5. Sustainability strategies for consumer products in cities

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INTRODUCTION

The scholarly literature on urban sustainability, as well as policy and planning practice, has mostly dealt with cities as geographically bounded places. This research has emphasized how buildings, land-use patterns and transportation systems in cities contribute to energy consumption, GHG emissions, water use and other aspects of resource consumption, as well as how to integrate nature into the local urban fabric (Portney 2003; Wolch et al. 2004; Kellert et al. 2011; Brown et al. 2008; Wheeler and Beatley 2004; Beatley 2010; Cervero and Sullivan 2011).

As a result, strategies to promote sustainable communities are largely place-based, with the scale of such efforts ranging from single buildings, to urban districts, larger communities, cities or metropolitan regions. One example includes the widely used LEED certification programs for individual buildings and new communities, and efforts such as California's legislation (SB 375 or the Sustainable Communities and Climate Protection Act) that requires jurisdictions to craft land-use and transportation planning strategies to reduce GHG emissions.

Sustainably designed buildings, land-use patterns and transportation systems are clearly important, but so too is understanding the consumption impacts of urban dwellers. The larger material flows highlighted by ecological footprint analysis (Wackernagel et al. 2006) and urban metabolism studies (Kennedy et al. 2008) are frequently excluded from city-scale planning action. In particular, products and their consumption are often ignored, despite the enormous volume of materials and embodied energy used in their manufacture, distribution and disposal, and the geographically variable impacts of their supply chains.

Municipal solid waste (MSW) data – which exclude construction, demolition and nonhazardous industrial wastes – can be used to characterize urban consumption and product material flows. In 2010, 250 million tons of MSW were generated in the USA, 85 million tons of which were recovered through recycling or composting. Of the total waste generation, durable goods (products lasting three years or more) comprised 19.6 percent, non-durable goods (products lasting less than three years) comprised 21.3 percent, and containers and packaging comprised another 30.3 percent. These three categories together accounted for 71.2 percent of MSW (EPA 2011c), much of which can be categorized as consumer products together with their packaging. Food and yard waste accounted for the remaining waste fraction. Table 5.1 provides an estimate of the waste generation for each product category (durable, non-durable and containers/packaging) in the USA from 1960 to 2010 in pounds per capita. The contribution of each product category to the total generation in a given year is also presented as a percentage. This serves as a very rough picture of the average consumer product consumption (or metabolism) in cities. It assumes that consumer product purchasing is equal to the rate of product retirement.

In this chapter, we explore opportunities for improving urban sustainability through strategies focused on consumer products. Consumer products are defined as 'any article, or component part thereof, produced and distributed for sale to . . . or for the personal use, consumption or enjoyment of a consumer in or around a permanent or temporary household or residence, a school, in recreation, or otherwise' (Consumer Product Safety Commission 2011). Although food is outside the scope of this definition, it also serves as an illustrative example for select sustainability strategies.

We present several strategies for improving the sustainability of these products, using case examples to illustrate them. Along with highlighting the potential benefits inherent to each one, the chapter conveys the associated tradeoffs that can occur when assessing sustainability performance from a product life-cycle perspective. Some of the strategies presented here are in direct conflict with one another, and some are easy to implement but capable of lesser relative impact compared to those that are difficult to implement with much greater impact potential. The chapter does not serve as an endorsement of each strategy, much less all of them together, but rather as a presentation of the many opportunities available for making consumer products in cities sustainable, and the substantial benefits possible from doing so.

Impacts of products consumed in cities spread far beyond the city boundary, depending on the life cycle of the product. For example, a product's use, service, retirement and recovery phases may occur in the city, as well as impacts associated with these phases, while other phases of the product life cycle (i.e. raw material acquisition, processing, manufacturing, assembly and disposal) may happen in other parts of the country or even other parts of the world (Figure 5.1). Many examples occur where some manufacturing happens within city boundaries for larger industrialized cities, and landfills can also be cited as occurring within a city's boundary.

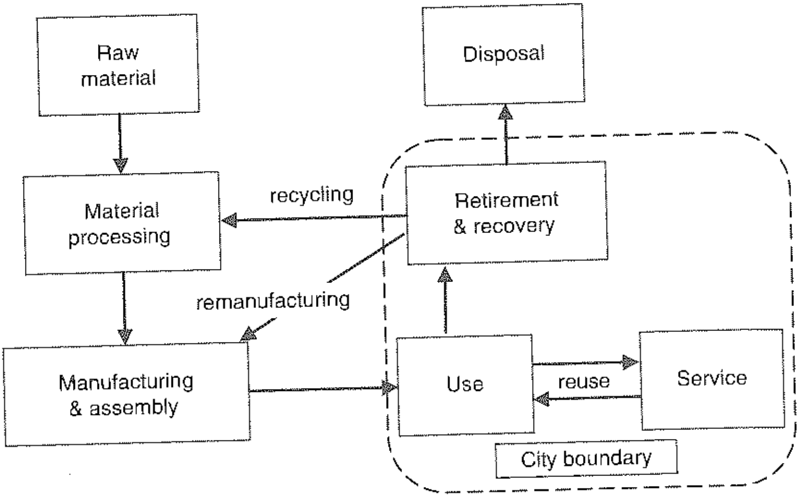
Table 5.1 MSW waste generation by product category

Products	Pounds per capita (Percentage)											
	1960		1970		1980		1990		2000		2010	
	%		%		%		%		%		%	
Durable goods	**110.6**	**11.3**	**144.3**	**12.1**	**192.5**	**14.4**	**239.7**	**14.3**	**276.1**	**16.0**	**317.9**	**19.6**
Appliances	18.2	1.8	21.4	1.8	26.0	1.9	30.3	1.8	33.3	1.9	36.3	2.2
Furnishings and Carpet	24.0	2.4	27.9	2.3	42.0	3.1	68.0	4.1	75.0	4.4	92.5	5.7
Rubber Tires	12.5	1.3	18.6	1.6	24.0	1.8	29.0	1.7	35.0	2.0	33.6	2.1
Batteries, Lead-Acid	*	*	8.1	0.7	13.2	1.0	12.1	0h	16.2	0.9	20.7	1.3
Miscellaneous Durables	56.0	5.7	68.4	5.7	87.2	6.5	100.3	6.0	116.6	6.8	134.8	8.3
Nondurable goods	**193.3**	**19.7**	**246.6**	**20.7**	**303.9**	**22.7**	**419.5**	**25.0**	**454.9**	**26.4**	**344.2**	**21.3**
Printed Media	100.7	10.2	117.9	9.9	127.5	9.5	143.5	8.6	134.6	7.8	80.7	5.0
(e.g. Newspaper, Magazines, Books)												
Office-Type Papers	17.0	1.7	26.1	2.2	35.3	2.6	51.5	3.1	52.7	3.1	34.1	2.1
Bulk Mail and Other Commercial Printing	14.1	1.4	21.0	1.8	27.5	2.1	66.6	4.0	92.0	5.3	44.2	2.7
Tissue Paper and Towels	12.2	1.2	20.5	1.7	20.3	1.5	23.8	1.4	22.9	1.3	22.6	1.4
Paper Plates and Cups	3.0	0.3	4.1	0.3	5.6	0.4	5.2	0.3	6.8	0.4	8.7	0.5
Other Nonpackaging Paper	30.1	3.1	35.7	3.0	37.3	2.8	30.9	1.8	30.2	1.8	27.1	1.7
Disposable Diapers	*	*	3.4	0.3	17.0	1.3	21.7	1.3	23.0	1.3	24.2	1.5
Clothing and Footwear	15.2	1.5	15.9	1.3	19.2	1.4	32.2	1.9	46.0	2.7	58.0	3.6
Other Miscellaneous Nondurables	1.1	0.1	2.0	0.2	14.1	1.1	44.1	2.6	46.7	2.7	44.6	2.8
Containers and Packaging	**305.3**	**31.1**	**428.7**	**36.0**	**465.0**	**34.7**	**518.9**	**31.0**	**539.0**	**31.3**	**490.0**	**30.3**
Glass Packaging	69.0	7.0	117.3	9.8	12.3	0.9	95.1	5.7	78.5	4.6	60.6	3.7
Beer and Soft Drink Bottles	*15.6*	*1.6*	*54.9*	*4.6*	*59.5*	*4.4*	*45.4*	*2.7*	*40.6*	*2.4*	*36.7*	*2.3*
Wine and Liquor Bottles	*12.0*	*1.2*	*18.7*	*1.6*	*21.6*	*1.6*	*16.3*	*1.0*	*13.6*	*0.8*	*11.0*	*0.7*
Other Bottles & Jars	*41.4*	*4.2*	*43.7*	*3.7*	*42.2*	*3.2*	*33.5*	*2.0*	*24.3*	*1.4*	*12.9*	*0.8*

Steel Packaging	52.0	5.3	52.9	4.4	31.9	2.4	23.2	1.4	20.4	1.2	17.7	1.1
Beer and Soft Drink Cans	7.1	0.7	15.5	1.3	4.6	0.3	1.2	0.1	*	*	*	*
Cans	41.9	4.3	34.8	2.9	25.2	1.9	20.4	1.2	18.7	1.1	14.9	0.9
Other Steel Packaging	2.9	0.3	2.7	0.2	2.1	0.2	1.6	0.1	1.7	0.1	2.9	0.2
Aluminum Packaging	1.9	0.2	5.6	0.5	11.2	0.8	15.3	0.9	13.9	0.8	12.3	0.8
Beer and Soft Drink Cans	*	*	1.0	0.1	7.5	0.6	12.5	0.7	10.8	0.6	8.9	0.5
Other Cans	*	*	0.6	0.0	0.4	0.0	0.2	0.0	0.4	0.0	0.5	0.0
Foil and Closures	1.9	0.2	4.0	0.3	3.4	0.3	2.7	0.2	2.7	0.2	3.0	0.2
Paper & Paperboard Packaging	157.4	16.0	210.6	17.7	232.6	17.4	262.8	15.7	283.8	16.5	244.1	15.1
Corrugated Boxes	81.8	8.3	125.6	10.5	150.8	11.3	193.1	11.5	214.7	12.5	188.2	11.6
Other Paper & Paperboard Packaging	75.6	7.7	85.0	7.1	81.8	6.1	69.7	4.2	441.4	25.6	55.9	3.5
Plastics Packaging	1.3	0.1	20.6	1.7	30.0	2.2	55.5	3.3	79.5	4.6	88.6	5.5
Plastic Bottles, Jars, and Containers	0.7	0.1	9.0	0.8	12.2	0.9	19.2	1.1	29.5	1.7	34.3	2.1
Bags, Sacks and Wraps	0.0	0.0	0.0	0.0	10.9	0.8	19.9	1.2	29.8	1.7	25.5	1.6
Other Plastics Packaging	0.7	0.1	11.6	1.0	7.0	0.5	16.4	1.0	20.2	1.2	28.8	1.8
Wood Packaging	22.3	2.3	20.4	1.7	34.8	2.6	65.8	3.9	61.2	3.5	64.4	4.0
Other Misc. Packaging	1.3	0.1	1.3	0.1	1.1	0.1	1.2	0.1	1.7	0.1	2.2	0.1
Total Product Wastes	**609.2**	**62.0**	**819.6**	**68.8**	**961.3**	**71.8**	**1178.2**	**70.3**	**1270.0**	**73.7**	**1152.1**	**71.2**
Other Wastes	**373.6**	**38.0**	**371.8**	**31.2**	**377.4**	**28.2**	**496.6**	**29.7**	**453.7**	**26.3**	**466.4**	**28.8**
Food Scraps	136.1	13.8	126.0	10.6	114.8	8.6	191.9	11.5	211.9	12.3	225.2	13.9
Yard Trimmings	223.1	22.7	228.3	19.2	242.8	18.1	281.5	16.8	217.0	12.6	216.4	13.4
Miscellaneous Inorganic Wastes	14.5	1.5	17.5	1.5	19.9	1.5	23.3	1.4	24.9	1.4	24.9	1.5
Total MSW Generated	***982.8***	***100***	***1191.5***	***100***	***1338.7***	***100***	***1674.8***	***100***	***1723.7***	***100***	***1618.5***	***100***

Note: * Data not estimated or assumed to be negligible.

Source: US EPA (2011c).



Source: Author.

Figure 5.1 Life cycle of a typical product consumed in cities

Therefore a holistic point of view is required to fully understand the impacts of consumer products and improvement strategies for cities.

Life-cycle assessment (LCA) is a comprehensive analytical tool to evaluate the full environmental impacts of a consumer product used in cities through various stages of its life cycle (ISO 2006). The major components of the LCA include: (1) goal and scope definition that establishes the objectives, audience and system boundaries of the study; (2) inventory analysis, which is a compilation of the inputs and outputs throughout the life cycle of the system; (3) impact assessment, which is a characterization of the magnitude and significance of the potential environmental impacts with respect to resource depletion and environmental and human health; and (4) interpretation, wherein the results of inventory analysis and impact assessment are combined to develop conclusions and recommendations.

The life-cycle inventory (LCI) is a fundamental phase of the LCA of consumer products and is compiled primarily using three methods: process-based; economic input–output; and the hybrid method. The process-based LCI quantifies energy/materials flows between unit processes from a 'bottom–up' perspective. Ideally, primary data for process-based LCI are collected from production facilities, or secondary data can be obtained from published studies and databases. Economic input–output LCI utilizes Leontief's (1986) economic input–output model to model the entire economy from a top–down perspective. Transactions between economic sectors are coupled with energy/materials flow data to compile LCI for a particular economic activity at industry level (Hendrickson et al. 1998). Government statistics are the primary source for economic input–output LCI. For the hybrid method, LCA practitioners often integrate the two methods to incorporate the best available data (Williams 2004). For consumer products, impacts occurring within the city (e.g. use, service) and close to the city (e.g. recycling, disposal) are relatively easy to measure using the process-based LCI, while economic input–output LCI may be more appropriate for examining impacts associated with upstream production processes if process-level data are not available.

Over the last three decades, LCA has developed rapidly and become a key tool for developing sustainability metrics and supporting sustainability-related research, policy making and practices in academia, government and industry (Keoleian and Spitzley 2006; Finnveden et al. 2009; Guinée et al. 2011). Recent development of spatially explicit LCA (Geyer et al. 2010a; 2010b; Newell and Vos 2012) and social LCA (Dreyer et al. 2006; Jorgensen et al. 2012) makes it possible, theoretically, to spatialize a consumer product's environmental and social impacts across its full life cycle. Finally, there is the life-cycle cost analysis of products – another measure of sustainability performance that accounts for the purchase, ownership and end-of-life management monetary costs and complements environmental and social indicators and metrics (Keoleian and Spitzley 2006).

CONSUMER PRODUCT SUSTAINABILITY STRATEGIES

A wide range of consumer-product-related strategies can be implemented for transforming the urban metabolism towards enhanced sustainability. These strategies foster environmental sustainability by reducing material and energy resource consumption throughout a product life-cycle system and also by limiting emissions and waste for production and consumption processes. These environmental and resource improvements can take place within or external to the city boundary in which the product is used. The strategies highlighted in this chapter were originally developed as part of a life-cycle design framework for integrating environmental objectives into product design (Keoleian and Menerey 1993; Keoleian and Menerey 1994; Keoleian et al. 1995). Similar strategies and principles for green design have also been formulated (Anastas and Zimmerman 2003; McDonough et al. 2003). Accordingly, we first present the role of product design in enhancing sustainability of cities. Subsequently, each sustainability strategy is presented along with specific case examples.

Fundamental Role of Product Design

Product design decisions affect the entire life-cycle environmental burden, and are thus a vital point of intervention in pursuing sustainability of consumer goods. Choosing and synthesizing sustainable design strategies to formulate successful products requires well-defined environmental goals and requirements, which must be balanced with other desired product features including functionality and aesthetics, cost and regulatory requirements.

Many of the strategies to improve the sustainability of products will be elaborated on in this chapter, and their efficacy hinges upon decisions made during product design and development. Product life extension can delay disposal and new consumption, and requires that designers target durability, adaptability, repairability, simplified maintenance or disassembly to enable remanufacture. Similarly, material life extension can reduce extraction of virgin materials, and requires that designers ensure the recyclability of products. Other design choices may include selecting sustainable materials, using fewer materials altogether, and improving the efficiency of processes and distribution. Decisions made during use and at the end of a product's life influence its life-cycle burden as well, but the range of options available at those stages is determined well in advance, at the point of product development (e.g. a consumer may wish to recycle a product at the point of retirement, but if it was not produced with recyclable materials, then this option is not available).

Examining the effect of product design on the full life cycle will ensure the fullest understanding of whether impacts are simply shifted from one phase to another (e.g. a less materially intensive product might reduce the extraction and distribution impacts, but it may also be less durable and therefore result in a greater waste burden), or are genuinely lessened. Nearly every design choice and sustainability strategy will entail some tradeoff, and only with an understanding of the product life cycle as well as consumer behavior and infrastructure for resource recovery can product developers identify opportunities to select the best approach for a given product.

Reducing Food Consumption and the Soda Ban in New York City

Industrialized production of food and rising incomes have combined to make food cheaper and, indirectly, promoted overconsumption. In 2000, per capita daily calorie availability reached an all-time high of 3900, while daily calorie consumption increased by an average of 300 over 1985 levels, with 23 percent of that increase coming from added sugars (Putnam et al. 2002). Predictably, over the past three decades, US obesity rates have risen alongside consumption (Smith et al. 2010). Added sugars are often consumed in the form of sugary drinks, namely sodas and juices, which numerous studies have linked to obesity (Drewnowski and Bellisle 2007; Smith et al. 2010; De Graaf 2011; Freudenberg et al. 2011). The soda ban is an example of city-scale planning action designed to reduce the impacts of consumption of a consumer product and therefore can be constructive in guiding similar efforts.

Through taxes and bans, municipal authorities have some leverage in influencing consumption within a city. A study by the Economic Research Service of the USDA found that soda taxes could reduce net calorie intake by 37 calories per day for adults and 43 for children, translating to 3.8 pounds and 4.5 pounds per year, respectively (Smith et al. 2010). Activists have disputed, however, whether such a tax would help the poor by making healthier choices more attractive, or whether it unfairly targets a consumer group already suffering from a lack of affordable food options. Seeking to support healthier consumption among its residents, the New York City Board of Health twice pursued a soda tax and was twice defeated due to lobbying from the soft-drinks industry (Freudenberg et al. 2011). Altering the approach, in September 2012 the New York City Board of Health approved a ban on the sale of sugary drinks over 16 ounces (Grynbaum 2012). The ban will be contested before it takes effect, and it has loopholes with respect to which establishments will be affected by it, but it represents a meaningful effort by a municipal government to reduce consumption.

Product Sharing

Joint ownership and product sharing is a potentially effective strategy for reducing consumption, although it is most applicable to expensive, durable goods that are used at irregular intervals (Mansvelt and Robbins 2011) and to which people do not become personally attached (Mont 2004a). The example of shared-use laundry facilities is provided here, which can be promoted in urban areas with high population density and a large proportion of multi-unit housing communities.

Communal laundry areas with shared use of machines can have a number of benefits, both to the environment and to the individuals involved. Among the benefits to individuals might be access to an item otherwise too expensive to afford (a high-quality washing machine, or a dryer) and relief from the burden of storing, maintaining and disposing of a bulky item. Benefits to the environment include a reduction in the overall number of items produced, and increased likelihood that more durable and efficient models will be employed (Mansvelt and Robbins 2011).

Higher intensity of use also means the washers and dryers will turn over more quickly and be replaced with still more efficient technologies as they are developed (Mont 2004b). As environmental performance increasingly contributes to competitiveness in the market, producers can also benefit from contracting with housing managers to maintain, upgrade and replace the machines, thereby regaining control over more life-cycle stages (Mont 2004b).

Also, sharing and renting equipment rather than buying less frequently used specialized equipment such as a power washer is an important strategy for better utilization of products.

Repair

Maintenance and repair of products can be an effective means of extending service lifetimes, thereby avoiding the environmental burdens associated with production and disposal (McCullough 2010). While the environmental tradeoffs of extending the useful lives of appliances that require substantial energy inputs during the use phase are described elsewhere in this chapter, for many products, repair remains an environmentally preferable alternative to replacement. Unfortunately, the service and repair sector for many goods has been declining in recent decades. Inexpensive overseas production has driven down the price of new products, while the price of repairs has increased due to a diminishing supply of labor in this field. This has skewed the value of repair and made replacement a more financially attractive option, despite the environmental burdens involved (McCullough 2009; 2010).

For certain categories of goods, extending the useful life through repairs can be both financially and environmentally preferable. Furniture, for example, does not stand to gain from efficiency improvements to new models because no use-phase energy is required. Its disposal does, however, comprise a portion of the 15.9 million tons of wood in US municipal solid waste (MSW) (in 2010), only 15 percent of which was recovered (Falk and McKeever 2012), and new furniture creates even larger upstream burdens from production processes. Because furniture is both expensive and durable, repairing it may be both financially and environmentally preferable to replacing it (Gregson et al. 2009). Small household appliances are another category of goods for which the repair sector is underdeveloped but which could represent substantial net environmental improvement from the avoidance of e-waste (McCullough 2009), with minimal compromise on use-phase energy efficiency.

Consumer choice and not product reparability play the biggest role in the repair/replace decision (Kinokuni 1999). Both the cost of repairs and consumer distrust or prior dissatisfaction with a repair experience leads consumers to favor replacement. Municipal or state governments can work to encourage repairs by eliminating sales tax on labor to make repairs more financially attractive, and by developing an easy-to-use system by which consumers can express grievances about repair technicians (McCullough 2009). Designing products to be repaired may be a step toward sustainability, but convincing consumers to take advantage of repair opportunities is likely to be a larger one.

Optimal Product Replacement

Extending the use phase of a product can avoid upstream environmental burdens associated with resource extraction and manufacturing as well as downstream energy inputs for recycling or contamination from landfill disposal. Despite decreased demand for production and disposal, the environmental benefits from extending a product's useful life depend on the environmental burdens associated with its use (Kim et al. 2003; Van Nes and Cramer 2006). For products without use-phase environmental burdens – for example shovels, which require no energy or water inputs and generate no emissions during their use – total life-cycle environmental impacts are indeed lessened by extending the product's lifetime, delaying disposal and additional production. For products with energy or water requirements for use, however, the optimal replacement time may come before the end of the product's useful life, in which case extending the use phase still further might cause net environmental harm (Kim et al. 2003; Van Nes and Cramer 2006).

A study of optimal replacement strategies for refrigerators determined that, because of ongoing technological advancements in energy efficiency, the optimal replacement time in terms of global warming potential from emissions and in terms of energy use was much shorter than the refrigerator's typical useful life (2–11 years, 2–7 years, and an average of 14 years, respectively). For refrigerators, the use phase dominates the total life-cycle energy requirement and related CO_2 emissions (Kim et al. 2006). In such cases, efficiency improvements in new models can result in sufficient use-phase environmental benefit to justify early replacement (ibid.; Van Nes and Cramer 2006). A study of optimal replacement time for air conditioning units revealed similar findings (De Kleine et al. 2011). Taken together, these studies suggest that, while extending the useful life of an appliance may be attractive from a cost perspective or in terms of production and disposal burdens, it comes with significant efficiency tradeoffs, and optimal replacement may be much sooner than the product's durability would otherwise permit.

Energy Efficiency/Grid Mix

Manufacturing efficient products can significantly contribute to reduced environmental burdens from their use, yet the true benefits gained from doing so depend on where they operate. Regional differences in the mix of primary energy sources used to provide electricity to the grid can significantly affect the emissions level and environmental impact associated with a product's manufacture and use (Marriott et al. 2010; MacPherson et al. 2012). Geography plays a large role in determining the source fuel used for power generation, and national averages fail to account for wide variations at regional scales: while the USA generates the majority of its energy using fossil fuels (nearly 70 percent from coal, natural gas and petroleum), coal specifically provides 96.18 percent of West Virginia's electricity, while Idaho gets 79.65 percent of its power from hydroelectric sources, and Vermont gets 73.61 percent from nuclear (EPA 2012). The carbon intensity of electricity use across the country is shown in Table 5.2. The life-cycle greenhouse gas emission factors to deliver one kilowatt hour (kWh) of electricity are provided for the 50 states in the USA. These data were derived from the US EPA EGrid Model and the Argonne National Lab GREET model. These results demonstrate that the use-phase greenhouse gas impacts from operating appliances and other products requiring electricity will vary widely ranging from 18 gCO_2-eq/kWh in Vermont (heavy nuclear) to 1109 gCO_2-eq/kWh in Wyoming (heavy coal). Smaller or larger grid boundaries could also be evaluated that would indicate different intensities for a city of interest.

The effect of grid mix on environmental performance of 'green' products can be so pronounced that in some places charging plug-in hybrid electric vehicles produces more emissions than the consumption of gasoline in traditional vehicles (MacPherson et al. 2012). In evaluating the life cycle of products the same product's carbon footprint may vary by as much as 50 percent depending on the grid mix where it is used (Weber 2012) – a level of detail often overlooked in life-cycle analyses, which lack standardized procedures to account for grid performance (Soimakallio et al. 2011).

Although grid boundaries are complex and unconfined by geographical borders, cities – where 75 percent of world energy consumption occurs and 90 percent of future population growth will be centered – have considerable leverage to promote renewable energy sources. Doing so will maximize the benefits of energy-efficient lighting and appliances as well as mitigate volatility in energy prices, support the local economy by creating jobs, and reduce GHG emissions both within the city and from upstream energy providers (Bhatt et al. 2010). Municipal governments can encourage the use of renewable energy by supporting renewable portfolio standards at the state level, or by initiating renewable energy targets of their own,

Table 5.2 State level greenhouse gas emissions from electricity usage

Total fuel cycle electricity greenhouse gas emission factor (gCO_2-eq/kWh) [cradle-to-wall outlet]

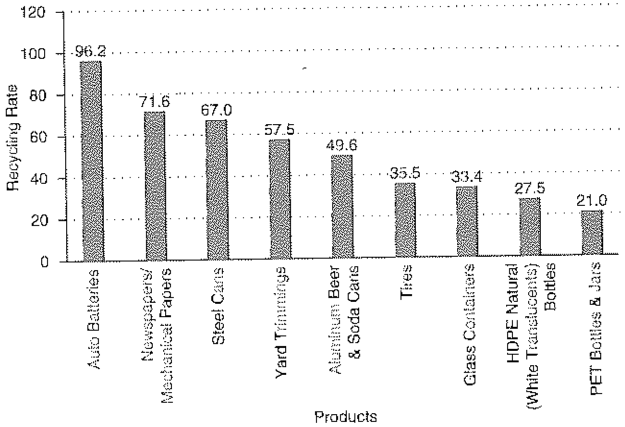
AK	655	MT	754
AL	566	NC	606
AR	600	ND	1049
AZ	612	NE	820
CA	368	NH	352
CO	943	NJ	331
CT	343	NM	983
DE	956	NV	643
FL	682	NY	343
GA	685	OH	921
HI	882	OK	819
IA	835	OR	228
ID	82	PA	608
IL	556	RI	579
IN	1046	SC	445
KS	864	SD	468
KY	1051	TN	557
LA	640	TX	713
MA	642	UT	994
MD	643	VA	541
ME	333	VT	18
MI	796	WA	167
MN	725	WI	791
MO	932	WV	1032
MS	626	WY	1109

Sources: Derived from the US EPA EGrid Model and the Argonne National Lab GREET model.

such as Ann Arbor, Michigan's target of 30 percent renewable energy by 2015 (Stanton 2011). In addition, individual households can contribute to renewable energy transformation through building integrated photovoltaics and small-scale wind turbines.

Recycling

Municipal solid waste (MSW) in the USA has increased significantly over the last half-century (from 88.1 to 250 million tons between 1960 and 2010), and recycling rates have climbed alongside (from 6.4 percent to 34.1 percent during the same period). Recycling rates took off noticeably in the mid-1980s, increasing from nearly 10 percent to 34.1 percent in the last 25 years alone (EPA 2011c), due in part to stricter EPA requirements for landfills and a growing sense that landfill space was becoming scarce, leading to the first introduction of curbside recycling programs (Jenkins et al. 2003). Despite its prevalence, recycling is generally less environmentally desirable than source reduction or reuse due to its energy input requirements and the sometimes lower-quality materials that it generates (King et al. 2006). On the other hand, when products are no longer suitable for reuse, recycling typically has the lowest total energy impact and global warming potential compared to final disposal alternatives like incineration or landfill (Björklund and Finnveden 2005). Energy recovery for discarded products, however, can be advantageous to recycling for some products. For example, the net non-wood (i.e. non-renewable energy) life-cycle energy in supplying one ton of kraft paper to consumers is 3.8 million Btu, with energy recovery compared to 14.3 and 14.7 million Btu for the landfill and recycling cases, respectively (Gaines 2012). For newsprint, on the other hand, recycling is the preferred strategy. Despite its shortcomings, recycling generally offers significant benefits and should be an important part of a city's sustainability strategy. Compared to landfill disposal, recycling improves air and water quality (Chester et al. 2008; EPA 2011a; Franchetti and Kilaru 2012), provides jobs, prevents disposal of valuable materials, and promotes resource conservation (EPA 2011a; 2011b). Recycling rates for a range of products and packaging are shown in Figure 5.2. Lead batteries from automobiles have the highest recycling rate, driven



Source: US EPA (2011c).

Figure 5.2 Recycling rates of selected products, 2010 by regulations and disposal fees, while PET bottles and jars are at the lower end. In this latter case, only one-fifth of the states have bottle bills to drive collection. There is also tremendous opportunity for increasing recycling rates for many other consumer products such as clothing and footwear (14 percent), carpets and rugs (9 percent), small appliances (6.9 percent), and furniture and furnishings (0.1 percent).

Cities seeking to promote recycling within a sustainability plan have a variety of programs and strategies from which to choose. If establishing recycling for the first time within the city, even drop-off centers can encourage recycling, but curbside recycling increases participation significantly by making it more convenient (reducing burden of storing and transporting recyclables) and visible (Jenkins et al. 2003). Among curbside recycling programs, cities can choose to offer dual stream (where recyclables are sorted at point of collection, which requires more effort from residents) or single stream (where wastes are collected together, then sorted and processed later). While dual stream simplifies processing, single stream may be preferable as it leads to higher volumes collected (Chester et al. 2008). Cities can also make use of pay-as-you-throw programs for waste disposal, in which residents either pay a subscription fee for city-provided containers for trash collection or buy tags with which to label each bag at the curb (Jenkins et al. 2003). Doing so can divert waste from landfills and prevent improper disposal of recyclables, but the incentive to recycle is only indirect and its effectiveness may be limited. The cost may be low enough or its payment detached enough from the act of disposal that it provides only a very weak signal (Jenkins et al. 2003). Rather the reverse of pay-as-you-throw schemes, recycling rewards programs offer direct incentives. Usually these are monetary, as Recyclebank's rewards program through which participants earn Recyclebank dollars that can be redeemed for discounts at partner businesses, but can also be non-monetary rewards such as public recognition. In either case, incentives can be effective especially when awarded randomly – the chance of winning encourages participants to continue engaging in the behavior (North Carolina Department of Environment and Natural Resources, n.d.).

Perhaps the simplest strategy for a city looking to improve its sustainability through recycling is to reorganize its collection routes. Redesigning collection zones within a city can reduce the number of trucks needed, leading to energy and maintenance savings without investment in new equipment or infrastructure. Similarly, consolidating routes so that wastes and recyclables are collected on the same truck can reduce the miles traveled – in either case, providing meaningful improvements at minimal cost (Chester et al. 2008).

The city of Portland, Oregon has taken a multifaceted approach to reduce waste and increase recycling rates to 75 percent by 2015. The first phase of the new program included the addition of recycling and yard debris roll-carts, making curbside recycling even more convenient and increasing the volumes of recyclable and compostable materials collected. The types of materials collected for recycling were also expanded, and waste hauliers were required to use pre-printed forms to give feedback to residents whose recycling was contaminated with non-recyclables or whose trash contained recyclable or compostable material. The second phase expanded the list of compostable materials to include food scraps, including meat and bones, which are not recommended for backyard composting but which industrial composting facilities can handle. Compostable and recyclable wastes are collected weekly, and, given these expansions, residents can now opt for every-other-week garbage collection. Adjusting service fees based on size of garbage can or frequency of collection (weekly, every other week, or monthly) provides incentive for residents to reduce their waste and increase their recycling rates (City of Portland 2007).

Packaging: Plastic Bag Policies

Packaging is an important factor in the resource intensity of goods. Single-use plastic carry bags have become a common point of intervention for cities seeking to reduce materials requirements and plastic wastes. Worldwide, 4–5 trillion plastic bags are produced each year (Sharp et al. 2010), contributing to the 100 billion used annually in the USA (Murdoch 2010). Although plastic bags have been ubiquitous since the 1980s (Sharp et al. 2010), and offer the advantages of convenience, strength, durability and low cost, they pose a significant waste problem in that they do not biodegrade (Sanghi 2008; Murdoch 2010).

Policies have been implemented at a variety of scales – a national bag fee in Ireland, a state-wide ban in South Australia, and a city-wide ban in San Francisco – to reduce consumption of single-use plastic carry bags (Murdoch 2010; Sharp et al. 2010). The fee in place in Ireland reduced bag use by 90 percent and bag litter significantly. The ban in San Francisco was enacted after lobbying defeated a proposed $0.17 fee per bag, but in the end consumers predominantly switched to paper bags, which were still available and which impose their own set of environmental burdens (Murdoch 2010). The City of Los Angeles recently instituted a similar ban on plastic bags. In South Australia, the ban did not have the desired degree of impact, as many consumers treated the charge for single-use compostable bags (which were made available as an alternative to the traditional plastic bags) as a fee and made no effort to carry reusable bags or reduce the number. This suggests that consumers are not as attitudinally involved in reduced bag consumption as they might have been if allowed to come to the decision on their own, and implies that behavior change achieved through policy is unlikely to be durable in its absence. Despite these tradeoffs, a fee or ban on plastic bags (a policy easily implemented at a municipal scale) is an effective way to achieve behavior change quickly without relying on slower and less effective information campaigns (Sharp et al. 2010).

Dematerializing Packaging

When thinking through the sustainability of consumer products, one also needs to consider packaging. Packaging represents nearly one-third of municipal solid waste in the United States (EPA 2010), and although much of it is recycled, reducing the amount required is environmentally preferable. The concept of dematerialization refers broadly to the reduction of materials used by society over time and dematerialization studies have been done for products, businesses, regions, nations and even the globe (Vos and Newell 2010). The potential to dematerialize packaging has been demonstrated by European producers in response to EU regulations specifying that packaging must be of the minimum possible volume and weight necessary to meet safety, hygiene and other performance standards (Sinclair 2000; Huang and Ma 2004; Varzinskas et al. 2009). Pressure to dematerialize packaging can also come from retailers in order to save shelf space, reduce shipping costs, and minimize waste. One of the products targeted is laundry detergent, and indeed, since 2008, US liquid laundry detergent producers have shifted focus to concentrated detergents (Sauers and Mitra 2009). Other strategies can be implemented individually or in conjunction with dematerialization, including using safe, renewable or recycled materials; recovery and reuse or recycling of packaging wastes and so on (Sustainable Packaging Coalition 2011). None, however, is likely to provide greater benefits than an improvement in the amount of packaging relative to the product, or the 'product-to-package ratio' – in terms of materials required and waste generated, as well as efficiency of freight and associated emissions reductions (Parmer 2010).

The history of the aluminum beverage can is an instructive example of opportunities for dematerialization. When aluminum cans were first introduced 50 years ago, they weighed over 80 g, whereas today cans average closer to 13 g (International Aluminum Institute 2012). Modifications in the process of dematerializing the aluminum include reducing the thickness of can walls and altering the design to minimize the size of the heavier, more expensive end pieces (EPA 1999; Das and Yin 2007). Given that 200 billion aluminum cans are consumed annually (Das and Yin 2007), and half of these in North America alone (Fuller and Ottman 2004), significant benefits can result from modest improvements – a single gram of weight reduction can save over 200 000 tons of aluminum annually, in addition to the energy savings and CO_2 reductions during transport of the lower-weight cans (International Aluminum Institute 2012). Only 50 percent of aluminum cans used for beer and soda were recycled in the US in 2010 (EPA 2011c). Environmental benefits from dematerialization may have even greater benefits when applied to other products by reducing the throughput of materials that are less easily recycled.

Dematerialization can also be achieved by increasing volumes contained in a particular package. A life-cycle study of yogurt packaging found that 58 percent of life-cycle energy was attributable to production of primary packaging, and that solid waste generation was inversely related to container size (27.3 kg of solid waste associated with production of 32 oz. containers, compared with 42.8 kg for 6 oz. containers). Substantial improvements were achievable by changing manufacturing techniques such that the mass of the container was reduced (and its product-to-package ratio improved), shrinking energy consumption by 10 percent, solid waste by 8.8 percent, and life cycle GWP by 6.6 percent. Even with these improvements, the dematerialization benefits of purchasing higher-volume containers was still evident: yogurt consumed from 32 oz. rather than 6 oz. containers saves 14.5 percent of total life-cycle energy and reduces solid waste by 27.2 percent (Keoleian et al. 2004).

Dematerialization is also an important strategy for products. Table 5.3 shows the material production energy requirements and greenhouse gas emissions for commonly used materials from virgin and recycled sources. It can be used to estimate energy savings benefits from dematerialization of packaging and products. Less material translates into less energy consumed and greenhouse gas emissions as long as other life-cycle attributes are not compromised, such as durability.

Distribution: Digital versus Physical

In today's technologically advanced world, a considerable amount of media – including books, music and movies – is available electronically. Whether consuming via download is more sustainable than traditional methods of distribution is an important question as the prevalence of portable music players and e-book readers increases. Some amount of dematerialization of media may be possible through digital distribution and consumption, as well as avoided impacts from physical production and transport. These benefits, however, may be offset or overtaken entirely by the burdens from manufacture, transport, use and disposal of the

Table 5.3 Production energy and greenhouse gas (GHG) emissions for various materials from GREET 2.7, transportation life cycle model

Material		Total energy (MJ/kg)	GHG emissions [(kg CO_2e)/kg]
Steel			
	Primary	27	3.6
	Secondary	19	1.2
Cast iron		33	0.5
Aluminum			
	Primary (Ingot)	149	10
	Secondary (Ingot)	13	0.9
Lead			
	Primary	29	0.9
	Secondary	5	0.5
Nickel			
	Primary	148	12
	Secondary	37	2.9
Copper			
	Primary	111	8.5
Plastics			
	Polypropylene	49	3.7
	Polyester	87	6.9
	High-density polyethylene	53	4.1
Glass-fiber-reinforced plastic		85	4.8
Carbon-fiber-reinforced plastic		160	9.7
Glass		20	1.6
Fiberglass		21	1.5
Rubber		44	3.2
Nickel hydroxide			
	Primary	104	8.2
	Secondary	6	0.5
Potassium hydroxide		11	0.8
Cobalt oxide			
	Primary	148	12
	Secondary	37	3
Zinc		121	8.8
Magnesium		372	29
Platinum		199	16
Zirconium		226	16
Rare earth		336	27

Table 5.3 (continued)

Material	Total energy (MJ/kg)	GHG emissions [(kg CO_2e)/kg]
Manganese	121	8.8
Nafion 117 sheet	24	1.8
Nafion dry polymer	24	1.8
Polytetrafluoroethylene	113	8.4

Note: Updated values for new and existing materials have been developed by the Center for Sustainable System and are currently under review for inclusion in the GREET model.

Source: Keoleian and Sullivan (2012).

electronic equipment through which the digital media is accessed (Hogg and Jackson 2008). When considering only the delivery of music itself (and not the associated consumption of a digital music player), electronic downloads indeed reduce energy use and emissions compared with traditional retail or online shopping with home delivery (Weber et al. 2010). In studies that examine both the impact of data delivery and associated consumption of electronics, however, the results are less conclusive. Whether digital media results in true savings depends on the efficiency, frequency of use, and useful life of the device with which it is accessed, as well as the extent to which digital consumption displaces consumer travel to traditional retail (Sivaraman et al. 2007; Hogg and Jackson 2008; Moberg et al. 2011). Thus the potential for environmental benefits from digital distribution can be maximized when overconsumption is reined in through opportunities for upgrade and repair of digital devices and when there exists a robust system for the recycling of e-waste at the end of its useful life (Williams et al. 2008; Kahhat et al. 2008). Additional studies are available comparing e-books and electronic journals to traditional print (e.g. Gard and Keoleian 2002; Kozak and Keoleian 2003).

Distribution: Online Shopping with Home Delivery

The Internet enables not only digital consumption of media, but also online shopping with home delivery. While some environmental benefits may be derived from the ability to browse multiple retailers without physically traveling to each, the true impacts of online ordering are more complex. Whether online shopping provides any real improvement in environmental performance over traditional retail may depend heavily on context: in urban areas, where consumers could walk or use public transit with relative ease, online shopping with home delivery may actually perform worse environmentally. Conversely, in rural locations, where consumers may need to drive long distances to make in-person purchases, delivery may be environmentally preferable (Sivaraman et al. 2007). On the other hand, rural consumers may be more likely to bundle errands into a single trip, thus reducing the environmental burden of any single in-person purchase. Factors like this, as well as shipping distances, frequency of returns, amount of packaging and mode of transport (of freight, or of consumers to traditional retail centers) complicate the matter (Fichter 2003).

Physical: Distribution Efficiency

For the majority of products that lack a suitable digital substitute, physical distribution channels will be required. The mode in which products are moved through these channels can substantially influence their life-cycle energy and emissions impact (Cholette and Venkat 2009). Increasing global movement of goods often requires multiple modes of transport – including trucks, trains, ships and planes – contributing to air pollution at multiple scales. Freight is economically vital, both in terms of the goods delivered and the industry itself: the USA spent 6–7 percent of GDP on freight transport moving more than 4600 billion ton-kilometers of freight in 2002 alone, representing a value of over $8.3 trillion. The distribution phase can impact life-cycle environmental performance significantly; one study of yogurt packaging found that distribution was responsible for one-third of total life-cycle energy and that substantial improvements to GWP and energy use were available through improving freight efficiency and distances (Keoleian et al. 2004). Freight transport relies on fossil fuels, and the resulting emissions represent 25 percent of the total CO_2, 50 percent of total NO_x, and 40 percent of total particulate matter from all mobile sources (Corbett et al. 2007). These emissions, concentrated in high traffic points of distribution like ports and rail yards, can have substantial environmental and human health impacts (Hricko 2006). Thus, when the transport of goods cannot be avoided (i.e. local sourcing and production are not feasible), it is essential to utilize the mode of distribution that is most environmentally preferable. While none, using current technology, will avoid emissions altogether, rail and coastal shipping were found to offer the lowest carbon intensity, and any form of ground transportation was determined preferable to air freight, which should be avoided whenever possible (Cholette and Venkat 2009; Corbett et al. 2007). Rail freight emissions are 50–94 percent lower than those of truck transport, depending on the pollutant in question, while air freight emits 35 times more CO_2 than rail and 18 times more than road transport on a ton-mile basis (Facanha and Horvath 2006). Given the scale of freight transport, and the likelihood that it will increase in an ever more globalized economy, minimizing emissions through transport mode choice can make a significant impact.

Local Sourcing: Urbanwood

Urban areas do not have the resources or capacity to produce everything their populations require. As such, a majority of consumer goods are imported to the city from elsewhere, expanding its environmental footprint (Pincetl et al. 2012) – both in terms of the area required to support the city itself and in terms of the emissions and ecological burdens resulting from transporting goods. Great potential for improving the sustainability of cities lies, then, in exploiting opportunities for local production wherever feasible. Local production and consumption can support all dimensions of sustainability, stimulating local economies by keeping money circulating within the community, producing social development by providing jobs and connecting community members, and improving environmental quality by reducing burdens from shipping products long distances (Mayer and Knox 2006; Robinson 2010; Sustainable Connections 2012). In some cases, further environmental gains are achieved by diverting valuable local resources from the waste stream.

The recovery of lumber from urban trees is one opportunity for local sourcing of materials for the production of consumer goods. From the approximately 4 billion urban trees in the USA, 25 million dry tons of residues (chips, logs, tops, brush and stumps) are produced annually. Of these, only 25 percent is recycled or used for new production (Bratkovich et al. 2008). In southeastern Michigan, a push to better utilize urban tree wastes emerged in the wake of the emerald ash borer infestation. Urbanwood (2012a), a network of family-owned businesses, was born of this effort to recover good logs from dead urban trees to use for lumber and flooring. It is estimated that dead urban trees throughout southeast Michigan could provide enough lumber to build 362 average-sized homes (Think Local First 2009) or provide wood flooring to more than 2300. Although local wood sourcing and production face challenges, mainly in terms of the quantity and quality of available wood and the cost of sourcing it at small scales (Bratkovich et al. 2008), it also represents a significant opportunity to create value from waste, create local jobs, and reduce the environmental burden of importing goods produced elsewhere (Urbanwood 2012b; Robinson 2010; Bumgardner et al. 2011; Sustainable Connections 2012). Notably, however, these benefits are achieved in part because the material sourcing, as well as the production and consumption, occurs locally. In a study of the life-cycle impacts of food, transportation of the food from the point of production to the point of final consumption was found to make up only 11 percent of total GHG emissions (Weher and Matthews 2008). The benefits of local production and consumption, however, should also include the closer connection and enhanced stewardship that a community can develop with its local environment.

CONCLUSION

Consumer products, along with residential buildings and transportation vehicles, are the physical embodiment of our urban metabolism. Tremendous opportunities exist to enhance the sustainability of consumer product systems across all stages of the life cycle, which encompasses production, use and retirement. The greatest leverage begins with product design, which is controlled by the manufacturer. From the city perspective, retailers, consumers and municipal government have the ultimate responsibility for managing sustainability of consumer products. Table 5.4 provides a summary of the consumer product sustainability strategies for cities that were characterized in this chapter. This table indicates the point of intervention in the product life cycle for each strategy and the key stakeholders that have the most direct influence in the application of these strategies. The table also highlights the potential sustainability benefits and tradeoffs that may exist, depending on the specific context. Improvement is dependent on the current state of practice, usage patterns, infrastructure conditions, including the nature of recycling systems and grid systems, spatial configurations that can impact transportation and logistics and the upstream impacts from production activities that generally occur outside the city boundary. A comprehensive assessment of sustainability performance requires tools such as life-cycle assessment to measure system-wide impacts. However, these are not accessible for households to utilize on a routine basis. Therefore general observations drawing on case examples that demonstrate benefits serve as guidance for moving towards enhanced sustainability.

Consumers ultimately have the most direct and powerful role in shaping urban metabolism through their product purchasing decisions and their stewardship of these products. Retailers can influence consumer behavior through their merchandising and marketing of more sustainable product alternatives. Municipalities and local governments can enact regulations, invest in more sustainable infrastructure and provide economic incentives to promote more sustainable consumer products systems for addressing societal needs. Finally, sustainable transformation of urban metabolism will accelerate only when consumer product systems that are developed

Table 5.4 *Summary of consumer product sustainability strategies: Points for intervention across the life cycle*

Point of intervention/life-cycle stage	Strategy	Description	Sustainability benefits	Tradeoffs	Major actors
Production & distribution	Local sourcing/ production	Using local resources (materials and labor) to produce goods	Reduced emissions from distribution; creation of local jobs	More expensive if economies of scale are not possible; increased emissions if production occurs locally but materials are sourced elsewhere (then shipping in final product is better)	Producers/retailers/ local government
Production/end of life	Optimized replacement	Retiring energy-using products with newer models available at the best time to minimize environmental burden	Reduced use-phase energy requirement and emissions	More frequent replacement, meaning increased overall production with burdens from resource extraction, production and distribution; increased waste from retired products	Consumers/local government
Distribution	Digital delivery	Distribution of media in digital formats (e.g. MP3 files or online streaming of movies) rather than physical	Dematerialization resulting from less physical production of music or movie discs and their packaging; fewer emissions from distribution	Increased production and rapid replacement of digital devices plus energy requirement during their use	Consumers; producers
Distribution	Online shopping w/ home delivery	Internet browsing replaces physical travel to shopping centers, physical products delivered	Reduced emissions from travel for single-purpose shopping trips	Energy use of device used for browsing internet; more emissions from delivery if errands could have been bundled or if shopping were done on foot or using public transit	Consumers/ retailers

Distribution	Physical distribution efficiency	Using rail for distribution of products where possible, optimizing other modes as needed, avoiding air freight whenever possible	Reduced emissions (rail 50–94 percent lower than truck; air emissions 35 times higher than rail and 18 times higher than road transport)	Emissions never eliminated altogether	Producers; distributors
Distribution	Packaging bans	Banning, taxing, or requiring producer takeback of packaging or plastic carry bags	Dematerialization of packaging; reduced emissions from distribution (less excess packaging weight); less waste; faster adoption of pro-environmental behaviors than voluntary initiatives	Bag bans may lead to increased use of paper bags (with their own burdens) or increased production of 'green' bags; behavior change less durable than if self-motivated	Local governments; producers; consumers
Distribution	Dematerialized packaging	Lightweighting packaging through design and materials choice; concentrating liquid products; optimizing container volumes	Reduced burdens from resource extraction and distribution; less waste	May reduce opportunities for reuse if packaging is less durable (less problematic if it is easily recycled)	Producers
Use	Product sharing	Joint ownership of expensive, durable goods used at irregular intervals	Reduced production, resource conservation; faster replacement of energy-using goods with more efficient models, reducing overall energy use; improved access for individuals (social sustainability)	Unlikely to be adopted without effective management; may entail travel to use items, with resulting emissions	Consumers

Table 5.4 (continued)

Point of intervention/life-cycle stage	Strategy	Description	Sustainability benefits	Tradeoffs	Major actors
Use	Reducing consumption	Either voluntarily reduced consumption through 'slow living', or policy that encourages reduced consumption	Less overall production and waste, reducing burdens from all life-cycle stages	Difficult to implement: self-motivated reduced consumption are slow-acting and unreliable; consumer resistance to policy	Consumers; policy makers
Use	Repair	Extending products' useful life through maintenance and repair; producers facilitate repair by making products repairable	Reduced burdens from production and disposal since products are used longer; service job creation	Increased use-phase burdens from energy if the lifetimes of inefficient products is extended beyond optimal replacement time	Producers; consumers
Use/energy	Renewables in grid mix	Supporting state-wide Renewable Portfolio Standards or implementing municipal goals	Reduced emissions from cleaner energy; local jobs; reduced volatility in energy prices	Burdens from production of renewable generation equipment	Municipal governments; energy providers
Use/end of life	Reuse	Extending functional products' lifetimes through reuse by another consumer following initial retirement	Reduced production and resource use; less disposal of waste; improved access for individuals through secondhand markets	Increased use-phase burdens from energy if the lifetimes of inefficient products is extended beyond optimal replacement time; may supplement rather than replace new consumption	Consumers
End of life	Recycling	Materials recovery for new production	Reduced burdens from resource extraction; less waste; local job creation	Requires energy for recycling processes; resultant materials are sometimes lesser quality	Producers; consumers; municipal governments

Source: Author.

and managed for optimal life-cycle environmental performance also achieve optimal life-cycle cost performance; systems that achieve convergence of environmental, economic and social sustainability is the ultimate goal.

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