Demand Management for Sustainable Supply Chain Operations

Niels Agatz, Moritz Fleischmann

December 2022

1 Introduction

Supply chain management (SCM) is about fulfilling demand. Based on given estimates of future demand, SCM invests the appropriate resources and then uses these resources to match supply to demand. The traditional SCM perspective takes demand as exogenous. The goal of SCM is then to serve the forecasted or materialized demand effectively and efficiently. How difficult it is to achieve this goal depends on the characteristics of that demand. For example, serving a stable, predictable demand is relatively cheap whereas serving an unpredictable, strongly fluctuating demand may imply less efficient operations characterized by high inventory built-up and low capacity utilization.

In the same way, demand characteristics impact not only the financial performance of the supply process but also its environmental impact. For example, satisfying demand for fresh produce during the harvesting season results in lower emissions than serving off-season demand which requires substantial storage and/or long-distance shipments from other growing regions.

Supply chain planning tasks commonly take demand as a given. For example, most of the models presented in this book treat demand as an exogenous parameter. However, demand itself is shaped by long- and short-term decisions on, for example, assortments and prices, but also lead times and service quality. These demand management decisions interact with supply (chain) management decisions in an iterative fashion, as visualized in Figure 1. For example, long-term assortment decisions drive demand expectations. Corresponding forecasts then serve as input for long-term production capacity decisions but also for short-term production and inventory planning. For a given available supply, short-term demand management, such as dynamic pricing, may seek to maximize revenues by exploiting differences in valuations between customers and over time. Such short-term demand management for fixed supply is at the heart of revenue management (Klein et al., 2020), with prominent applications in the airline, car rental and hospitality industries. For corresponding approaches in a production setting, see Quante et al. (2009).

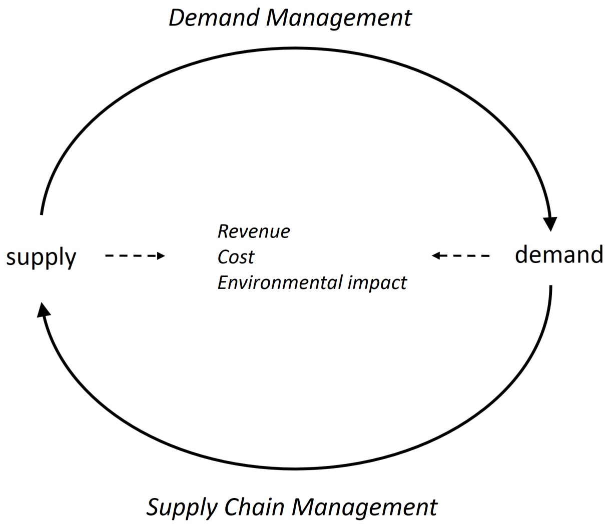

Figure 1: Interaction between supply chain management and demand management.

The most common objective of demand management is revenue. However, as sketched above, the resulting demand patterns may also impact the cost of the corresponding supply operations. Managing these interactions to achieve alignment is at the heart of a firm's sales and operations planning (S&OP) processes. On the operations side, the focus of S&OP is often on production processes. More recently, the interaction with short-term demand management, akin to traditional revenue management, has also been addressed for delivery operations, especially in online retailing (Waßmuth et al., 2022).

In addition to revenues and costs, demand management also has the potential to impact a firm's environmental performance in the broadest sense, i.e., emissions, waste, and material and energy consumption. While the idea as such is not new, real-life applications of sustainability-oriented demand management are only starting to emerge. Several factors drive this development. First, growing consumer concerns, pressure from both NGOs and investors (requesting reporting of ESG criteria), and expanding legislation (such as the recent German Supply Chain Due Diligence Act and the planned EU Corporate Sustainability Due Diligence Directive) put more weight on corporate social responsibility (CSR) in general, including firms' environmental performance. Second, companies that underestimate the impact of their demand management decisions on their operations are struggling. For example, the competition among online retailers for ever shorter delivery times leaves many delivery services unprofitable, thereby repeatedly forcing some of them to close their doors. Third, new information and communication technology makes it easier to track and predict customer behavior and to respond by changing prices and service offerings in real-time.

One example of using demand management to encourage more sustainable behavior is the use of 'green labels' in grocery home delivery to steer customers toward sustainable delivery options (Agatz et al., 2021). Another example is the Amazon Day Delivery service, which allows for the consolidation of packages on the last mile to the customer's home. In addition to the transport and service dimensions, product assortment decisions also drive demand and impact the environmental sustainability of operations. The decision of French grocery retailer Carrefour to stop selling strawberries in the off-season winter period (Carrefour, 2021) exemplifies this type of demand management.

Most of the current supply chain literature models demand as an exogenous factor. This also holds true for sustainable supply chain management, as addressed in the preceding chapters of this book. In this chapter, we complement this perspective and discuss opportunities for endogenizing demand. We proceed as follows. In Section 2, we discuss the impact of relevant demand characteristics on a firm's environmental performance. In Section 3, we first introduce common demand management levers and then review examples of how they have been applied to manage environmental objectives. Section 4 synthesizes our main observations and discusses potential avenues for future research.

2 Environmental Impact of Customer Demand

In this section, we highlight different ways in which customer demand impacts a firm's environmental performance. The discussion serves as a basis for investigating opportunities for sustainability-oriented demand *management* in Section 3.

In principle, the motivation for all of a firm's processes is to meet demand. Therefore, demand ultimately drives a firm's entire environmental performance. Dependent on the firm's position in the supply chain, this demand comes from final users (B2C) or from intermediaries (B2B). For a discussion of coordination issues arising from the interdependence of demand at different supply chain stages we refer to Mentzer et al. (2007). To structure our assessment, we follow the steps of the classical SCOR model, - i.e., source, make, deliver, and return - and discuss them separately. We include demand for both physical products and services, e.g., home delivery, and comment on the differences between both cases where needed.

Note that while, for ease of exposition, we discuss environmental impact by process, the individual effects may interact. For example, switching suppliers may reduce shipping distances in sourcing but lead to higher emissions in production, due to inferior product quality. Effects may also interact across geographical regions and across different players in the supply chain. For example, switching from home-delivery to click-and-collect in online retailing reduces the retailer's transport emissions but likely increases those of the consumer. Furthermore, environmental impact by itself is fundamentally multidimensional. Reducing the impact on one dimension can lead to negative effects in other dimensions. To identify the environmentally most favorable solution, demand management must take these inter- and intrafirm dependencies into account, as in a life cycle assessment (LCA) (see Chapter XXX). In addition, demand management, as with any sustainability instrument, also must consider the interactions between economic, environmental, and social performance. We return to this issue in Section 3.

In what follows, we discuss the potential impact of different demand attributes on the environmental performance of a firm's source, make, deliver, and return processes. Table 1 summarizes our main observations. We start by highlighting two generic effects that apply to all process steps.

The first generic relationship is between demand *volume* and environmental performance. Since any supply chain activity entails a certain environmental impact there is no truly 'green' product: more demand inevitably means a higher impact (Zink and Geyer, 2016) even though economies of scale might reduce the impact *per unit* of demand. Environmentally-oriented demand management thus faces a fundamental inherent trade-off that makes the question of the 'right' demand volume an intricate one. Note that in traditional supply chain models this issue does not typically appear since those models take demand as exogenous. Demand management, however, endogenizes demand, and thus the question of an appropriate target demand volume arises naturally. Its answer does not reside within the domain of supply chain management, however, but rather touches upon a more fundamental economic and ecological debate related to degrowth (Kallis et al., 2018) and the planetary boundaries (Steffen et al., 2015), which is beyond our scope. We highlight the issue here and refer to the literature on rebound effects as a helpful source of inspiration from a supply chain perspective (Zink and Geyer, 2017).

The second generic effect concerns product substitution. Demand management may affect a firm's environmental performance by shifting demand from one product variant to another. The argument as such applies to all supply processes. Relevant differences between products are process specific. We provide examples of the different supply processes in the discussion below.

2.1 Source

We highlight three sources of environmental impact, associated with a firm's sourcing processes: (i) transportation, (ii) storage of input materials and components, and (iii) suppliers' operations. The main physical processes on the supply side of the firm are inbound shipments and storage. That is, it is the emissions and resource consumption of these processes that matter. Among these, the impact of transportation processes, i.e., emissions and energy consumption for shipping items to the firm are dominant, in general. This holds true especially in the case of global sourcing, with items being shipped over large distances. Energy consumption for storage matters especially for items requiring special conditions, such as refrigerated items. For a detailed discussion of the environmental impact of general transportation and storage processes we refer to Chapters XXX and XXX of this book, respectively. Additional environmental impacts arise further upstream in the value chain, from the source, make, and deliver processes of the firm's suppliers (WBCSD, 2004). For a discussion of managerial issues arising from the supplier interaction see Chapter XXX.

The aforementioned environmental impacts interact with demand in manifold ways. However, due to the upstream position of the sourcing processes, the demand influence is more indirect in many cases than, for example, for distribution (see Section 2.3 below). In addition to driving *how much to source* (see the introductory discussion to Section 2), demand affects the environmental performance of the sourcing processes by influencing:

- *What to source*: Alternative available components may differ in their environmental footprint in manifold ways, including their material composition, durability, and underlying production process. Whether demand drives the firm's choice among these alternatives depends on whether the customer is aware of the differences.
- *From whom to source*: The argument is very similar to the previous one, but concerns differences in environmental performance between alternative suppliers.
- *From where to source*: Global versus local sourcing has a strong impact on transportation-related environmental performance. Again, transparency toward the customer is a prerequisite for steering demand toward the more sustainable alternative. It is worth noting that the available sourcing options may be time dependent, e.g., for fresh produce. Therefore, shifting demand over time may also be a way to manage sustainability in sourcing - offering strawberries in summer versus in winter.
- *Mode of transport*: The promised delivery lead time toward the customer may influence the mode of transport of inbound shipments, invoking a trade-off between speed and sustainability. However, the argument holds true only for order-specific sourcing, as in make-to-order production, since the sourcing lead time is otherwise sunk.

2.2 Make

The environmental impact of a firm's make processes, i.e., production processes in a broad sense, include (i) process emissions, (ii) material consumption, and (iii) energy consumption. They require little explanation. In addition, the 'make' stage also includes transportation and storage between production steps. The assessment of these logistics processes is very similar to the corresponding sourcing processes discussed above; thus, we do not address them separately. Naturally, which of the mentioned impacts is most relevant is highly product specific.

For a discussion of how to manage these 'make´-related environmental impacts through technology choice, we refer to Chapter XXX. Hereunder we discuss again their dependence on selected demand attributes.

Like for the 'source' processes, demand directly drives environmental impact through the decision of *how much to make*. Note that in a make-to-stock (MTS) setting, it is not only the expected demand but also the degree of demand uncertainty that is relevant to safety buffers. Other relevant demand derivatives include the following:

- *What to make*: Different product variants may differ in the environmental impact of their production. This includes, e.g., new products versus remanufactured products, but also large versus small product variants. Demand management may stimulate substitution effects between these product variants. Similarly, product specifications may also be a relevant factor. Again, demand management may aim to push more favorable specifications, e.g., by avoiding production waste. More generally, a broader assortment tends to have a higher environmental impact, due to missing economies of scale and lack of demand pooling. Demand management may thus improve environmental performance by concentrating demand on fewer product variants.

- *How to make*: There may be multiple options for making a given product, which differ in their environmental impact. For example, different ways of catching tuna fish differ in how they affect other sea-life; cleaning of production equipment may use biodegradable or toxic solutions; energy can be generated from renewable or fossil resources. Demand management may favor more sustainable production process options, provided they can be communicated effectively and credibly to customers.

- *When to make*: The timing of production also influences sustainability. Preproduction for seasonal peaks that exceed capacity results in inventory, i.e. items being stored and potentially heated or cooled. Appropriate sequencing of the items produced on a shared production line may reduce the need for cleaning, and thereby water consumption and/or the use of hazardous chemicals. Production timing may also synchronize the production process with the availability of renewable energy (Materi et al., 2020). In all of these cases, demand management may seek to shift demand to the most environmentally favorable time.

2.3 Deliver

Akin to sourcing, a firm's main physical processes associated with delivery include (i) transportation and (ii) storage, with particularly intense transportation operations arising for online delivery services. Another relevant factor is (iii) the scrapping of obsolete items. Concerning the environmental impact of transportation and storage, the discussion in Section 2.1 applies analogously. In the case of scrapping, obsolescence implies wasted resources, including material and energy, as well as wasted production and transportation emissions but also, potentially, additional emissions from waste processing and from accelerating new production.

Like for the preceding processes, demand drives the scale of the delivery-related environmental impacts by affecting *how much to deliver*. More interestingly, demand influences the environmental footprint of a firm's deliver processes through the decisions discussed below. While some of the effects are analogous to those for a firm‘s ‘source’ and ‘make’ processes, differences arise from the fact that ‘deliver‘ is a pure service process whereas the output of the ‘source’ and ‘make’ processes are often storable.

- *What to deliver*: Demand substitution between products may help reduce obsolescence. For perishable products, shifting demand toward items that are approaching their expiration date may avoid having to scrap them.
- *How to deliver*: This includes the choice between transportation modes, e.g., cargo bikes versus vans in home-delivery services, but also, between distribution channels, such as home-delivery versus pickup versus a traditional store. These choices largely shape the delivery-related transport operations and thus the associated environmental impact. They also impact the required amount of packaging material. More fundamentally, how to deliver also includes the strategic choice of the firm’s business model, notably the choice between leasing and selling. From an environmental perspective, this choice fundamentally impacts opportunities for used product recovery and thus the ‘return’ processes discussed below.
- *When to deliver*: Relevant aspects include the timing of delivery within the week and within the day, as well as the delivery lead time. The former may have a strong impact on routing efficiency by allowing or prohibiting joint delivery to geographically close destinations. This is a particularly relevant issue in attended home delivery where narrow time windows are common. Similarly, the delivery lead time also determines the potential for consolidating shipments, e.g. for same-day delivery services. In addition, the delivery timing also influences the need for storage, as discussed for the ‘make’ processes in Section 2.2.

2.4 Return

‘Return’ refers to the collection, handling, and processing of products from a customer, either before or after their use. Examples are commercial returns of unwanted items, e.g. in online retailing, and the recycling or remanufacturing of used items. For an in-depth discussion of such ‘product recovery’ strategies we refer to Chapter XXX.

The potential environmental impacts of return processes include (i) transportation, (ii) emissions from recovery operations, and (iii) material and/or energy recovery. Transportation processes arise in the collection of items from the customer. Analogous to the ‘last mile’ in distribution, it is the ‘first mile’ in the return channel that is the most transportation intense. In addition to the direct transportation-related impact, returns may also involve additional packaging material, see also chapter XXX. Recovery operations are a special case of a ‘make’ process, such that the discussion of Section 2.2 applies. The impact of material and energy recovery is different from those discussed in the preceding sections in that they represent a potential environmental benefit, rather than a burden, as a replacement for some new production. However, for judging the overall environmental performance it is crucial to carefully assess the extent of replacement versus market expansion (Zink and Geyer, 2017).

Another difference from the preceding sections is with regard to the role of the customer. Due to the ‘reverse’ direction of the corresponding supply chain flows, the customer is situated on the supply side of the return process. Thus, steering customer behavior boils down to ‘supply management’ (denoted as product acquisition management in the literature (Guide et al., 2003)) rather than ‘demand management’. Alternatively, one may interpret supply from the customer as negative demand. We include this setting in our discussion because of the conceptual analogy and the similarity of the relevant approaches. The aspects through which supply management can influence environmental performance of return processes include the following:

- *How much to return*: This refers to the customer’s choice between returning an item, - i.e., making it available for recovery - and disposing or storing it. Ensuring a sufficient supply of used items of appropriate quality is a serious bottleneck in many product recovery systems (Guide and Van Wassenhove, 2009).

- *What to return*: The required recovery operations, and, thus, the associated environmental impact, may depend on the quality of the returned product. For example, worn-out products require more extensive remanufacturing steps than lightly used products. Supply management may seek to shape the quality mix of the available supply, e.g., by influencing how the customer is using the product.

- *When to return*: Related to the previous point, the timing of returning a product also influences the available recovery options, either due to shifts in demand or to progressing product deterioration during usage. For example, used consumer electronics may partially substitute for new products in the market sufficiently early in the product life-cycle, whereas they have to be recycled at a later stage, due to a lack of demand.

3 Sustainability-oriented Demand Management

3.1 Demand Management Levers

Demand management encompasses a wide range of decisions. In line with Waßmuth et al. (2022) and Agatz et al. (2013), we map these along two dimensions, (i) the demand management lever and (ii) the hierarchical planning level. We distinguish three main levers: (i) offering, (ii) pricing, and (iii) communication. The first two of these, offering and pricing, capture the main characteristics of the product or service by specifying the offered product variants and the associated prices. In the context of sustainable behavior, we

Process	*Demand dimension*	*Potential impact*
Generic	How much?	(Potentially non-linear) scaling of all environmental impacts
Source	Inbound transport, storage, supplier operations	
	What?	Component substitution: Durability, composition, production processes
	From whom?	Alternative suppliers: Supplier performance
	From where?	Local versus global: Transportation
	Mode of transport?	Lead time: Speed vs. sustainability
Make	Process emissions, material consumption, energy consumption	
	What?	Product substitution: Large/small, new/remanufactured
	How?	Production process choice: Cost vs. sustainability
	When?	Production scheduling: Inventory build-up, cleaning
Deliver	Outbound transport, storage, scrapping	
	What?	Product substitution: Product substitution: Expiration
	How?	Mode of transport, channel choice, business model: Transport emissions, used product recovery
	When?	Delivery timing, lead time: Transport consolidation / bundling
Return	Return transport, recycl./reman. operations, energy / material recovery	
	What?	Core quality: Reprocessing intensity
	When?	Acquisition timing: Product wear, demand potential

Table 1: Environmental impact of selected demand dimensions by process step

identify a third dimension which is related to communication. This refers to the information provided to customers on the environmental performance of products or services.

As is common in many areas of supply chain planning, we can also distinguish between different planning levels, notably long-term strategic, medium-term tactical, and short-term operational demand management. Furthermore, the customer order decoupling point influences the way demand management interacts with supply chain management decisions (compare Figure 1). For example, in a make-to-stock setting, emissions from production processes are sunk when customer orders materialize. Thus, short-term, customer-specific demand management only affects the environmental impact of delivery (and potentially return) processes; and production performance can only be managed through forecast-based tactical demand management. In contrast, in a make-to-order setting, short-term demand management can steer the environmental impact of an individual order at the production stage and potentially even at the sourcing stage. In what follows, we elaborate further on the different demand management levers. Table 2 summarizes the resulting distinct settings.

Offering refers to both the long-term design of the product and service assortment and to the short-term management of their availability. The assortment decision involves trade-offs between revenues, costs, and sustainability aspects. As in traditional assortment planning, these problems are challenging as they involve modeling customer behavior while taking into account different practical constraints and business rules. This includes, for example, modeling different preferences and customer flexibilities with respect to the speed of delivery. Our context adds an additional layer of complexity related to evaluating the environmental impact of different assortment offerings and substitution behavior between products and firms.

Naturally, companies can also influence demand through their *pricing* decisions. We use 'pricing' to denote a wide range of incentives for steering customer choice behavior. Pricing can be used to manage demand to better match supply. As such it is complementary to supply chain efforts focusing on improving the flexibility to handle demand seasonalities and shocks. Often, pricing is used as a tool to exploit differences in product valuations between customers and across time to maximize revenues from a given supply (comp. Gallego et al. (2019)). However, pricing can also be used as a tool to improve the environmental performance, e.g., reduce waste or emissions.

Finally, companies can manage demand by means of *communication*. There is a large body of empirical research on encouraging pro-environmental behavior through the use of eco-feedback on resource consumption. Research suggests that feedback on costs and environmental impacts can reduce the energy and water consumption of households (Abrahamse et al., 2005). A popular form of eco-feedback in the context of energy consumption is to report the associated carbon emissions or the number of trees required to offset these emissions (Sanguinetti et al., 2018).

	Offering	*Pricing*	*Communication*
Strategic/tactical	What (green) products and services to offer?	How to price the offered options?	How to communicate the offering?
Operational	How to dynamically adjust the offering?	How to dynamically update prices?	How to dynamically adjust communication?

Table 2: Demand management approaches by lever and planning horizon

3.2 Models for Sustainability-Oriented Demand Management

In this subsection, we highlight models from the Operations Research (OR) and Operations Management literature that support sustainability-oriented demand management. We also point out potential trade-offs between different performance metrics, notably between profit and environmental performance. We structure the discussion again along the steps of the SCOR model, analogous to Section 2. Contributions to this stream of literature are few and far between. In addition, they are distributed very unevenly over the SCOR elements, with a dominant focus on delivery. Table 3 lists the corresponding papers that we have been able to identify.

Source

We are aware of a single demand management model geared towards the environmental performance of a source process. Hovelaque and Bironneau (2015) consider pricing as a means for steering demand so as to manage carbon emissions of a generic batch supply process. Emissions have an EOQ-type structure, consisting of a fixed amount per replenishment and a batchsize-dependent amount. Reflecting environmentally-conscious customers, demand decreases in total emissions, in addition to price. Assuming EOQ-type costs, the paper points out a tension between profit and emissions. In fact, minimizing emissions would force demand to zero. This reflects the general demand–volume issue, sketched in Section 2. In response to this issue, the paper assigns the task of controlling emissions to a policy-maker, rather than to the firm and investigates the impact of different policy instruments on the emissions ensuing from the firm's profit-maximizing price.

We are not currently aware of available optimization models for demand management addressing any of the other environmental impacts discussed in Section 2.1.

Make

There is a growing interest in the carbon footprint labeling of products. Evidence suggests that credible labels can potentially change customer purchase behavior and steer customers away from certain polluting products. However, the overall potential reduction in carbon emissions due to product labeling is still unclear due to complex feedback and rebound effects in demand and supply (Cohen and Vandenbergh, 2012). Customers, for example, may increase their consumption of more environmentally-friendly products, thereby partially offsetting the corresponding carbon reductions.

An emerging stream of research focuses on studying the behavioral responses to carbon labels, focusing on food products, restaurant menus, air travel and detergents. From a modeling perspective, several papers have considered product portfolio decisions for manufacturers that intend to add green products to their product line. Yenipazarli and Vakharia (2015) address pricing decisions for a manufacturer expanding her product line with a green offering. The paper explores the conditions under which a firm can use

	Offering	*Pricing*	*Communication*
Source		Emissions from batch supply (Hovelaque and Bironneau, 2015)	
Make		Pricing of green portfolio (Yenipazarli and Vakharia, 2015; Hong et al., 2018; Ovchinnikov et al., 2014) Pricing of renewable energy (Dutta and Mitra, 2017)	Carbon footprint product labels (Cohen and Vandenbergh, 2012)
Deliver	Time-slot management for routing emissions (Manerba et al., 2018)	Subscription pricing for routing emissions and food waste (Belavina et al., 2017) Pricing for reduced food waste (den Boer et al., 2022; Sanders, 2022; Yang et al., 2022)	Green time-slot labels (Agatz et al., 2021) Green labels for intermodal transport (Heinold et al., 2022)
Return		Used product acquisition pricing (Guide et al., 2003)	Advertising to stimulate used product returns (Hong et al., 2015)

Table 3: Published optimization models for sustainability-oriented demand management

pricing to limit the impact of the cannibalization of green products on existing products. Hong et al. (2018) consider the pricing strategies of a green product based on consumer environmental awareness and reference behavior. The results suggest that the optimal price of the green product is not always higher than that of the regular product. The green manufacturer should adopt a pricing strategy based on the quality of the green product and on consumers' levels of reference recognition and environmental awareness.

In a similar vein, there is a substantial body of work that addresses the decision for (original equipment) manufacturers to offer remanufactured products alongside new ones, taking into account cannibalization, competition, market expansion and the number of available used products (Rizova et al., 2020). Several papers in this line of research address pricing and market segmentation (Debo et al., 2005; Abbey et al., 2015b,a), primarily to maximize profits. Ovchinnikov et al. (2014) specifically focus on the tension between profit maximization and environmental performance in remanufacturing and provide a modeling framework to analyze when these two goals align. Their findings suggest that remanufacturing frequently aligns firms' economic and environmental performance by increasing profits and decreasing the total environmental impact.

Renewable energy is an example involving significant supply constraints. Specifically, supply is often unpredictable and volatile. In this setting, pricing can be used to temporally shift demand for electricity to better match supply (Dutta and Mitra, 2017). A better balance between demand and supply can help reduce wasting renewable energy in peak supply periods and reducing conventional energy resources in peak demand periods. In the context of industrial make processes, we see the advent of demand response initiatives in which production systems automatically vary their electricity demand over time based on the availability of supply, e.g., by interrupting noncritical processes or by shifting time-flexible processes (Shoreh et al., 2016).

The work in the 'make' stage primarily addresses questions on the strategic/tactical planning horizon. That is, most research focuses on decisions related to adding products to the product portfolio based on expected demand and market forecasts.

Deliver

Most work on sustainability-oriented demand management focuses on the 'deliver' processes. A prominent example is the offering of delivery options for attended home delivery. Several papers focus on the impact of time slot length on the expected route distances. The use of longer time windows for delivery is generally associated with fewer vehicle miles, as there is more flexibility in route planning (Lin and Mahmassani, 2002). Focusing specifically on the environmental impact, Manerba et al. (2018) show that longer delivery time windows can significantly reduce carbon emissions. A related, very active line of research is focusing on the real-time management and pricing of delivery time slots (Campbell and Savelsbergh, 2005, 2006; Yang et al., 2016; Vinsensius et al., 2020). This means dynamically deciding which time slots to offer at what price for a specific customer order, based on, e.g., the customer location, already accepted orders, and forecasts of future orders. The offered time slots may all have the same length or consist of a mix of different lengths (Köhler et al., 2020). Campbell and Savelsbergh (2005) show that dynamically integrating order capture and order delivery may significantly improve the profitability of grocery delivery operations. Campbell and Savelsbergh (2006) study the use of price incentives to influence consumer behavior in real-time to reduce delivery costs. They suggest that small incentives may suffice to change customer behavior in this context. Research in this area often focuses on profit maximization, taking into account differences in both revenues and travel distances. As is often the case for transportation operations, routing costs tend to be highly correlated with environmental objectives as fuel consumption and emissions are strongly dependent on driving distances. We are not aware of papers that explicitly study the trade-offs between environmental and economic objectives in this context.

In a similar setting, Yildiz and Savelsbergh (2020) focus on using discounts to persuade customers to allow for flexibility in the previously agreed time windows as this enhances opportunities for consolidating delivery orders that are geographically close.

The paper develops a dynamic programming algorithm to compute optimal discount offers to customers. Their numerical experiments show that offering discounts in return for delivery time flexibility can generate cost (distance) savings of more than 30% and that customized discounts lead to much better performance than offering the same discount to all customers.

In addition to price incentives, some researchers have investigated the use of communication as a lever for managing transport emissions of delivery operations. Based on a stated-preference survey, Ignat and Chankov (2020) conclude that communication can indeed be an effective means in this context. Nogueira et al. (2021) support this conclusion but show that customer willingness to sacrifice delivery speed for more sustainable delivery, i.e., fewer carbon emissions, differs per product category and customer type.

Agatz et al. (2021) study the use of green labels that specify time slots as environmentally friendly in an e-grocery home delivery setting. They specifically compare the use of green labels that intrinsically motivate customers to choose a specific delivery time slot to price incentives based on extrinsic motivation. Their experimental findings suggest that green labels are effective in steering customer choice behavior in different environments and work in fundamentally different ways than price incentives. In addition, simulation findings suggest that green slots, compared to price incentives or no incentives, offer providers a way to effectively steer consumer time slot choices to yield shorter routes, fewer delivery vehicles used, and more per-customer revenue. One challenge with eco-labels is that the message should be simple and credible, which is difficult to achieve here, given the complex and multidimensional nature of the environmental impact.

Finally, it is worth mentioning subscription models (Bray et al., 2021) and proactive customer contacting (Schwamberger et al., 2022) as recent demand management approaches for home-delivery services. Belavina et al. (2017) study the environmental impact of a subscription model in which customers pay a fixed fee to receive free grocery deliveries over a given period. They find that subscription incentivizes smaller and more frequent grocery orders, which increases delivery-related emissions but may reduce food waste on the customer side. Agrawal et al. (2012) address a related issue outside of the field of delivery services by comparing the environmental performance of leasing versus selling. We are not aware of any approach that explicitly considers environmental performance of proactive customer contacting initiatives.

Apart from last-mile operations in e-commerce, carbon or climate labels have also been investigated in other retail settings as a means to provide information on the environmental impact of offered products.

In addition to the labeling of products, we also see the advent of labels for logistics services. Kirschstein et al. (2022) propose an eco-labeling system that communicates emissions rate categories for different types of freight transportation. Heinold et al. (2022) consider the operational planning of an intermodal transport network that lets customers select eco-performance requirements. This gives rise to dynamically arriving shipment orders with different eco-labels. They model the problem as a multiobjective sequential decision process taking into account expected costs and eco-label violations.

Another delivery-related topic in retailing that has received significant attention in the context of environmentally-oriented demand management is centered on food waste. For perishable food items, retailers may use discounts to encourage customers to buy products that are close to their expiration date. This can help prevent food waste while also enhancing revenues. Most academic papers on the dynamic pricing of perishable items specifically focus on maximizing profitability; see e.g., Chatwin (2000); Lu et al. (2018); Azadi et al. (2019). However, the goals of reducing waste and increasing revenues tend to be well aligned, as selling at a discount generally leads to more revenues than scrapping a product.

A recent study suggests that simple dynamic pricing policies can help to simultaneously reduce waste and increase profit (den Boer et al., 2022). In another recent paper, Sanders (2022) show that dynamic pricing is likely to be more effective in reducing retail food waste than an increase in disposal costs. Based on structural econometric analysis of sales, perishability, and marginal cost data from a grocery retailer's artisan bread category, the author estimates that the use of dynamic pricing would reduce the retailer's waste by 21% and increase the chain's gross margins by approximately 3%. In particular, dynamic pricing Pareto-dominates organic waste bans that prohibit retailers from disposing of waste in landfills and instead require an alternative means of disposal, such as composting. In a similar setting, Yang et al. (2022) focus on product quality and investigate the combination of price discounts and information disclosure. To this end, they consider three different pricing policies, namely, quality-independent pricing, quality-dependent pricing, and quality-dependent pricing with disclosure of quality information. Based on a simulation study, they find that combining dynamic pricing with information disclosure allows for a decrease in food waste while simultaneously increasing profits.

In the 'deliver' stage, most contributions focus on short-term operational decisions related to adjusting prices, labels and product offerings based on real-time demand. In this phase, it is specifically helpful to adapt future demand based on already materialized orders and updates on the expected future demand.

Return

Recall that for return operations, customers act as suppliers. Acquisition management denotes the active management of this supply source, as opposed to treating returns of used products as exogenous (Guide and Van Wassenhove, 2009). Many researchers have proposed optimized acquisition strategies (Wei et al., 2015). Most approaches use pricing as a lever to influence the quality, quantity, and timing of product returns (Guide et al., 2003). Hong et al. (2015) alternatively investigate the use of advertising as a way to steer product returns. For both levers, particular complexities arise from the need to align used-product acquisition and the remarketing of recovered products. To the best of our knowledge, all currently available acquisition models take a profit-maximizing perspective. Whether this objective is aligned with environmental performance is far from obvious, given manifold interactions between forward and reverse channels, new and recovered products, and different environmental impacts. The work in this space focuses on both operational acquisition control and strategic and tactical return strategies.

4 Conclusions

While traditional supply chain planning treats demand as exogenous, demand itself can be shaped by, for example, assortment and pricing decisions, but also by tailored communication. This type of demand management provides new levers for managing a firm's environmental performance since different demand patterns vary in how environmentally costly they are to serve.

Compared to sustainable supply (chain) management, sustainable demand management is still at a nascent stage. Following the categories of the SCOR framework, available studies focus primarily on the 'deliver' stage. However, even these contributions are few and far between, with a notable cluster on e-commerce last-mile transportation operations. Sustainable demand management approaches for other SCOR processes, namely source, make, and return, are even more scant. The predominant focus in demand management on deliver processes is intuitive, given that these are the most downstream, customer-facing processes. Shaping demand to facilitate more upstream processes further away from the customer is more difficult, due to diluting effects from the interaction with intermediate processes and supply chain actors. As we argue in this chapter, demand patterns nevertheless have a significant impact on the environmental cost also of upstream supply processes. In conclusion, we see manifold opportunities for relevant future research on environmentally-oriented demand management in supply chains.

The trade-offs underlying such types of demand management differ from those on the supply side. In particular, they crucially involve customer behavior which is not typically the case for supply planning. Moreover, the relationship between environmental and financial performance also changes. Most noteworthy, we observe a fundamental trade-off between both performance dimensions with respect to demand volume. Since any supply chain process has an environmental impact, the impact-minimizing demand management would be to eliminate demand - which obviously is not economically sustainable. How to systematically deal with this fundamental tension is largely an open question.

While one may argue that the same is true for costs – the cost-minimal solution is again zero demand – we have revenues as a counterweight in this case, which is missing in environmental performance. This asymmetry renders setting an appropriate objective for sustainable demand management nontrivial.

For some other demand attributes, economic and environmental performance go hand-in-hand. This is the case, for example, for temporal shifts in demand that allow for reducing inventories and for consolidating shipments to neighboring destinations, thereby reducing delivery mileage. Both of these effects can be observed, for example, in online retailing. In this case, companies may be facing another challenge, namely, being accused of greenwashing when emphasizing the environmental benefits of certain actions that are also financially beneficial.

To conclude, demand management complements supply (chain) management by providing an additional set of levers for managing the sustainability of a firm‘s operations. Both perspectives are important and must be aligned to make strides on the path toward sustainability. To date, sustainability-oriented demand management is much less developed, both in the academic literature and in practice, than its supply-side counterpart. In this chapter, we have attempted to outline the potential of this nascent field. We hope that our discussion will contribute to tapping this potential, to the benefit of a sustainable future.

References

J. D. Abbey, J. D. Blackburn, and V. D. R. Guide, Jr. Optimal pricing for new and remanufactured products. *Journal of Operations Management*, 36:130–146, 2015a.

J. D. Abbey, M. G. Meloy, V. D. R. Guide, Jr, and S. Atalay. Remanufactured products in closed-loop supply chains for consumer goods. *Production and Operations Management*, 24(3):488–503, 2015b.

W. Abrahamse, L. Steg, C. Vlek, and T. Rothengatter. A review of intervention studies aimed at household energy conservation. *Journal of Environmental Psychology*, 25(3): 273–291, 2005.

N. Agatz, A. M. Campbell, M. Fleischmann, J. Van Nunen, and M. Savelsbergh. Revenue management opportunities for internet retailers. *Journal of Revenue and Pricing Management*, 12(2):128–138, 2013.

N. Agatz, Y. Fan, and D. Stam. The impact of green labels on time slot choice and operational sustainability. *Production and Operations Management*, 30(7):2285–2303, 2021.

V. V. Agrawal, M. Ferguson, L. B. Toktay, and V. M. Thomas. Is leasing greener than selling? *Management Science*, 58(3):523–533, 2012.

Z. Azadi, S. D. Eksioglu, B. Eksioglu, and G. Palak. Stochastic optimization models for joint pricing and inventory replenishment of perishable products. *Computers & industrial engineering*, 127:625–642, 2019.

E. Belavina, K. Girotra, and A. Kabra. Online grocery retail: Revenue models and environmental impact. *Management Science*, 63(6):1781–1799, 2017.

J. Bray, M. D. S. Kanakaratne, M. Dragouni, and J. Douglas. Thinking inside the box: An empirical exploration of subscription retailing. *Journal of Retailing and Consumer Services*, 58:102333, 2021.

A. M. Campbell and M. Savelsbergh. Incentive schemes for attended home delivery services. *Transportation Science*, 40(3):327–341, 2006.

A. M. Campbell and M. W. Savelsbergh. Decision support for consumer direct grocery initiatives. *Transportation Science*, 39(3):313–327, 2005.

Carrefour. Carrefour suspends sales of strawberries until mid-february. `https://www.carrefour.com/en/actuality/fraisesjanvier`, 2021. [Online; accessed 2-8-2022].

R. E. Chatwin. Optimal dynamic pricing of perishable products with stochastic demand and a finite set of prices. *European Journal of Operational Research*, 125(1):149–174, 2000.

M. A. Cohen and M. P. Vandenbergh. The potential role of carbon labeling in a green economy. *Energy Economics*, 34:S53–S63, 2012.

L. G. Debo, L. B. Toktay, and L. N. Van Wassenhove. Market segmentation and product technology selection for remanufacturable products. *Management Science*, 51(8):1193–1205, 2005.

A. V. den Boer, H. M. Jansen, and J. Zhao. Waste reduction of perishable products through markdowns at expiry dates. *Available at SSRN*, 2022.

G. Dutta and K. Mitra. A literature review on dynamic pricing of electricity. *Journal of the Operational Research Society*, 68(10):1131–1145, 2017.

G. Gallego, H. Topaloglu, et al. *Revenue management and pricing analytics*, volume 209. Springer, 2019.

V. D. R. Guide, Jr and L. N. Van Wassenhove. Or forum—the evolution of closed-loop supply chain research. *Operations Research*, 57(1):10–18, 2009.

V. D. R. Guide, Jr, R. H. Teunter, and L. N. Van Wassenhove. Matching demand and supply to maximize profits from remanufacturing. *Manufacturing & Service Operations Management*, 5(4):303–316, 2003.

A. Heinold, F. Meisel, and M. W. Ulmer. Primal-dual value function approximation for stochastic dynamic intermodal transportation with eco-labels. *Transportation Science*, 2022.

X. Hong, L. Xu, P. Du, and W. Wang. Joint advertising, pricing and collection decisions in a closed-loop supply chain. *International Journal of Production Economics*, 167: 12–22, 2015.

Z. Hong, H. Wang, and Y. Yu. Green product pricing with non-green product reference. *Transportation Research Part E: Logistics and Transportation Review*, 115:1–15, 2018.

V. Hovelaque and L. Bironneau. The carbon-constrained eoq model with carbon emission dependent demand. *International Journal of Production Economics*, 164:285–291, 2015.

B. Ignat and S. Chankov. Do e-commerce customers change their preferred last-mile delivery based on its sustainability impact? *The International Journal of Logistics Management*, 2020.

G. Kallis, V. Kostakis, S. Lange, B. Muraca, S. Paulson, and M. Schmelzer. Research on degrowth. *Annual Review of Environment and Resources*, 43(1):291–316, 2018.

T. Kirschstein, A. Heinold, M. Behnke, F. Meisel, and C. Bierwirth. Eco-labeling of freight transport services: Design, evaluation, and research directions. *Journal of Industrial Ecology*, 2022.

R. Klein, S. Koch, C. Steinhardt, and A. K. Strauss. A review of revenue management: Recent generalizations and advances in industry applications. *European Journal of Operational Research*, 284(2):397–412, 2020.

C. Köhler, J. F. Ehmke, and A. M. Campbell. Flexible time window management for attended home deliveries. *Omega*, 91:102023, 2020.

I. I. Lin and H. S. Mahmassani. Can online grocers deliver?: Some logistics considerations. *Transportation Research Record*, 1817(1):17–24, 2002.

J. Lu, J. Zhang, and Q. Zhang. Dynamic pricing for perishable items with costly price adjustments. *Optimization Letters*, 12(2):347–365, 2018.

D. Manerba, R. Mansini, and R. Zanotti. Attended home delivery: reducing last-mile environmental impact by changing customer habits. *IFAC-PapersOnLine*, 51(5):55–60, 2018.

S. Materi, A. D'Angola, and P. Renna. A dynamic decision model for energy-efficient scheduling of manufacturing system with renewable energy supply. *Journal of Cleaner Production*, 270:122028, 2020.

J. T. Mentzer, M. A. Moon, D. Estampe, and G. Margolis. Demand management. *Handbook of global supply chain management*, pages 65–85, 2007.

G. P. M. Nogueira, J. J. de Assis Rangel, and E. Shimoda. Sustainable last-mile distribution in b2c e-commerce: Do consumers really care? *Cleaner and Responsible Consumption*, 3:100021, 2021.

A. Ovchinnikov, V. Blass, and G. Raz. Economic and environmental assessment of remanufacturing strategies for product+ service firms. *Production and Operations Management*, 23(5):744–761, 2014.

R. Quante, H. Meyr, and M. Fleischmann. Revenue management and demand fulfillment: matching applications, models and software. In *Supply Chain Planning*, pages 57–88. Springer, 2009.

M. I. Rizova, T. Wong, and W. Ijomah. A systematic review of decision-making in remanufacturing. *Computers & Industrial Engineering*, 147:106681, 2020.

R. E. Sanders. Dynamic pricing and organic waste bans: A study of grocery retailers' incentives to reduce food waste. *Available at SSRN 2994426*, 2022.

A. Sanguinetti, K. Dombrovski, and S. Sikand. Information, timing, and display: A design-behavior framework for improving the effectiveness of eco-feedback. *Energy Research & Social Science*, 39:55–68, 2018.

J. Schwamberger, M. Fleischmann, and A. Strauss. Feeding the nation—dynamic customer contacting for e-fulfillment in times of crisis. *Service Science*, 2022.

M. H. Shoreh, P. Siano, M. Shafie-khah, V. Loia, and J. P. Catalão. A survey of industrial applications of demand response. *Electric Power Systems Research*, 141:31–49, 2016.

W. Steffen, K. Richardson, J. Rockström, S. E. Cornell, I. Fetzer, E. M. Bennett, R. Biggs, S. R. Carpenter, W. De Vries, C. A. De Wit, et al. Planetary boundaries: Guiding human development on a changing planet. *science*, 347(6223):1259855, 2015.

A. Vinsensius, Y. Wang, E. P. Chew, and L. H. Lee. Dynamic incentive mechanism for delivery slot management in e-commerce attended home delivery. *Transportation Science*, 54(3):567–587, 2020.

K. Waßmuth, C. Köhler, N. Agatz, and M. Fleischmann. Demand management for attended home delivery–a literature review. *ERIM Report Series Reference Forthcoming*, 2022.

W. WBCSD. The greenhouse gas protocol. *A corporate accounting and reporting standard, Rev. ed. Washington, DC, Conches-Geneva*, 2004.

S. Wei, O. Tang, and E. Sundin. Core (product) acquisition management for remanufacturing: a review. *Journal of Remanufacturing*, 5(1):1–27, 2015.

C. Yang, Y. Feng, and A. Whinston. Dynamic pricing and information disclosure for fresh produce: An artificial intelligence approach. *Production and Operations Management*, 31(1):155–171, 2022.

X. Yang, A. K. Strauss, C. S. Currie, and R. Eglese. Choice-based demand management and vehicle routing in e-fulfillment. *Transportation Science*, 50(2):473–488, 2016.

A. Yenipazarli and A. Vakharia. Pricing, market coverage and capacity: Can green and brown products co-exist? *European Journal of Operational Research*, 242(1):304–315, 2015.

B. Yildiz and M. Savelsbergh. Pricing for delivery time flexibility. *Transportation Research Part B: Methodological*, 133:230–256, 2020.

T. Zink and R. Geyer. There is no such thing as a green product. *Stanford Social Innovation Review*, 14(2):26–31, 2016.

T. Zink and R. Geyer. Circular economy rebound. *Journal of Industrial Ecology*, 21(3): 593–602, 2017.