Incorporating sustainability in inventory planning models: a systematic literature review of existing approaches

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Abstract: Sustainability has gained an increasing relevance in different supply chain management (SCM) processes. Companies undertake sustainability initiatives not only with the aim to cause less harm to the environment and the society, but also to build competitive advantage based on sustainability. Inventory planning and management (IP&M) is a cornerstone process for managing a supply chain, since the decisions regarding how much, where and for how long to keep inventories have important impact on the planning of production, purchasing and distribution. Therefore, this paper focuses on the decision-making process for IP&M and aims at investigating how the extant literature has explored the integration of it with economic, environmental and social sustainability. Notably, we adopt the Sustainable Development Goals (SDGs) framework to explore the how IP&M approaches support or hinder different sustainability objectives. Through a systematic literature review, we derive a list of 35 papers published in the main academic reference journals in Scopus database in the last 9 years. From a synthesis of available evidence, we develop a classification of the contributions along two dimensions. A first dimension is represented by the extent to which the decision-making process is focused on: i) strategic planning (e.g., location-inventory model) or ii) tactical planning (i.e., sustainable lot sizing decisions o inventory replenishment rules) decisions. A second dimension of classification is represented by the role assumed by sustainability. Sustainability ranges from being integrated in the strategic objective function of IP&M models (i.e., a sustainable economic order quantity is computed considering the minimization of the environmental impact), or as a constraint. This study aims to be the starting point for the development of a new generation of IP&M models that can become useful decision support systems for practitioners to include sustainability in their decision-making.

Keywords: inventory planning, sustainability, sustainable development goals.

1. Introduction

Traditionally, the main dilemma of Inventory Planning & Management (IP&M) was the balance between a lower efficiency – due to higher stock holding costs and working capital – and a higher effectiveness - deriving from the harmonisation of harmonise supply and demand (Slack *et al.*, 2013). To face such dilemma, researchers and practitioners several different techniques, from the Economic Order Quantity (EOQ) (Harris, 1990), to simulations (e.g., Keramydas *et al.*, 2017).
However, this dilemma has become more complex in recent years, due to the urgency of including sustainability in IP&M decisions. Sustainability is defined as utilising resources to meet the needs of the present without compromising the future (WCED, 1987). Sustainability practices should adopt a triple bottom line (3BL) perspective: environmental, social and economic (Ahi and Searcy, 2013). Recent studies showed that sustainability should be included into IP&M decisions, considering its impact on carbon emissions (e.g. Martí, Tancrez and Seifert, 2015), food wastes (e.g. Biuki, Kazemi and Alinezhad, 2020), and safe work (e.g. Andriolo *et al.*, 2016). The need to face these became clearer after the "United Nations Conference on Sustainable Development" held at Rio de Janeiro in 2012, which identified 17 Sustainable Development Goals (SDGs) to orient society towards a more sustainable future (sustainabledevelopment.un).
Although several studies on sustainable IP&M have been published in the last decade, none of them – to the best of our knowledge – has provided a holistic view on this topic. So, with the present study, we aimed at answering the following research question (RQ): *"How do IP&M decisions support the achievement of SDGs by embedding sustainability in IP&M models?"*
The paper will unfold as follows. Section 2 provides the theoretical background of the study. Session 3 describes our methodology. Section 4 presents a

descriptive and thematic analysis of the reviewed papers. Section 5 discusses the answer to our RQ, while Section 6 outlines a future research agenda. Section 7 concludes the paper with its main contributions and possible limitations.

2. Theoretical background

According to Banasik *et al.* (2018), inventory management includes decisions on how inventory is controlled, determining the reorder points and reorder quantities, while inventory routing deals with the optimization of inventory in multiple locations (Banasik *et al.*, 2018). IP&M decisions can be classified in two levels: tactical and strategic (Chopra and Meindl, 2013). *Strategic IP&M* decisions have a long-term impact, e.g. the supply chain's configuration, the allocation of inventories, or the actions adopted by companies to respond to the state's cap and trade regulations (Chopra and Meindl, 2013). *Tactical IP&M* decisions concern the functioning of a supply chain over a specified period of time, problems such as single- and multi-item lot sizing, and models such as EOQ or VMI (*ibidem*).
IP&M has a long history, witnessed by a proliferation of literature reviews, recently reviewed by Bushuev *et al.* (2015), who identified two main trends: i) the rise of sustainable practices, which reflects the importance of sustainability not only in the context of operations management (as in Bouchery *et al.*, 2012) but also as a source of competitive advantage (as in Ciccullo *et al.*, 2020); ii) the emergence of a multi-echelon perspective, which allows to consider inventory management problems in multiple locations.
As for literature reviews that share a similar intent with our research focus we can mention Das and Jharkharia (2018), who identify low carbon EOQ, newsvendor problem and lot size problem as inventory management and routing decisions that have an impact on the carbon footprint of a supply chain. Moreover, the systematic literature review by Bazan, Jaber and Zanoni (2016) focuses on summarising the knowledge on different modelling approaches for reverse logistics inventory systems that are based on EOQ/EOP settings. However, to the best of our knowledge, the current debate in IP&M has yet to develop a more holistic view on sustainability that extends beyond the limited focus on the environmental concerns.
All in all, this paper aims at addressing the limitations of the current academic debate, integrating the tactical and strategic perspectives on IP&M in offering a critical and holistic view on the role of sustainability in these processes with use of the framework of the SDGs.

3. Methodology

To map and evaluate the existing body of knowledge intertwining sustainability and IP&M, we adopted a systematic literature review (Tranfield *et al.,* 2003). We referred to the PRISMA framework (Moher *et al.,* 2015) as a guideline for our methodology, whose main steps are summarised in Figure 1.
The systematic review began with the identification of the search terms (Denyer and Tranfield, 2009). Consistently with the research questions, our search was limited only to certain subject areas: Business, management and accounting, Engineering, Computer science, Decision science, Environmental science, and Social science.
We set the starting year in 2012, as it marks a cornerstone for our research focus for two reasons: is the year of publication of one of the most cited paper on incorporating sustainability into IP&M decisions, i.e. Bouchery et al. (2012) and the Rio de Janeiro conference takes place, where the concept of sustainable development has been formalised. We limited the results to book chapters and peer-reviewed articles in English. The choice of focusing just journal articles and book chapters reflects the high maturity of the IP&M and the sustainability literature. Moreover, restricting the sample of papers in English allow to include just those high quality contributions with an international outreach.
The search query we used was the following one, which resulted in finding 363 papers: ("stock plan*" OR "stock manag*" OR "stock model*" OR "inventory plan*" OR "inventory manag*") AND ("sustainab*" OR "social*" OR "green*")

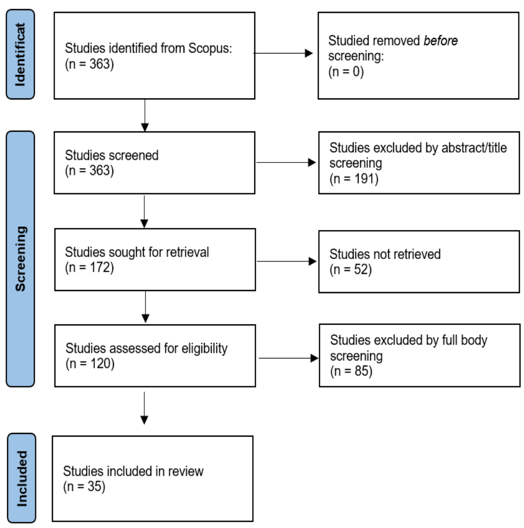

Figure 1 – Systematic Literature Review Methodology

For what concerns the filtering, we firstly checked the title, keywords and abstracts to check our inclusion and exclusion criteria. More specifically, we rejected papers on production planning with no reference to inventory management, papers too focused on the technical aspects of sustainable practices not related to our research question; and papers not related with sustainable inventory management at all. As a result, 172 articles remained. After downloading as many papers as possible (52 studies could not be retrieved), we full-text scouted the remaining ones, and discarded mainly the articles with sustainable practices under discussion not related to any IP&M policy (e.g., emission reduction in transportation).
The selection process returned a list of 35 papers, which we then analysed to extract both demographic and thematic information.

4. Results

Our study demonstrates an increase in the trend of publications by year, especially after 2016. Two first hits were reported in 2012, which coincide with the starting year set by our selection criteria.
Regarding the research methodology, mathematical modelling shows a clear dominance (see Table 1), while only few of the papers took a second step in further integrating the case study (CS) research method .

Table 1 – List of papers with ID

ID	Reference	Method
1	(Mallidis *et al.*, 2014)	Optimisation
2	(Daghigh *et al.*, 2016)	Optimisation
3	(Soysal, 2016)	Optimisation (CS)
4	(Abdallah, Diabat and Simchi-Levi, 2012)	Optimisation
5	(Martí, Tancrez and Seifert, 2015)	Optimisation
6	(Rau, Budiman and Widyadana, 2018)	Evolutionary, Heuristic
7	(Silbermayr, Jammernegg and Kischka, 2017)	Simulation
8	(Tang, Ji and Jiang, 2016)	Evolutionary
9	(Zhalechian *et al.*, 2016)	Optimisation, Heuristic
10	(Fichtinger *et al.*, 2015)	Simulation
11	(Battini, Persona and Sgarbossa, 2014)	Analytical
12	(Chen, Benjaafar and Elomri, 2013)	Analytical
13	(Zadjafar and Gholamian, 2018)	Optimisation
14	(Lee, Yoo and Cheong, 2017)	Analytical
15	(Tiwari, Ahmed and Sarkar, 2019)	Optimisation
16	(Sarkar *et al.*, 2018)	Optimisation
17	(Mishra *et al.*, 2020)	Optimisation
18	(Tiwari, Daryanto and Wee, 2018)	Optimisation
19	(Digiesi, Mossa and Mummolo, 2013)	Optimisation
20	(Ugarte, Golden and Dooley, 2016)	Simulation
21	(Bozorgi, 2016)	Optimisation
22	(Stellingwerf *et al.*, 2018)	Optimisation + CS
23	(Darom *et al.*, 2018)	Heuristic
24	(Khan, Hussain and Saber, 2016)	Optimisation
25	(Bouchery *et al.*, 2012)	Optimisation
26	(Andriolo *et al.*, 2016)	Optimisation + CS
27	(Halat and Hafezalkotob, 2019)	Game Theory, Optimisation
28	(García-Alvarado *et al.*, 2017)	Optimisation
29	(Biuki, Kazemi and Alinezhad, 2020)	Optimisation
30	(Keramydas *et al.*, 2017)	Simulation
31	(Hasanov *et al.*, 2013)	Fuzzy Modelling
32	(Gautam and Khanna, 2018)	Optimisation
33	(Mishra, Wu and Sarkar, 2020)	Optimisation
34	(Fan *et al.*, 2019)	Optimisation
35	(Huang, Fang and Lin, 2020)	Optimisation

While the majority (25) of the selected articles does not deal with any specific industry, the rest covers a range of different sectors including retail, electronics, bulb production, beverage, flowers, automotive and whitegoods industries.

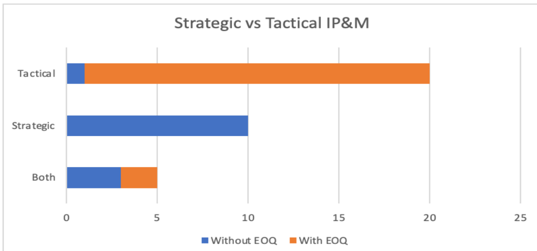

Figure 2 – Contributions by perspectives for IP&M

Figure 2 shows the different focus of the analysed papers, distinguishing between tactical IP&M, strategic IP&M, and papers that combine both the perspectives. For what concerns the tactical perspective of IP&M, Figure 3 shows a preponderance of papers related to the EOQ model. While almost all the papers with the tactical IP&M perspective have revisited the original EOQ model in light of sustainability concerns, it is worth pointing out that the literature still has not coined a common terminology of *sustainable EOQ (SEOQ)* models. The different alternatives presented in literature include *sustainable EOQ* or SEOQ (Bouchery *et al.*, 2012; Digiesi, Mossa and Mummolo, 2013; Battini, Persona and Sgarbossa, 2014; Lee, Yoo and Cheong, 2017); *carbon constrained EOQ* (Chen, Benjaafar and Elomri, 2013); *green EOQ* (Zadjafar and Gholamian, 2018; Tiwari, Ahmed and Sarkar, 2019); and *sustainable economic production quantity* (Mishra *et al.*, 2020). All these papers expand the original EOQ model by introducing new cost-related variables “translated” from the various sustainability impacts. The studies showed different angle of sustainability. Some of these studies are limited to the integration of the environmental perspective: for instance, Battini, Persona and Sgarbossa (2014) and Lee, Yoo and Cheong (2017) consider the average carbon emission costs related to transportation, warehousing, and waste collection and disposal. However, there are studies taking into account the social perspective, too. Zadjafar and Gholamian (2018) review 25 papers on sustainable IP&M, identifying 17 relevant variables, among which they cite two social ones related to ergonomics (worker fatigue and metabolic energy consumption). However, their review is yet to be exhaustive, as they neglect, for instance, the consideration of workers’ injuries (Bouchery *et al.*, 2012), accidents, noise and congestion (Digiesi, Mossa and Mummolo, 2013).

There is still no agreement on what variable to consider when developing a SEOQ and how to translate them into the original EOQ model. All the studies show interest in Greenhouse Gases (GHG) Emissions, especially those due to transportation, while fewer ones consider other pollution sources, like the energy necessary to the functioning of warehouses. On top of that, the methodology used to translate air pollution into economic costs differs paper by paper. For example, Mallidis *et al.* (2014) use: the price per ton of CO2 under the 2014 EU Emissions Trading Scheme (EU ETS), equal to 5.71; the penalty cost for no compliance to the EU emissions cap, which is 100€ per ton of CO2 according to the 2009 EU standards; and the CO2 emissions tax under the 2011 EU energy taxation directive, equal to 20€ per ton of CO2. This clearly shows the need for EU and the other institutions to develop clearer regulations.

Besides SEOQ, our study shows limited insight on inventory pooling models (e.g. Silbermayr, Jammernegg and Kischka, 2017); multi-item IP&M (e.g. Fichtinger *et al.*, 2015; Bozorgi, 2016); and VMI (e.g. Khan, Hussain and Saber, 2016; Soysal, 2016; Stellingwerf *et al.*, 2018).

For what concerns the strategic perspective of IP&M, instead, the main themes emerged from the literature review are: facility location (Abdallah, Diabat and Simchi-Levi, 2012; Mallidis *et al.*, 2014); inventory location (Daghigh *et al.*, 2016; Silbermayr, Jammernegg and Kischka, 2017; Halat and Hafezalkotob, 2019); supply chain network design (Martí, Tancrez and Seifert, 2015; Soysal, 2016; Keramydas *et al.*, 2017; Biuki, Kazemi and Alinezhad, 2020); route design (Tang, Ji and Jiang, 2016; Zhalechian *et al.*, 2016; Hong and Leffakis, 2017; Rau, Budiman and Widyadana, 2018) and joint route planning (Stellingwerf *et al.*, 2018).

A common theme emerged from these papers is the trade-off between economic and sustainable targets. For instance, in the inventory routing problem studied by Rau, Budiman and Widyadana (2018), they observe that optimizing the total cost rate increases the fuel consumption and warehouse energy consumption, causing higher emission rates, and vice versa. Another example is the inventory location problem studied by Daghigh *et al.* (2016), who conclude that economic, environmental and social sustainability are not compatible among each other: in other words, a firm must spend more money to maintain environmental and social aspects than in the case where it cares only about economic aspects. In this sense, a possible solution to make sustainability convenient is acting on incentives and disincentives, and the literature provides frameworks to guide policymakers: for instance, the framework by Abdallah, Diabat and Simchi-Levi (2012) can be used to size carbon credits, in order to offset the losses that original equipment manufacturers would incur if they sought a high sustainability performance.

However, further studies on the trade-off between sustainability and economic variables are still needed, as the relationships between them are very complex. For instance, Mallidis *et al.* (2014) combine the strategic and tactical perspective by proposing a model that jointly optimizes network design and inventory planning. Interestingly, they find that cost and CO2 emissions minimization objectives are not aligned at the tactical level, but they are aligned at the strategic level – thanks to the positive impact of increasing the number of distribution centres on both these aspects. Therefore, this work exemplifies how a “holistic” perspective leads to richer results than a “narrow” one.

5. Discussion

Our results revealed a plurality of ways through which IP&M supports the achievement of SDGs, as reported in Table 2. First and foremost, the classification demonstrate that the most supported targets of the SDGs framework are those connected to the GHG and carbon emissions (i.e., SDG target 13.1 and SDG target 9.4). Both strategic and tactical decisions are considered in different contributions, but with a different role assigned to sustainability parameters. According to Silbermayr *et al.* (2017), carbon emissions are a constraint (i.e., they impose emissions to not increase beyond a certain limit) in a model that aims at evaluating different inventory pooling options (i.e., centralised vs decentralised) and different inventory allocation options. Within the environmental dimension, the reduction of energy consumption connected to storage and transportation assets (i.e., SDG target 9.4 and SDG target 7.3) is supported by tactical IP&M in specific cold chain that are typically energy intensive (Cannas *et al.*, 2020). For instance, Bozorgi (2016) in his multi-product inventory model considers emissions connected to refrigeration systems (e.g., HFC refrigeration gases) as part of an objective function with is separated from the main cost objective function of a tactical IP&M model.

Table 2 – Contributions supporting SDGs

Focus	SDG/target[1]	Tactical IP&M	Strategic IP&M
GHG and carbon emissions	13 (whole)- reduction of GHG emissions 9.4: more sustainable infrastructures	7; 10; 11; 14; 15; 16; 17; 18; 19; 20; 21; 22; 23; 24; 25; 31; 32; 33; 34; 35	1; 2; 3; 4; 5; 6; 7; 8; 9; 27; 28; 29; 30; 35
Energy consumption of the supply chain infrastructures	9.4 *(Ref. Above)* 7.3: increase energy efficiency	21; 31	
Job opportunities and local economic development	8.5: increase employment rate	24; 26	9; 2; 29
Waste generation and disposal	12.2: efficient use of natural resources	31	

Second, within the social dimension, the creation of new employment opportunities is inserted in the design of tactical and strategic IP&M models. Interestingly, Daghigh *et al.* (2016) include the creation of new job opportunities and local economic development in the objective function of a multi-products inventory locations problems. Similarly, Daghigh and colleagues consider three different objective functions: costs, environmental impact, and social responsibility objectives. On the tactical IP&M side, Andriolo *et al.* (2016) develops a multi-objective approach with two objective functions that expand the traditional EOQ framework thanks to the social impact of inventory decisions to assure decent working conditions, quantified in term of the ergonomics of handling activities.

This variety of ways through which the SDGs are supported by IP&M decisions highlights that sustainability is not considered equally on the three dimensions of the Triple Bottom Line, with a clear unbalance towards the environmental dimension. Notably only four SDGs are supported by the different models explored by our sample of papers. In addition, sustainability is also considered in a variety of ways also in terms of strategic importance. In some papers, sustainability impact is qualified as one of the objective functions, although not the only one. In other cases, sustainability has the role a constraint, underlining the marginal role compared to other operational/economic performance.

6. Future Research Agenda

Our paper has highlighted an ample ground for future research development. Firstly, we call for future investigation to extend the perception of sustainability in IP&M research, since extant IP&M studies has mainly treated sustainability as an additional cost item in the objective functions to evaluate the trade-offs among alternative decisions. Being considered mostly in the context of adjusting traditional operations practices in warehouses, transportation and handling activities, extant research overlooks the fact that sustainable and technological innovations may result in added-value rather than cost. Such approaches fall short in considering the value of sustainability as a potential lever to exert positive impact on demand and sales, and process efficiency improvements.

Second, future research should focus on integrating the social aspects of sustainability in IP&M – as a constraint or in the objective function – being the less explored dimensions of the triple bottom line. Further considerations can be made on additional elements of IP&M models that have the potential to be studied in relation to the different sustainability aspects (or SDGs) that they support, or that might potentially undermined.

Lastly, future research should push the frontier of the application of advanced technologies in facilitating the integration of sustainability in IP&M decisions. As our interest goes beyond the translation of sustainability into cost and credits for emissions, which is the primary focus of extant literature, more should be explored and quantified on how this translation could be managed, facilitated and monitored with the use of advanced digital technologies. Examples are the use of smart contracts for sustainable management of inventory transaction, sizing and allocation, and the support of smart packaging (i.e. big data) for inventory management and preservation.

7. Conclusions

This paper presents the results of a systematic literature review on 35 papers aimed at investigating

[1] The numbers refer to the SDGs and targets (see also: sdgs.un)

how IP&M literature has addressed sustainability in supporting the achievement of SDGs in supply chains. Our study shows that sustainability considerations can be integrated both in the strategic and tactical level of IP&M decisions. At the tactical level, existing studies have revisited the traditional EOQ models, while at the strategic level, the trade-off between economic and sustainable targets of sustainability is frequently debated with a triple-bottom line perspective. Sustainability-concerned IP&M literature has primarily resulted in supporting the enhancement of SDGs related to the arisen attention on environment, e.g., by reducing GHG and carbon emissions. Additionally, it can have positive implications for the creation of jobs opportunities and local economic development (e.g. SDG 8.5). Our paper provides the practical implication indicating how IP&M models can be used to pursue the listed SDGs.

We have proposed relevant topics to be addressed in the upcoming literature: i) new approaches to integrate sustainability into IP&M models considering the different strategic importance of sustainability; ii) other production and supply chain elements in IP&M that can be connected with sustainability, especially the social aspects; iii) the interaction of digital technologies in IP&M to support and amplify the seek on SDGs.

One potential limitation of the paper lies in the selection of literature collection database. So, future research can extend the search to other databases.

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