Production Distribution Planning in a Multi-Echelon Supply Chain Using Carbon Policies: A Review and Reflections

S. Jane Jedidah, V K Manupati, Kushal Kumar Chode, Biswajita Mohanty, Leonilde Varela, Maharshi G Parekh

***Abstract*—Sustainability of a supply chain has gained more attention from economists, environmentalists, consumers, manufacturers, government and the academia. In this paper, the literature survey has been performed on production allocation problem in a multi-echelon supply chain with carbon policies. With web-based search engines such as Scopus and Web of Science several resources such as journals, conference proceedings and books are selected and reviewed. It is observed from the literature that the mentioned problem traces the progression of carbon policies in a supply chain over the past 22 years to provide substantiation for Green Supply Chain. The research papers are then analyzed and categorized to construct the useful foundation of previous studies. Moreover, the importance of this problem in recent years needs has been highlighted by mentioning the gaps in the literature. Further, at the end of the paper, several future work directions in this area also suggested.**

***Index Terms*—Carbon policies, multi-echelon, production-distribution, supply chain**

I. Introduction

Companies today, are faced with a dual task of increasing profitability while growing sustainably. One of the various economically and environmentally viable options is Green Supply Chain Management. It can be defined as 'integrating environmental thinking into supply chain management including product design, material sourcing, and selection, manufacturing processes, delivery of the product to the consumers as well as end-of-life management of the product after its useful life' [1]. Fig 1 depicts the same, with the various ways that green supply chain management can be implemented. This paper focuses on green operations among green design and green Supply Chain Management. In particular the production distribution and allocation problem with carbon policies.

Kyoto Protocol has three different carbon policies as shown in Fig 2. They include Strict Carbon Capping, which implies that the firm should regulate its emission such that they do not exceed the cap (the limits set); Carbon Taxing implies that the firm should pay a certain amount of tax for an unit amount carbon released; and Carbon Capping and Trading suggests that the firms that exceed the cap buy carbon credits from another firm that are yet to consume the allotted amount of carbon [2]. The review includes two parts, the first being to map the evolution of production-allocation problem in a supply chain. The second part gives a comprehensive summary of the incorporation of carbon policies in a supply chain

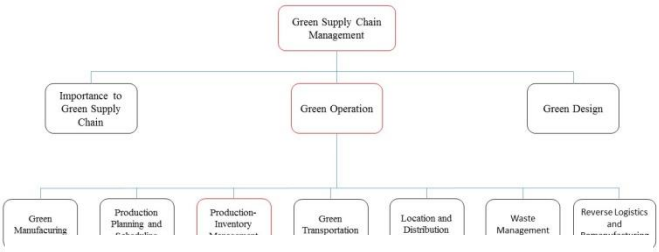

Fig. 1 Breakdown of Green Supply Chain Management

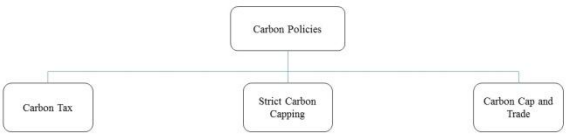

Fig.2 Carbon Policies According to Kyoto Protocol

II. RESEARCH METHODOLOGY

We have adopted content analysis method for the review of papers. Content analysis is an observational research method that is used to evaluate the symbolic content of all forms of record communication systematically. This review work is limited to the published articles from different journals, books and conference proceedings and various search engines such as Google Scholar, Science direct, Informs, Scopus database, and Willy database are used to explore the literature related to Networked manufacturing. Keywords such as 'Production Distribution,' 'Carbon

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Emission Policies,' 'Multi-echelon,' 'green supply chain, are used to find the related literature. In this research, nearly 174 journal publications have been reviewed, and these publications are mostly during 2000–2017. 37 out of 174 have discussed on production distribution problem in the multi-echelon supply chain with carbon policies. The detail description of review protocol is given in Table 1

Table 1: Description of Review Protocol

Inclusion criteria	Peer-reviewed journal: Articles were identified during the database search Topic: Production distribution in multi-echelon supply chain with carbon policies Language: English Time Span: Before 2017 Article type: all	
Keywords	Carbon Emission Policies, Production , Distribution, Multi-echelon, Supply chain	
Keyword search	Total search selected online databases with the keywords defined above: a) Article b) Review c) Conference review d) Conference Paper e) Article in Press f) Book/book chapter	 138 21 1 2 0 2
Consolidation	Consolidation of articles Articles contain at least one of the keywords First content analysis of the articles by defined criteria Relevance of content by subjecting all papers to a manual analysis of their abstract	
Working Sample size		174
Content analysis Final Sample Size	All papers in the working samples have been fully read to identify their content	37

Table 2: Table of Top 10 Sources of Literature

Source	No of Publications	Percentage
International Journal Of Production Economics	16	9.195
Journal Of Cleaner Production	12	6.89
Transportation Research Part E: Logistics and Transportation	10	5.747
Computers And Chemical Engineers	7	4.022
European Journal of Operation Research	7	4.022
Computers And Industrial Engineers	6	3.44
Sustainability Switzerland	4	2.29
ACS Sustainable Chemistry And Engineering	3	1.72
AIChE Journal	3	1.72
Applied Mathematical Modelling	3	1.72

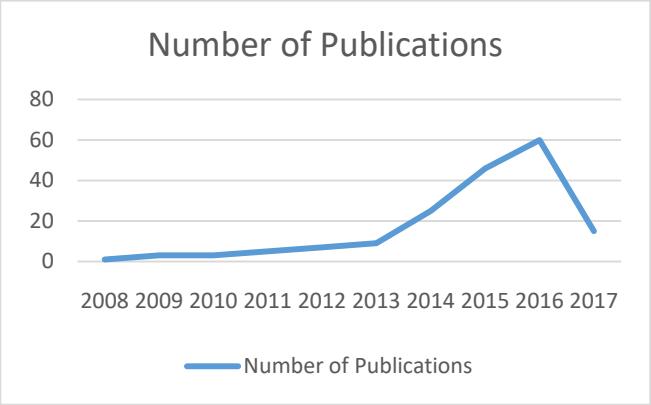

Fig. 3: Chart of Number of Publications for the past ten years

The reviewed articles are published from various journals such as International Journal of Production Economics, European Journal of Operational Research, Omega, Transportation Research Part E- Logistics and Transportation Review, etc. From Table 2, it is observed that production allocation problem in a multi-echelon supply chain is carried out in International Journal of Production Economics and Journal of Cleaner Production followed by Transportation Research Part E: Logistics and Transportation and Computers And Chemical Engineers. The percentage share of published articles in International Journal of Production Economics is more compared to other journals. From Figure 3, it is observed that there are a higher number of hits in the period of 2012–2016. From this, one can easily infer that interest of the scientific community in this area has grown significantly in recent years.

III. LITERATURE

Keeping in view, our research work, The review of literature is divided into two sections (i) Literature related to Production distribution problem and (ii) secondly, literature related to carbon policy on production distribution problem and these are briefly discussed in the following sub-sections.

A. Literature related to Production distribution problem

We review the model-based literature on green supply chain in particular to production and inventory management with carbon policy as an environmental consideration. From the different perspectives, environmental issues in literature have been considered as the operations management which has led to a significant number of published papers. We present hereafter some representative works selected based on their adequacy with the topic of our paper. The works on Green Supply Chain Management in Green operation for the Production-Inventory problem is taken into the consideration.

The Supply Chain network design problem is traditionally studied as a facility location problem [3] The supply chain costs can be divided into three categories: inventory costs, facility establishment, and transportation costs There are four categories of Supply Chain design: deterministic

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analytic model, stochastic analytic models, economic models, and simulation models. The supply chain is consists of two basic and integrated processes: (1) the production planning and inventory control process, and (2) the distribution and logistics process.

Sabri and Beamon [4] developed a multi-objective Supply Chain model to strategic and operational SC planning, simultaneously. In their research, the SC structure consists of four echelons: suppliers, plants, distribution centers, and customer zones. The model incorporates production, delivery, and demand uncertainty, and reduces complexity via reasonable simplifications. The proposed model also provides an appropriate performance measure by using multi-objective analysis for the entire SC network. Flipo and Finke [5] in their paper investigated a multi-facility, multi-product, and multi-period industrial problem. In their problem, both production and distribution costs are significant and inter-related. They formulated this combined production– distribution problem in the form of a network flow problem with relatively few additional 0–1 variables describing the linking constraints between various periods. Computational experiments showed that the encountered real size problems could be solved in a reasonable time by using commercial linear programming application. Daskin, Coullard, and Shen [6], Shen, Coullard, and Daskin [7], and Shu, Teo, and Shen [8] presented similar versions of an Uncapacitated Facility Location Problem (UFLP) model incorporating the inventory control decisions. In these works, the ordering decisions are based on the economic order quantity (EOQ) model. These model structures assume normality and independence for the retailers demand pattern. Indeed, while Daskin et al. [6] applied LR method, Shen et al. [7] reformulated the problem as a set covering problem, which was then solved through a hybrid heuristic mixing columns generation and branch and bound methods. In Daskin et al. [6] and Shen et al. [7] studies, the clients represent retailers, each of which is a potential candidate for a distribution center. The model of the subsequent study (Shu et al., 2005) [8] was originally proposed in Shen et al. [7]. Since the previous model was able to solve only two special cases of the general model efficiently, then they proposed an efficient algorithm to solve the general pricing problem. Together with the variable fixing technique, this yields a highly effective approach to solve a moderate to large-scale network design problem to near optimality.

Chen and Lee [9] proposed a multi-product, multi-stage, and multi-period scheduling model to deal with multiple incommensurable goals for a multi-echelon SC network with uncertain market demands and product prices. Miranda and Garrido [10] developed a mathematical programming model to locate a set of capacitated facilities in storage and ordering size optimally. These facilities were intended to serve as a set of dispersed customers with stochastic demands that must be satisfied to a given level of service at minimum system's cost. The model was solved through using LR approach.

Chan, Chung, and Wadhwa [11] developed a hybrid GA for a production and distribution problem in multi-factory SC models. For structuring and organizing interrelated decision-making criteria in SC problems, they utilized analytic hierarchy process (AHP). Their paper provided a systematic approach for decision makers to assign weightings objectives and relate them to each other.

Lim, Jeong, Kim, and Park [12] presented a mathematical model to determine capacities of facilities such as manufacturing plants and distribution centers. Considering the uncertainty and complexity of solving such networks, they developed a simulation approach. Computational, experimental results showed the effectiveness and viability of the proposed models. Selim, Araz, and Ozkarahan [13] developed a multi-objective linear programming model for collaborative production–distribution planning problems in SC systems. They asserted that fuzzy goal programming approaches could effectively be used in handling the collaborative production–distribution planning problems in both centralized and decentralized SC structures.

Wu and Chang [14] propose a production-planning optimization problem in an uncertain environment for the textile industry using a grey programming approach. Environmental costs (pollution charges and water resources fees) are considered in the calculation of the unit production cost.However, the decision variables in this model, namely production yield and inventory level, are not explicitly correlated to the environmental costs. Letmathe and Balakrishnan [15] integrate environmental concerns into a production planning model under environmental legislations. To manufacture a product, different technologies that differ by their emissions and resources consumptions may be used. The objective is to maximize the total profit (revenues – costs). Their venues are generated by selling products and traded emissions. Costs are relative to the use of resources in manufacturing operations, the purchasing prices of traded emissions, and the emissions penalties. The demand for products is assumed to be decreasing with increasing levels of emissions.

The impacts of production-inventory decisions on the environment have been addressed in some pioneer papers by Hua et al. [16], Wahab et al. [17], Bouchery et al., [18] and recently Benjaafar et al. [19]. While there is clearly value in such efforts, they ignore the impacts of lead time constraints on emissions. In addition, most of these works consider a simple SC structure and deal only with the emissions associated with the final product (raw materials and intermediate products are not considered). There is a clear need to address environmental considerations in more

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realistic production-inventory models to consolidate the insights derived so far in the literature and to investigate new insights relative to real-world complexities.

B. Literature related to Carbon policy on production distribution problem

The Supply chain network design considering carbon emission is broadly divided into three categories: Single, Multi and Infinite Planning horizon periods and each period is further classified into Single and Multi-stages. In single period, single stage Rosic and Jammernegg [20] explored the economic and environmental sustainability of dual sourcing with an offshore and an onshore supplier taking emission by transportation into account and solved using extend dual sourcing model based on newsvendor framework approach. Zhang and Xu [21] describes Multi-item production planning problem on the basis of carbon emission due to production. Su and Xiao [22] investigates the transportation problem under carbon policies to find the optimal transportation cost. Xiaoping et al. [23] studied the supply chain coordination problem and adopted green technology to make Pareto improvement for the firms. In single period, multi-stage Swami and Shah [24] elaborated "greening effort" on profit function in centralized and decentralized Supply Chain using profit maximization model. Table 3 gives a comprehensive look at the papers in single period.

In multi-period, single stage Dobos [25] discussed the effect of emission trade on production-inventory strategy extended by Arrow-Karlin model. Absi et al. [26] included Multi-sourcing lot sizing problem under different carbon policies in Production as well as in transportation facility and solved using Multi-sourcing lot sizing problem. Li and Gu [27] investigated the effect of carbon banking on the production–inventory using Arrow-Karlin Model. Benjafar et al. [19] developed EOQ like models under different carbon policies with ordering and inventory sources of carbon emission. Li [28] proposed Production-inventory model for deteriorating items with trade emission in production department. Peng et al. [29] minimized the total cost and the total emission of the supply chain while taking into consideration carbon capping and taxing. For multi-period, multi-stage Benjafar et al. (2013) [19] extended EOQ like model for multi-echelon under strict carbon cap in ordering and inventory department. Ghosh et al [30] incorporated the three carbon policies in two-echelon SC, using sensitivity analysis to examine the impact of the parameters on the total cost and emission. Li et al [31] examined a two-echelon supply chain under two carbon policies i.e. carbon cap-and-trade and carbon tax. Fareeduddin et al. [32] proposed an optimization model integrating carbon policies in a closed loop SC. Table 4 refers to the papers related to multi-period horizon.

In infinite planning horizon period, single stage Bonney and Jaber [33] extend EOQ models to include environmental cost and Hua et al. [34] examines how operational adjustments can handle both economic and environmental concerns using extend EOQ model approach. Bouchery et al. [15] included sustainability criteria into inventory model by Multi-objective formulation of EOQ. Chen et al. [35] develop EOQ like models under different carbon policies, and Toptal et al. [36] developed three EOQ like models for various carbon policies considering emission reduction investment using extend EOQ model considering emission due to Procurement, ordering, and holding.

For infinite planning horizon period, multi-stage Wahab et
al. [17] develop a national and an international supply chain with defective items and return policy. Bouchery et al. [18] include sustainability criteria into inventory model using Multi-objective formulation of EOQ and Jaber et al. [37] a two-level supply chain model with a coordination mechanism is developed while accounting for greenhouse gas emissions using EPQ into the process. Fareeduddin et al. [38] present an optimization model that is based on the three carbon policies. Table 5 includes the literature related to infinite planning horizon period.

IV. SOME KEY ENABLING TECHNOLOGIES FOR FUTURE WORK

In this paper, three different avenues for further scientific research have been incorporated. Table 6 gives a clear view of some of the future opportunities for research. Meta-heuristic evolutionary algorithms can be used for production distribution in a multi-echelon supply chain under the three existing carbon emission policies. A closed loop supply chain can be designed with consideration of carbon policies using many-objective optimization simulation or agent-based approach. By the use of heuristics or meta-heuristics or CPlex, a remanufacturing supply chain in production allocation problem can be designed by considering carbon policies.

Table 6. Future research work and their approaches

Sl .No	Future tools and approaches for carbon policies in multi-echelon supply chain	Tools / Approach
1	Production distribution in a multi-echelon supply chain using carbon policies by considering carbon capping, carbon tax, and carbon cap and trade	Meta- heuristic evolutionary algorithms
2	Designing a closed loop supply chain with consideration of carbon policies with many objectives	Many objective optimization, simulation, Agent-based approach
3	Designing of remanufacturing supply chain in production allocation problem by considering carbon policies	Heuristics/ Meta-heuristics/ CPlex for solving mixed integer programming models

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Table 3: Table for literature on single period planning

Period	Stage	Authors	Demand		Carbon Policy			Decision Variable	Source of Emission	Problem Description	Solution Approach
			Deterministic	Stochastic	CT	SCC	CCT				
Single	a) Single	Rosic and Jammernegg (2013)	–	✓	✓	–	✓	Offshore order quantity, expected onshore order quantity	Transportation	Explored economic and environmental sustainability of dual sourcing with an offshore and an onshore supplier	Extend dual sourcing model based on newsvendor framework
		Zhang and Xu (2013)	–	✓	✓	–	✓	Production quantity, amount of carbon traded	Production	Multi-item production planning Problem	Multi item production planning problem
		Su and Xiao (2015)	✓	–	✓	✓	✓	Amount of carbon produced	Transportation	Investigated the optimal solution to transportation problem under carbon policies	Profit maximization with all three policies incorporated
		Xiaoping et al (2017)	✓	–	–	–	✓	Carbon emissions	Production	Study emissions in a Make-To-Order SC under cap-and-trade regulation	Pareto improvement for firms in the SC
	b) Multi	Swami and Shah (2013)	–	✓	✓	–	–	Manufacturing, retailing price amount of investment	Production	"greening effort" on profit function in centralized and decentralized SC	Profit maximization model

Table 4: Literature on multi-period planning horizon

Period	Stage	Authors	Demand		Carbon Policy			Decision Variable	Source of Emission	Problem Description	Solution Approach
			Deterministic	Stochastic	CT	SCC	CCT				
Multi	a) Single	Dobos (2007)	✓	–	–	–	✓	Production rate, inventory level	Production	Discussed the effect of emission trade on production-inventory strategy	Extend Arrow-Karlin model
		Absi et al. (2012)	✓	–	–	✓	–	Production rate, inventory level	Production facility & transportation	Multi-sourcing lot sizing problem under different carbon policies	Multi-sourcing lot sizing problem
		*Li and Gu (2012)	✓	–	–	–	✓	Quantity supplied, mode	Production	Investigated the effect of carbon banking on the production–inventory	Extend Arrow-Karlin model
		Benjafar et al. (2013)	✓	–	✓	✓	✓	Production rate, inventory level, carbon traded	Ordering, inventory	Developed EOQ like models under different carbon policies	Extend EOQ model
		Li (2013)	✓	–	–	–	✓	Order quantity, back order, inventory, amount of CCT	Production	Production-inventory model for deteriorating items with trade emission	Extend Arrow-Karlin model
		Peng et al. (2016)	✓	–	–	✓	✓	Greenhouse gas emission, Product Quantity	Transportation, Inventory	Minimizes the total cost and emissions in a multi-period one-stage supply chain	Extend EOQ model
	b) Multi	*Benjafar et al. (2013)	✓	–	–	✓	–	Order quantity, back order/ inventory for each period	Ordering, inventory	Extend EOQ like model for multi echelon under strict carbon cap	Extend EOQ model
		Ghosh et al (2016)	–	✓	✓	✓	✓	Optimal ordering quantity	Ordering, Set-Up, Production, Inventory And Transportation	Minimize the total cost.3 different models have been proposed to integrate the policies.	Sensitivity analysis has been done
		Li et al (2017)	–	✓	✓	–	✓	Order Quantity; Carbon Emissions	Production and Transportation	Extension of basic EOQ model to incorporate the two carbon policies	Extend EOQ model
		Fareeduddin et al (2017)	–	✓	✓	✓	✓	Carbon emissions,	Transportation, Technology Selection	Robust optimization is used to handle uncertainties while optimizing the SC	RO model

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Table 5: Table of Literature for infinite planning horizon

Period	Stage	Authors	Demand		Carbon Policy			Decision Variable	Source of Emission	Problem Description	Solution Approach
			Deterministic	Stochastic	CT	SCC	CCT				
Infinite Planning Horizon	a) Single	Bonney and Jaber (2011)	✓	–	✓	–	–	Order quantity	Transportation	Extend EOQ models to include environmental cost	Extend EOQ model
		Hua et al. (2011)	✓	–	–	–	✓	Order quantity, carbon trading quantity	Inventory, transportation	Examines how operational adjustments can handle both economic and environmental concerns	Extend EOQ model
		Bouchery et al. (2012)	✓	–	✓	–	✓	Order quantity	Inventory, ordering	Include sustainability criteria into inventory model	Multi-objective formulation of EOQ
		Chen et al. (2013)	✓	–	✓	✓	✓	Order quantity	Inventory, purchasing	Develop EOQ like models under different carbon policies	Extend EOQ model
		Toptal et al. (2013)	✓	–	✓	–	✓	Order quantity, investment for carbon emission reduction; traded quantity	Procurement, ordering and holding	Developed three EOQ like models for different carbon policies considering emission reduction investment	Extend EOQ model
	b) Multi	Wahab et al. (2011)	✓	–	✓	–	–	Shipping quantity, vendor-buyer coordination multiplier	Transportation	Develop a national and international supply chains with defective items and return policy	Extend EOQ model
		*Bouchery et al. (2012)	✓	–	✓	–	✓	Order quantity, warehouse-retailer coordination multiplier	Inventory, Ordering	Include sustainability criteria into inventory model	Multi-objective formulation of EOQ
		Jaber et al. (2013)	✓	–	✓	–	–	Production rate, vendor-buyer coordination multiplier	Production	A two-level supply chain model with a coordination mechanism is developed while accounting for greenhouse gas emissions	EPQ
		Fareeduddin et al. (2015)	✓	–	✓	✓	✓	Order Quantity	Transportation	Develop an optimizational model incorporating all carbon policies	Comparison of all the three policies.

V. Conclusion

In this paper, a literature survey pertinent to the carbon policies in a multi-echelon production-distribution in a supply chain has been considered from a vast number of publications in various journals, scientific and conference proceedings. Nearly 37 out of 174 journal publications between the years 2000 and 2017 have been reviewed and validated to find the future opportunities of research for integrating carbon policies in a multi-echelon supply chain.

The various planning horizons are identified, and carbon policies in each horizon have been described in detail. It has been observed that publications on green supply chain have been gradually growing but integrating carbon policies has been of high interest since 2013. The review has traced the evolution of the carbon policies in a supply chain while giving a comprehensive study of the production-distribution problem over the years. Here, content analysis has been used to study the literature. The review shows that researchers are focusing on devising models and proposing various approaches of improving the economic profitability while incorporating one or more carbon policies. Therefore, the challenge is to design an economically stable and environmentally beneficial supply chain. Finally, a few future directions of research on carbon policies in a multi-echelon supply chain have been given.

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