	●
	Resistance to change/ Inertia	●	●	●	●	●	●	●	●	●	●	●
Organization	Attitude /Other priorities	●	●	●●●●	●	●	●	●	●	●	●	●
	Communication	●	●	●	●	●	●	●	●	●	●	●
	Workplace and task	●	●	●	●	●	●	●	●	●	●	●
	Organizational system	●	●	●	●	●	●	●	●	●	●	●
Management behavior	Commitment/ Awareness	●	●	●	●	●●	●	●	●	●	●	●
	Expertise	●	●	●	●	●	●	●	●	●	●	●
	Not trained/skilled	●	●	●	●	●	●	●	●	●	●●	●
Workers behavior	Awareness	●	●●	●	●	●	●●	●	●	●	●	●
	Involvement	●	●	●	●	●	●	●	●	●	●	●
	Incorrect behavior	●●	●●	●	●●	●	●	●	●	●	●	●
Information	Lack of information	●	●	●	●	●	●	●	●	●	●	●
	Trustworthiness of info. source	●	●	●	●	●	●	●	●	●	●	●
Technology/ Service	Lock in	●●	●●●	●	●	●	●	●	●	●	●	●●
	Limited access to capital	●	●	●	●	●	●	●	●	●	●	●
Economic	Hidden cost	●●	●	●	●	●●	●	●	●●	●	●●●	●
	Risk	●	●●	●	●	●●	●	●	●	●	●	●
	Investments cost	●	●	●●	●	●●	●●	●●	●	●●	●	●
	PBT	●	●	●	●	●	●	●	●	●	●	●

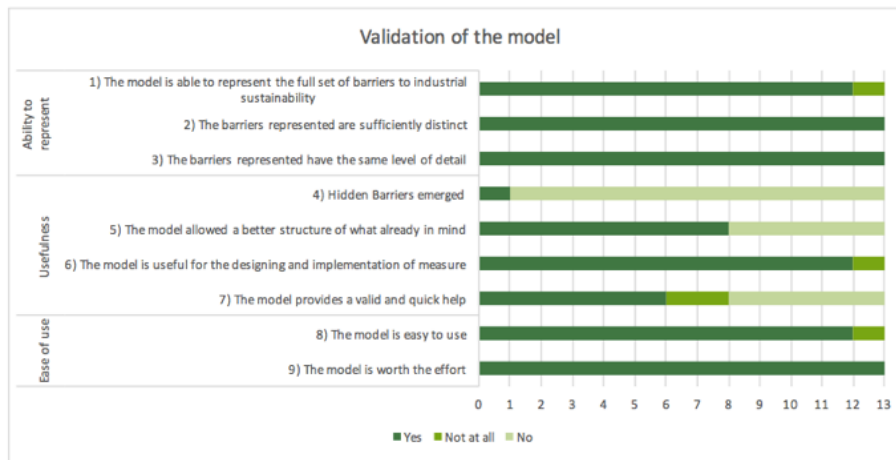
Table 9: Company 3's results. Detail of the barriers identified. Measures have been categorized according to their impact on IS's areas. The number of the points corresponds to the identified value of the Likert-like scale (one point, light green: value 1, "not relevant"; two point, dark green: value 2, "low-medium relevance"; three points, orange: value 3, "medium-high relevance"; four points, red: value 4, "high-very high relevance").

6.2 Whole sample

We here base our evaluation of the model on the judgments of all the thirteen interviewees, rather than on firms' overall judgments, as in some cases interviewees from the same firm had slightly differing opinions. This is a very interesting result, as it illustrates the existence of different perspectives on barriers to implementation of ISMs, even within a firm, and is in line with a strand of literature that emphasizes the importance of considering the varying perspectives of all decision-makers when implementing a measure (Cagno and Trianni, 2014; Reddy, 2013; Thollander and Palm, 2012).

The results of this preliminary validation study were positive with respect to all three performances (as shown in Figure 2, while the main findings from each case study can be found in Table 10). Regarding *ability to represent*, the model was judged complete and all the thirteen interviewees considered the barriers specified in the model to be sufficiently distinct and detailed. For what concerns *usefulness*, the model makes hidden barriers emerge, and widely helps interviewees better structure what they may have already in mind; moreover, almost all the interviewees judged the model as very useful for the designing and implementation of measures, but also to provide a valid and quick help for the identification of barriers. Indeed, in some firms investigated, interviewees affirmed they tried to developed approaches in order to identified problems related to the adoption of ISMs, but these approaches were not comprehensive or structured as the one proposed. Concerning *ease of use*, the model resulted very easy to use for the vast majority of interviewees; but, it is worth noting that also who deemed the model as a bit complex, offered here a quite positive judgment, highlighting that it was worth to use it because of the high quality of the information provided.

Figure 2: Results of the validation of the new model



	Person interviewed	Main Comments Emerged
Company 1	Health Safety and Environment Manager 1	<i>"The model contains all the things that we need [...] it takes in considerations all the relevant aspects that need to be evaluated in a risk business situation, also according to legislation: organizational, technical and procedural measures" "We are aware of our problems and limitations, but having such a model would be very helpful in order to improve our management system".</i>
	Health Safety and Environment Manager 2	<i>"It considers all the aspects in which we are interested in"</i>
	Maintenance Manager	Positive judgment of the model
Company 2	Health Safety and Environment Manager	<i>"Well structured" "Very useful during the implementation of measures, because it allows to have a complete view on those that could be the related problems"</i>
Company 3	OHS Manager	Positive judgment of all the model. Identification of a new barrier: <i>"I would have not considered the training...we should give serious thought to workers training"</i> Considered the whole model as an outline for the design and implementation of measures

	Energy and Environmental Manager	Considered as significant only the last part of the model. I would use only the last part of the model, that I think are the keys points.
Company 4	OHS Manager	"It would have been difficult for me to create such a model"
Company 5	OHS Manager	"Personally, thanks to my experience I had already identified the barriers"
	Technical Director	"Absolutely useful for the implementation of Industrial Sustainability measures" "I would have not been able to identify all the barriers on my own"
Company 6	Health Safety and Environment Manager	The model resulted interesting also in a company that already have an internal system for the evaluation of measures.
Company 7	Health Safety and Environment Manager	The model resulted interesting also in a company that already have an internal system for the evaluation of measures. It helped the manager to focus better on Information related barriers
Company 8	CEO	"It could be useful as a structure on which moving" Company 8 was the only one to find difficulties in using the model, stating however difficulties were totally overcome by the fact of having an already done model like the one proposed.

Table 10: Main comments emerged from investigation

7 Discussion and conclusion

Sustainability is becoming more and more relevant. Focusing on IS areas, i.e. OHS, EE, EnEff, firms can improve their IS performance adopting measures whose implementation is hindered by barriers. Extant literature does not offer so far a comprehensive model of all the barriers to IS that covered all areas.

In this study we have presented a novel model, aimed at contributing in addressing the aforementioned gaps. The model is based on barriers identified in the literature review and specifies nine categories of barriers, both external (*regulatory, support and market barriers*) and internal (*organization, management behavior, worker behavior, information, technology/service and economic barriers*).

We have successfully conducted the preliminary validation of the new model thanks to semi-structured case studies into northern Italy manufacturing firms. People responsible for different areas of IS (i.e., energy, environment and safety) evaluated the model as able to represent the full set of barriers to IS with sufficient distinction among them and with same level of detail. Moreover, when applying our model, they appreciated the capability to point out hidden barriers, but also to offer a structured view on already identified barriers to the adoption of ISMs, with valuable information offered in a simple way.

Despite the exploratory nature of this preliminary investigation among companies (that for sure needs to be complemented with further empirical research), we have shown the existence of similarities and differences in the barriers to implementation of measures in the different IS areas. Several of the main barriers to implementation of ISMs that were identified by firms are relevant to IS generally. In particular, *organization* and the *economic* barriers affect specific areas of IS as well as IS more generally. In the following specific examples are reported:

- *Lack of time* and *lack of staff* were considered the most important organization barriers confirming e.g. (Maximiano, 2005) for IS, (EASHW, 2010) for OHS, (Chan, 2008) for EE, (Sorrell et al., 2000) for EnEff;
- *Investment cost* and *payback time* were considered the most important *economic* barriers, confirming e.g. (Collins et al., 2010) for IS, (Quinlan and Mayhew, 2000) for OHS, (Zilahy, 2004) for EE, (Anderson and Newell, 2004) for EnEff;
- *Lock-in* barrier had independent effects on all three areas;
- *Incorrect behaviour of workers* was considered to have a large impact on implementation of OHS measures, confirming (Whysall et al., 2006)
- *Economic* barriers' relevance is in line with the extant literature on trade-offs among the different factors related to IS, in particular trade-offs between social/environmental factors and economic performance (Beckmann et al., 2014; Haffar and Searcy, 2017).

Another important finding relates to barriers to implementation of specific measures. First, the main

barriers to implementation of measures related to specific IS areas by our interviewees were not mentioned in the literature on that IS area. This was the case for *lock-in* as a barrier to OHS measures and *incorrect behavior of workers* as a barrier to EnEff. Secondly, main barrier to a measure related to a specific IS area was not identified as a main barrier by the empirical literature of that area, i.e., *payback time* in the case of OHS, *lock-in* in the case of EE and *communication* in the cases of OHS and EnEff. This demonstrates that barriers to the implementation of ISMs are worth being analyzed using an integrative model that encompasses all IS areas; moreover, it shows that there may be specific barriers to implementation of specific measures that are different from the barriers identified at a general level. This last finding corroborates the results of a study of barriers to specific EnEff measures (Cagno and Trianni, 2014). We also demonstrated the existence of different perspectives among people in different positions of responsibility. In particular, different perspectives were observed both regarding barriers to specific ISMs and the validation of the model. This extends (Cagno and Trianni, 2014) findings and confirmed also (Reddy, 2013; Thollander and Palm, 2012). Our model of the barriers to implementation of ISMs is certain to be of great interest to industrial decision-makers, as it will help them organize their resources and develop an implementation strategy. Indeed, from the validation of the model, it emerged that interviewees express an overall positive judgement on the utility of the model as in valid help for the identifications of all the barriers related to an ISM adoption. Company managers, after a proper identification and evaluation of the different perspectives on sustainability, could develop most effective ways to tackle barriers and improve sustainability within their firm. The model should also be of interest to policy-makers as it may help them to develop a regulatory framework, design incentives to encourage industry to adopt measures and identify the most effective methods of enhancing IS within firms.

One limitation of the study is that, considering the sample investigated, it was not possible to interview the desired professional figures in all the firms, i.e. one for each area of IS, and so different perspectives have not been evaluated in every firm. Moreover, it should be pinpointed that the study has been developed focusing on specific areas of IS (OHS, EE, EcoEff), thus limiting the scope and not addressing implications related to the remaining areas of sustainability in general terms.

From a theoretical perspective, our study, currently focused on barriers to the adoption of ISMs, opens several streams of future research. Here, we see large room for addressing drivers to the adoption of ISMs, so to overcome existing barriers. Furthermore, research could focus on a joint modelling and analysis of the barriers and drivers related to the implementation of ISM, as well as considering how the perspectives of people with different areas of responsibility from the same firm may differ on the adoption of the same ISM. Indeed, because of their different backgrounds, aims and commitments, different people may have differing perceptions of the barriers to the implementation of specific measures. Additionally, to give a broad vision on the issues related to the implementation of ISMs, it would be of great interest to evaluate the mechanism between barriers and drivers, so to more precisely pinpoint policy-making actions to foster ISMs.

From an empirical perspective, valuable findings could come from model's application to a set of various clusters of enterprises, e.g. differing with respect to sector, size, labor and capital intensity, energy intensity, etc. This would lead to a specific identification and evaluation of similarities and differences in the barriers according to different types of enterprise experience in relation to the adoption of ISMs. Interestingly, differences in perspectives over IS could also be analyzed by proper clustering of companies according to related to firms' characteristics (e.g. size, sector, geographical region, general behavior towards sustainability). Such an analysis would provide a basis for describing the set of relationships underlying the implementation of an ISM, i.e. evaluating whether implementation of a specific ISM related to an IS area can be facilitated or hindered by factors related to another area of IS, as well as from e.g., struggling forces between different industrial decision-makers within the same firm. Finally, it would be great not only to model, but also to empirically evaluate barriers and drivers to the adoption of ISMs according to the adoption key performance indicators for sustainability, so to see how companies with different sustainability performance behave with respect to barriers and drivers to the adoption of IS measures.

Annex

Table A1: Selected measures with description, references and impact.

Type	Name	Description	References	Impact
Motors	Energy-efficient Belts	Substitution of belts with more energy efficiency ones	Carbon Trust, 2011c; De Almeida and Greenberg, 1995; IAC, 2007; Trianni et al., 2014; U.S Department of Energy, 2005	ENEFF+ EE
	Right size	Substitution of an oversized motor (typically used under 50% of load) with a more appropriate sized one.	Carbon Trust, 2011a; IAC, 2007; Saidur et al., 2012; Trianni et al., 2014	ENEFF+ EE
	More efficient type of motors	Substitution of the motor with a more efficient one. A HEM (High Efficiency Motor) is defined whose efficiency class is at least one or more grades higher than the market average	Cagno and Trianni, 2012; Carbon Trust, 2011a; Carbon Trust, 2011c; De Almeida et al., 2003; IAC, 2007; Trianni et al., 2014	ENEFF+ EE
	Inverter (VSD/AFD)	Device that modulates the power frequency of fan electric motor and then his speed as a function of load	Abdelaziz et al., 2011; De Almeida et al., 2003; De Almeida et al., 2005; Ferreira et al., 2011; IAC, 2007; Trianni et al., 2014	ENEFF+ EE
Lighting	Use daylight	Use daylight as much as possible.	IAC, 2007; Li et al., 2010; Trianni et al., 2014	ENEFF+ OHS
	Reduce illumination (to minimum safe level)	Reduce the over-illumination of an area to minimum safe level so that activities can be carried out safely.	IAC, 2007; Trianni et al., 2014	ENEFF
	More efficient lamps/light source	Use more efficient type of lamp or light source	Cagno and Trianni, 2012; Gaglia et al., 2007; IAC, 2007; Mahlia et al., 2011; Trianni et al., 2014	ENEFF
	Personal dimming controls	Provide workstations with personal dimming controls so that employees are able to adjust the level of illumination according to their need.	Boyce et al., 2006; IAC, 2007; Jones and Richman, 2005; Trianni et al., 2014	ENEFF+ OHS
	Presence sensors	Install presence sensor in order to make the light turn on only when necessary (person in the room)	Cagno and Trianni, 2012; IAC, 2007; Trianni et al., 2014	ENEFF
Compressed Air	Right size of compressor	Reduce the size of the air compressors (part load is very inefficient)	CAC, 2003; IAC, 2007; Trianni et al., 2014	ENEFF
	Pressure of compressed air to minimum required	Because of pressures higher than those recommended the degree of usury increases.	CAC, 1998b; CAC, 2003; Cagno and Trianni, 2012; IAC, 2007; Trianni et al., 2014	ENEFF
	Detection/elimination of leaks	Identification of leaks in the air compressed system and subsequent elimination.	Abdelaziz et al., 2011; CAC, 1998a, 2003; Cagno and Trianni, 2012; IAC, 2007; Trianni et al., 2014	ENEFF
	Intakes in coolest location	Site the air compressed system in a coolest location.	Cagno and Trianni, 2012; IAC, 2007; Trianni et al., 2014	ENEFF
HVAC	More efficient HVAC unit	Improve the energy efficiency of the system; the improvement is possible also changing one of the components	Carbon Trust, 2011b; Gaglia et al., 2007; IAC, 2007; Trianni et al., 2014	ENEFF
	Right size of HVAC unit	Substitution of an oversized HVAC system	IAC, 2007; Trianni et al., 2014; U.S Department of Energy, 2002	ENEFF
	Lower ceiling o reduce conditioning space	Lower ceilings or reduce space that need air conditioning in order to use less energy	IAC, 2007; Trianni et al., 2014	ENEFF
	Air conditioning only when/where necessary	Use air condition in places or times in which it is necessary	IAC, 2007; Trianni et al., 2014	ENEFF
	Reduce air ventilation to minimum	Make air ventilation less necessary finding alternative method	Carbon Trust, 2011b; IAC, 2007; Trianni et al., 2014	ENEFF
	Personalized ventilation	Every employee, through personal devices, can control and optimize temperature, speed and direction of his "personal air"	IAC, 2007; Melikov, 2004; Trianni et al., 2014	ENEFF+ OHS
Training	Energy awareness	Make the employee and the management aware or more aware about energy issue	-	ENEFF+ EE
	Energy saving related to equipment	Adequate training to make those who use the machinery aware of the energy expenditures of the equipment and the ways to reduce them.	-	ENEFF
	Training on machinery	Adequate training should ensure that those who use the machinery are competent to use it safely. This includes ensuring they have the correct skills, knowledge, and experience and risk awareness. Sometimes formal qualifications are needed, e.g. for chainsaw operators.	Cagno et al., 2014; Gardner et al., 1999; HSE, 2012b; HSE, 2013a; HSE, 2013c	OEE
	Training on safety procedures	Safety procedures training. It can be referred both to basic training and to particular procedures within the firm.	Cagno et al., 2014; Gardner et al., 1999; Hale et al., 2010; HSE, 2013a; Novartis, 2014	OHS
	Training on environmental impacts	Training about the environmental impact of industrial activities in general and/or about the (potential) environmental impact of the firm's activities.	Barbeau et al., 2004	ENEFF+ EE
Training on consequences of non-compliance with environmental procedures	Adequate training about the consequences of an improper behavior of an employee	-	OEE	
Staff	Job rotation	Job rotation involves an employee changing positions within the same organization and eventually returning to the original position. It can refer to different types of rotations: task rotation, position rotation	NYCOSH, 2014	OHS
	Redefinition of organizational procedures	Redefinition of organizational procedure to better ensure safety	Barbeau et al., 2004; Micheli and Cagno, 2008	OHS
	Medical check-up for workers	Medical check-up are established according to the level of risk to which each employee is exposed	-	OHS
Equipment	Preventive Maintenance	Maintenance measure is performed before failure occurrence	ACCI, 2004; Barbeau et al., 2004; Furlanetto et al., 2006; HSE, 2012b; HSE, 2013c	OHS+ENEFF
	Guards	Use fixed guards to enclose, whenever practicable, machinery's moving parts. Use best material for these guards. If fixed guards are not practicable, use other methods, eg interlock the guard.	HSE, 2012b; HSE, 2013c; Samant et al., 2006;	OHS
	Safety sheet (description of the machinery)	The sheet contains a description of the machinery and how it works and draws attention to aspects on how to use it safely.	UEA, 2007	OHS
	Criteria for design or purchasing	Set safety requirement related to the purchase/design of a new machinery	Hale et al., 2010	OEE
	Emergency buttons	Equip the machinery with safety buttons or change their position so that they are more easily reachable.	HSE, 2013c; Samant et al., 2006	OHS

	Replacement of the machinery	Substitution of a not safe machinery	-	OEE
PPE	PPE	Provide the adequate PPE to workers with reference to the tasks they have to perform.	Barbeau et al., 2004; Cagno et al., 2014; Hale et al., 2010; HSE, 2013b; Novartis, 2014	OHS
Noise	Barriers against noise	Using screens, barriers, enclosures and absorbent materials to reduce the noise on its path to the people exposed	EASHW, 2003; HSE, 2012a; NYCOSH, 2014	OHS
	Lay out changes	(Re)designing and laying out the workplace to create quiet workstations)	EASHW, 2003; HSE 2012a.; NYCOSH, 2014	OEE
	Change machinery	Substitution of machinery with another less noisy (low noise purchasing policy)	EASHW, 2003; HSE, 2012a; NYCOSH, 2014	OEE
Set policies	Written policy	The policy identifies hazards and assessing risks, deciding what precautions are needed. Health and safety policy should influence all activities, including the selection of people, equipment and materials, the way work is done	ACCI, 2004; Gardner et al., 1999; HSE, 2013a	OHS
Set standards	Level of emission	Specifying levels of emissions that are accepted	HSE, 2013a	OHS+ EE
	Level of waste	Specifying level of waste that is acceptable	HSE, 2013a	OHS + EE
Performance	Measures of performance	It is necessary to evaluate performances in order to understand where the firm is compared to where it would like to be. Evaluate the performance in a particular way at set time. The performance can be evaluated against the setting standards	HSE, 2013a	OEE
Safety record	Checklist	Make use of checklist as an operational tool to simplify and make it faster for the organization to verify the level of compliance with legal regulations but also with its possible internal policies of its system of prevention and protection	ACCI, 2004; HSE, 2013a; Novartis, 2014	OHS
	Hazards/accidents record	Keep a record of accidents that have occurred in the firm and of the hazardous present	ACCI, 2004; Barbeau et al., 2004; Gardner et al., 1999; HSE, 2013a; Novartis, 2014	OHS
	Hazardous substances register	Keep a record of all the toxic or dangerous substances used by the firm for its processes with their relative potential effect on environment and human being	ACCI, 2004; Barbeau et al., 2004; Gardner et al., 1999; HSE, 2013a; Novartis, 2014	OHS+ EE
Material	Replace toxic/dangerous material	Substitution of toxic and/or dangerous material both for environment and human being with a less or not toxic/dangerous one.	NYCOSH, 2014	OHS + EE
Air quality improvement	Customized air ventilation system	Considering different aspects of the workplace when designing a ventilation system in order to choose the best one	Calabrese, 2011	OHS + EE
	Air ventilation system near workstation	Localized distribution: ventilation system's input near workplace	Calabrese, 2011	OEE
Reduction of use	Change product specification to use a different raw or recycled raw material (no dangerous)	Modification of product specification in order to use a different material both raw or recycled	IAC, 2007	EE
	Modify the process to reduce material use/cost	Modification of process in order to reduce the use of material (reducing also the cost of it)	IAC, 2007	EE
	Modify the process to reduce the use of water	Modification of process in order to reduce the use of water.	IAC, 2007	EE
Reduction of emission	Pollution/contaminants reduction	Reduction of the contaminants the firm release in the environment and reduction of emission of substances that make land, water, air, etc., dirty and not safe or suitable to use	Gimenez et al., 2012; Pagell and Gobeli, 2009	OEE

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