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Limitations of the waste hierarchy for achieving absolute reductions in material throughput

S. Van Ewijk [a,*], J.A. Stegemann [b]

[a] Institute for Sustainable Resources (ISR), University College London, Central House, 14 Upper Woburn Place, London WC1H 0NN, UK
[b] Department of Civil, Environmental & Geomatic Engineering, Centre for Resource Efficiency & the Environment (CREE), University College London, Chadwick Building, Gower Street, London WC1E 6BT, UK

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ABSTRACT

Dematerialization can serve as a measurable and straightforward strategy for sustainability and requires changes in management of material inputs and waste outputs of the economy. Currently, waste management is strongly inspired by the waste hierarchy, an influential philosophy in waste and resource management that prioritizes practices ranging from waste prevention to landfill. Despite the inclusion and prioritization of prevention in the hierarchy, the positive contribution of the application of the waste hierarchy to dematerializing the economy is not inevitable, nor has it been conclusively studied. In this paper, the waste hierarchy is analyzed on a conceptual level by studying its original aims, its potential to fulfill those aims, and its actual policy implementation. Issues with the hierarchy include limited specification and implementation of prevention, a lack of guidance for choosing amongst the levels of the hierarchy and the absence of a distinction between open-loop and closed-loop recycling. Also, the hierarchy only communicates relative priorities and therefore does not support decisions that affect other sectors as well as waste management. The article concludes that the waste hierarchy in its current form is an insufficient foundation for waste and resource policy to achieve absolute reductions in material throughput. Suggested improvements are the adoption of a value-based conception of waste and related collection practices, more stringent and targeted policies on least desirable options like landfill, the specification of waste management targets based on dematerialization ambitions, and the use of the waste hierarchy within a resource productivity-oriented framework.

1. Introduction

Global sustainability is fundamentally dependent on the natural systems in which economies and societies are embedded. The role of natural systems in human life can be expressed through the concept of environmental functions as pioneered by Hueting (1980) and Groot (1987). Environmental functions include climate regulation, food production and many others (Groot et al., 2002) and make up the "natural capital" (Pearce, 1988) that is essential to human well-being. Environmental sustainability is only achieved if we safeguard the "maintenance of important environmental functions into the indefinite future" (Ekins, 1997).

The ability of the natural system to provide environmental functions is generally recognized as being finite, as exemplified by the concepts of planetary boundaries (Rockström et al., 2009). Respecting these boundaries implies an absolute limit to the environmental impacts associated with production, consumption and disposal. Dematerialization of the economy reduces the risk of impairing the carrying capacity of nature (Bartelmus, 2003). As material flows are easier to measure than their associated environmental impacts, reducing material throughput is an attractive criterion for achievement of sustainability (Hinterberger et al., 1997).

Reducing material throughput has two key aspects that can be summarized as dematerialization: the reduction of raw material inputs and reduction of waste outputs. These two aspects are directly related as waste outputs arise from raw material inputs. At the same time, waste prevention, recycling and reuse can considerably reduce the need for virgin material, material processing, and product manufacturing, as well as reduce associated environmental impacts. Absolute reductions in material throughput imply an absolute decrease in raw material inputs and waste outputs over time.

* Corresponding author.
E-mail address: stijn.ewijk.13@ucl.ac.uk (S. Van Ewijk).

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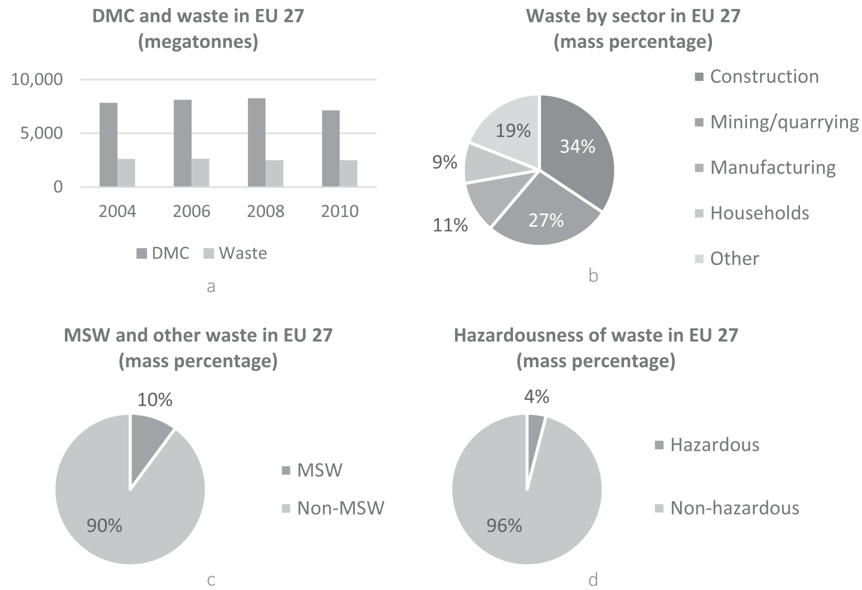

Fig. 1. Domestic Material Consumption (DMC) and waste in the EU 27 in 2010 (Eurostat).

Fig. 1 presents data on Domestic Material Consumption (DMC)[1] and waste in the EU 27. The sectors that appear to produce most waste are construction, and mining and quarrying. Of the entire waste flow, only about 4% is hazardous waste, but most wastes have the potential to harm the environment (e.g., by causing biogeochemical imbalances, such as eutrophication). Although Municipal Solid Waste (MSW) (mostly household or domestic waste) is the most publicly visible sector, this flow corresponds to only 10% of the total waste flow and has a relatively low share of hazardous substances. Total waste generated in the EU 27 equated to 30–35% of DMC over the period 2004–2010.

The waste hierarchy is a preferential order of waste treatment options that aims to reduce environmental impacts by prioritizing prevention, reuse, recycling, and recovery over landfill (Hultman and Corvellec, 2012). Developments in waste management cannot be traced back entirely to the application of the hierarchy, for instance Parto et al. (2007) analyze transitions in the Dutch waste sector through a variety of specific events and institutionalization processes. However, it is undeniable that the waste hierarchy has had its influence, since it has enjoyed wide support in most developed countries as a guide for waste management (Dijkgraaf and Vollebergh, 2004). Acknowledging the importance of management of waste flows to dematerialization, and of the waste hierarchy to management of waste flows, this paper explores whether, and to what extent, the waste hierarchy fits within a dematerialization agenda.

The paper proceeds as follows. Section 2 explains the waste hierarchy, dematerialization, and decoupling, and presents a basic flow model for analyzing the relationships between waste and resources. Section 3 scrutinizes the aims of the hierarchy, its potential to fulfill those aims and the actual implementation of the hierarchy, and contrasts the findings with the aims of dematerialization. Section 4 discusses the features of the hierarchy that limit its value as a tool for reducing material throughput. Section 5 discusses more resource-oriented approaches that could supplement or substitute the hierarchy, before statement of our conclusions in Section 6.

2. Concepts and methods

2.1. The waste hierarchy

The waste hierarchy is commonly described as: 1) a priority order for (at least three)[2] waste management options, 2) based on assumed environmental impacts (e.g. Hultman and Corvellec, 2012). Most probably, the waste hierarchy stems from about 1980 and originates in prioritizing reduction, recycling and reuse of hazardous waste over treatment or disposal. In the United States, pollution prevention became a priority with the 3M Corporation and the state of North Carolina in the seventies (Overcash, 2002). According to Wolf (1988), the California Office of Appropriate Technology was "one of the first actors" (presumably in the United States) to define a hierarchy for hazardous waste management, in a publication on alternatives to land disposal of hazardous waste (Office of Appropriate Technology, 1981). A publication by the National Research Council in 1985 emphasizes cost, liability, and public opposition to landfill as reasons for hazardous waste reduction (National Research Council, 1985). The hierarchy then became popular for MSW in the eighties (US Congress Office of Technology Assessment (1989)) and is today also understood as a tool for "sustainable" waste management (Price and Joseph, 2000).

In Europe, a waste hierarchy was formulated by former scientist and Dutch politician Ad Lansink who proposed it in Dutch Parliament in 1979 (Parto et al., 2007). Subsequently, "A Community Strategy for Waste Management" (EC, 1989) stated that prevention is "the first guideline" while waste that could not be prevented is best recycled or reused, and waste that could not be recycled or reused ought to be disposed, effectively suggesting a three-tier waste hierarchy (Ekins, 2009). The strict priority order was

[1] List of abbreviations used in this article: Best Practicable Environmental Option (BPEO), Domestic Material Consumption (DMC), Life Cycle Assessment (LCA), Municipal Solid Waste (MSW), Reduce, Reuse, Recycle (3R), Resource Conservation and Recovery Act (RCRA), Waste Electrical and Electronic Equipment (WEEE), Waste Framework Directive (WFD).

[2] Logically, a preference order must contain at least three options in order to not be simply a preference. As such, a preference for all options but landfill should not be regarded as the waste hierarchy. Also, a preference order should be distinguished from listings of waste treatment that resemble the waste hierarchy, but do not demand adherence to that specific order.

introduced in EU legislation only with the 2008 Waste Framework Directive (WFD) which distinguishes prevention, preparing for reuse, recycling, recovery, and landfill on a preferential scale (EC, 2008). This paper uses this five-tier formulation of the hierarchy formalized by the WFD, although the "3 Rs" (reduce, reuse, recycle) version is also in common use worldwide (Sakai et al., 2011).

2.2. Dematerialization and decoupling

The concept of dematerialization essentially simplifies the complex interactions between nature and the economy by linking environmental degradation to material throughput. Hinterberger et al. (1997) refer to dematerialization as a scientifically and practically attractive "management rule" for sustainability. Fig. 2 considers the material flows that make up the economy. The inputs are primary materials (virgin extraction) and secondary materials (recycling, reuse, and recovery). Material only leaves the system as waste is landfilled; in addition, there are dissipative losses that are usually neglected. Dematerialization ideally prioritizes reduction of the generally more harmful primary inputs over reduction of the secondary inputs and ultimately aims to limit both.

All flows relate to each other and contribute in some way to the economic output of the system. The relationships between raw material use, waste generation, and economic output are mutually reinforcing. Decoupling signifies breaking the link between raw material use and economic output or between waste output and economic output. Absolute decoupling coincides with absolute reductions in material throughput, as it requires material use and waste generation to remain stable under growing economic output.

The waste hierarchy does not necessarily have a positive impact on dematerialization and decoupling, as it focuses only on waste and does not address material inputs directly, nor consider economic output. The aims of this paper are to increase the understanding of the role of the hierarchy in the flows shown in Fig. 2, and to examine the utility of the waste hierarchy as a guiding instrument in achieving absolute reductions in material throughput.

3. Aims, evidence and implementation of the waste hierarchy

3.1. Waste hierarchy aims and evidence

All the original concerns that culminated in the waste hierarchy (Section 2.1) can be summarized as a desire to divert waste from landfill. In the Netherlands, Lansink's Ladder was developed in response to "mounting volumes of waste coupled with a shortage of landfill space" (Parto et al., 2007). In the United States, the hierarchy resulted from the understanding that landfilling untreated hazardous waste posed a potential threat to the environment and human health (Wolf, 1988) while Schall (1992) argues that the shift from disposal-based waste management to the hierarchy resulted from the three-fold waste crisis regarding cost, contamination and capacity in the 1980s.

As such, the priority order between the alternatives appears to be related to the ability of each option to achieve diversion from landfill. However, adherence to the waste hierarchy is also often equated with the least environmental impact and saving of resources. For instance the WFD states that the "waste hierarchy generally lays down a priority order of what constitutes the best overall environmental option in waste legislation and policy" (EC, 2008). Also, it mentions a reduction of the use of resources as a policy goal, as do many other documents.

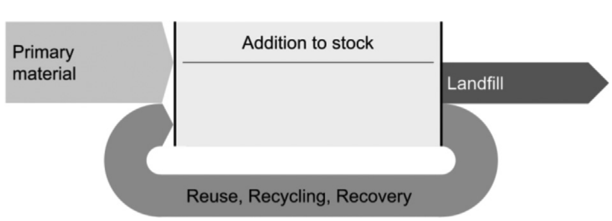

Fig. 2. Basic material flows in the economy.

The waste hierarchy thus makes three different claims, which relate in different ways to dematerializing the economy.

- Diversion from landfill can only serve dematerialization, as it results in waste being recovered, recycled, or reused and thereby substitutes virgin inputs.
- Reducing environmental impacts is also the goal of dematerialization, but the waste hierarchy does not by definition live up to this promise.
- Saving resources by prioritizing recycling, reuse and recovery does not guarantee dematerialization, as it reduces primary inputs but still allows secondary flows to grow unrestrained.

Based on the above, it results that the aims of the hierarchy coincide largely with those of dematerialization, but also that the validity of the hierarchy with regard to some of those aims is disputable. Only the claim of diversion from landfill is hard to deny. Recovery through incineration reduces landfill to the resulting ashes, recycling reduces landfill only to processing wastes, reuse prevents the entire product from ending up in landfill except for repair waste, and prevention of waste generation logically avoids landfill completely.

The claims regarding environmental impacts are more uncertain. A review of Life-Cycle Assessments (LCA) for MSW by Cleary (2009) finds that the weighted results "tend to confirm" the waste hierarchy. However, an example by Finnveden et al. (2005) shows that landfilling of MSW could be more attractive than incineration when transport distances increase, or when the environmental impacts from landfill are assumed to occur over a relatively short time frame. Also, LCA evidence suggests that the waste hierarchy does not hold for certain materials, specifically food waste, garden waste and low-grade wood (DEFRA, 2011). Unfortunately, the inconsistent results may not only reflect the limitations of the hierarchy but also the uncertainties associated with LCA methods. Especially, the selection and relative weighting of environmental impacts is a subject of much debate (Clift et al., 2000). Additionally, LCA is a time-consuming analysis which requires potentially subjective interpretation of a highly parameterized model, as well as large amounts of accurate quantitative data about flows and environmental impacts. As a consequence, relatively few credible analyses exist, even for MSW, and most are far from exhaustive. The context-dependence of each LCA case makes it difficult to compare with others developed in different contexts.

With regard to saving materials, the validity of the hierarchy depends on the type of recycling and prevention. Closed-loop recycling allows a product to be remade many times, with virgin material only compensating for process inefficiencies. However, with open-loop recycling, materials move from one product life-cycle into another, possibly causing important environmental impacts beyond the original product life-cycle (Ekvall, 2000). With regard to dematerialization, closed-loop recycling has the potential of avoiding almost all primary material consumption if demand is stable, whereas open-loop recycling can usually only substitute lower grade primary inputs, and after several iterations of open-loop recycling many materials have lost all value. Unfortunately, the hierarchy does not distinguish between different forms of recycling. Instead, published recycling rates are easily boosted by pursuing open-loop recycling practices that have relatively low environmental or dematerialization merit.

In addition, the success of limiting primary material inputs through the hierarchy depends on whether the top priority of prevention avoids primary inputs better than reuse, recycling, and recovery do. Preventative measures targeting demand, production, or use can effectively reduce both waste output and material input. However, if prevention merely affects the act of disposal, it may result in unused additions to stock, based on an insatiable desire for luxury goods and ill-functioning markets for used goods. For instance, small electronics like mobile phones can easily be stored if unused and replaced by new products. A survey in Japan suggests that computers are held unused in stock for 2.9 years on average by consumers before being sold, given away, or disposed of, which possibly prevents the demand for reuse of such machines being met (Williams and Hatanaka, 2005). Prevention is thus not necessarily the best option for saving resources, it is only so if there is actual avoidance of primary inputs.

In theory, the hierarchy can serve dematerialization by achieving diversion from landfill. The best environmental outcome is however not guaranteed, nor is it certain that natural resources are saved most effectively by following the hierarchy. However, the actual implementation of the hierarchy matters greatly and is discussed in the next section.

3.2. Policy implementation of the waste hierarchy

The waste hierarchy has become more entrenched in European legislation than in US legislation. The WFD explicitly promotes the application of the waste hierarchy in waste policy. In contrast, the Solid Waste Disposal Act of 2002 (US Congress, 2002) and originating from 1965 (popularly known as the Resource Conservation and Recovery Act (RCRA) which amended it in 1976) does not mention anything like the hierarchy. It is however "frequently assumed" that RCRA outlines the hierarchy for MSW (US Congress Office of Technology Assessment (1989)). This assumption is somewhat justified, since the Environmental Protection Agency, which developed RCRA, has also published guidance documents on RCRA in which it encourages communities to use the hierarchy as a guideline for considering treatments of MSW (US Environmental Protection Agency, 2011).

Based on the literature, it seems that implementation of the hierarchy has emphasized the less desirable alternatives to landfill. Wilkinson (2002) studied international, European and national law and concluded that waste management generally focuses on more clear-cut issues like safe transportation and disposal instead of moving up the hierarchy. Mazzanti and Zoboli (2008) argue that waste collection and landfill diversion policies such as the UK landfill tax have dominated the field. In Australia, most effort has been directed at recycling and composting, prevention being almost wholly ignored (Gertsakis and Lewis, 2003). Finnveden et al. (2013) conclude that, for Sweden, most policies focus on diversion from landfill, with the exception of Extended Producer Responsibility, and pay-as-you-throw taxes that several studies have shown to reduce waste generation (Dahlén and Lagerkvist, 2010).

Prevention could focus on demand for products, the wastefulness of the manufacturing of products, or the actual disposal of products. Price and Joseph (2000) argue that demand reduction, before the start of the product life-cycle, receives little attention in the waste hierarchy in spite of a huge potential to reduce material flows and associated harms along the product life-cycle. On the consumer side, there is little effort to decrease the sale of any product or material, with, for instance, taxes on plastic bags (Convery et al., 2007) being a notable exception. As exemplified by Ekins (1999), the literature tends to pay more attention to taxes on air, water, energy, and waste than products, which most likely reflects the policy reality.

Globally, rather than questioning consumer freedom, efforts regarding sustainable consumption have aimed at increasing resource efficiency of production (Fuchs and Lorek, 2013). The wastefulness of the manufacturing of consumer products is addressed through policy and legislation directed at industry, and often specific industrial sectors. Process improvement or cleaner production comes down to an attempt to discourage the use of certain materials and products in industry and business in order to avoid waste. For instance, the Integrated Pollution Prevention and Control Directive (now superceded by the Industrial Emissions Directive (EC, 2010)) required, among other things, "low waste technologies" (EC, 1996) and is enforced through permitting procedures. A comparable piece of legislation in the United States is the Pollution Prevention Act (US Congress, 1990). Also, the EU Eco-design directive (EC, 2009) and the Directive on Waste Electrical and Electronic Equipment (WEEE) (EC, 2012) require adaptation of industry rather than the consumer.

4. Conceptual difficulties of the waste hierarchy

4.1. Prevention and reuse as waste management options

A conceptual problem of the waste hierarchy that may hamper prevention efforts through policy is the inclusion of prevention in a tool essentially meant for waste managers. Already in 1989, the Office of Technology Assessment argued against the hierarchy as they considered prevention fundamentally different from waste management (US Congress Office of Technology Assessment, 1989). The main difference is arguably the fact that prevention is not the domain of waste management; waste managers are practically powerless when it comes to prevention (Kijak and Moy, 2004). Importantly, the only life-cycle phase concerned with prevention that waste managers may actually control is collection.

However, achieving prevention by changing the tradition of accepting any discarded goods as waste is difficult, since there is a vested interest among waste collectors to collect as much as possible. Weight or volume-based collection fees may act as a deterrent to disposal, but still do not discriminate between goods that are justifiably disposed of and goods that may better go somewhere else (e.g., second-hand shops). The legal definition of waste may reinforce the collectors' predisposition towards maximizing the collected amounts, since the WFD defines waste as "any substance or object which the holder discards or intends or is required to discard", the act of discarding is thus left unquestioned, hampering prevention efforts.

Once discarded and collected, materials are controlled as waste and there is no further opportunity for prevention, only "preparing for reuse". The reuse of things that are already waste can be much more complicated than the reuse of objects that were not discarded and collected in the first place, since they cannot be easily removed from controls on waste management if the subsequent owner finds them valuable. The sensible reuse of waste can be deemed an illegal practice merely because the substance was called waste in the first place, as exemplified in jurisprudence (Wilkinson, 2002). Wilkinson (1999) argues there is something wrong about treating any waste as a potential environmental hazard since products and materials are more likely to be treated with care if they are regarded as having value.

4.2. Shortcomings of a priority order

At first glance, priority orders have great potential for policy making as they provide a seemingly clear-cut message on what

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needs to be done first. However, a priority order implicitly judges the included options in three ways that may be counterproductive. Firstly, inclusion of an option in a priority order legitimizes its existence. For instance, instead of categorically rejecting landfill, the waste hierarchy states that other options are better than landfill. As such, it resides in between two extremes: on one hand approaches that accept landfill as a possible best option based on contextual factors, and on the other hand approaches that radically aim to achieve zero landfill, zero incineration, or zero waste. While the former promote a workable outcome, the latter send a clear message that may rally more support and achieve greater change. The waste hierarchy however, may fail to achieve either: there is no indication as to when landfill is an acceptable means, nor does it inspire radical change. The 3 Rs concept may be better in this regard since it omits landfill.

In relation to the above, a common understanding of the hierarchy is that one needs to "move up" the hierarchy, rather than necessarily achieve the highest priority. A hierarchical order cannot communicate which treatment is good or bad, but merely communicates which ones are better or worse; moving from landfill to energy recovery is thus considered "good", whereas prevention in itself is merely "relatively better". The hierarchy thus informs user on direction of change rather than on the end goal that needs to be reached. As a result, the hierarchy provides a helpful framework for stimulating incremental progress rather than radical change. On the other hand, the hierarchy can stimulate improvement irrespective of the starting situation, whereas targeting prevention straightaway may require a leap that is prohibitively large.

Lastly, as a priority order, the hierarchy merely communicates the relative desirability of waste management options but does not give any pointers regarding trade-offs with activities outside waste management. Environmental policy may affect many different sectors, in which case decision-makers must be able to compare the merit of changes in waste management with the merit of changes in other sectors such as energy and transport. For instance, the relative desirability of recycling over incineration does not communicate whether limited investment funds need to be directed at a recycling facility rather than a public transport project. In contrast, notwithstanding the criticisms noted earlier (Section 3.1), LCA results can be weighted using monetary valuation (Ahlroth et al., 2011), allowing trade-offs with other monetarily quantified activities. As such, decision-makers may be provided better guidance by using LCA, or any other environmental impact assessment method, for deciding on the distribution of financial resources over waste management and other sectors.

4.3. *Difficulties in implementing the priority order*

The success of the hierarchy in achieving dematerialization may be significantly affected by how the priority order is implemented: under what conditions is it permissible to move from a higher priority waste management practice to a lower one? The hierarchy describes which practices first need to be exhausted before the lower options become of interest; consequently, the criteria by which options are judged to be exhausted are at the center of the debate (Wolf, 1988). Regulations and guidance are generally not particularly clear in this regard. For instance, the Scottish Government abstrusely refers to "exhausting" the higher priority options (Scottish Government, 2013). The WFD states that: the hierarchy should be applied as a "priority order in waste prevention and management", but, at the same time, waste policy is also expected to "favor the practical application" of the waste hierarchy (EC, 2008). Unambiguous interpretations seem exclusive to landfill, which is banned for several materials including (categories of) liquid waste, hospital and clinical waste, and tires (EC, 1999).

Instead of reducing uncertainty by clearly specifying when an option can be considered to have become exhausted, regulations often emphasize when the hierarchy should be overridden. There is a history of use of terminology such as Best Practicable Environmental Option (BPEO) to describe preferred pollution control options in a way that trade-offs between environmental benefits and other considerations (e.g. DEFRA, 2000). The WFD opens the way to departure from the waste hierarchy for reasons of "technical feasibility, economic viability and environmental protection" (EC, 2008). As argued by Wilkinson (2002), the considerations for diverting from the hierarchy prove the flawed nature of the waste hierarchy. It is questionable to what degree the hierarchy is useful if important voter concerns like costs are likely to invalidate it. If "exhausting" top priorities were to truly entail adhering to them insofar that is economically feasible, decision-making in the waste management sector would be effectively reigned by economic considerations and the hierarchy would be left useless. In fact, disabling lower priority alternatives supports the economic feasibility of higher priority alternatives, as, for example, implementation of the landfill tax in the UK, supports growth of higher ranked options.

5. Discussion: achieving absolute reductions

Although the waste hierarchy and its current policy implementation can lead to reductions in material throughput by diverting materials from landfill, following the waste hierarchy does not necessarily save natural resources, nor guarantee the best environmental outcome. Specific difficulties with regard to dematerialization include the following.

1. Poor policy support of prevention as the top level of the hierarchy, as prevention is not under the control of waste managers.
2. Leniency towards lower options of the hierarchy and a lack of incentives to aim for the top priority of prevention.
3. A lack of guidance for choosing amongst the levels of the hierarchy, and for making trade-offs between investments in waste management and other sectors such as transport and energy.

The limitations of the waste hierarchy can be remedied by redefining waste and adopting associated collection practices, by providing stricter guidance on the implementation of the hierarchy, and by using the hierarchy within an overarching resource management strategy that compensates for its shortcomings.

Prevention and reuse could be facilitated by integrating collection of materials for reuse into collection schemes. Ideally, materials are reused before they are controlled as waste rather than through "preparing for reuse" once a material has become waste. The latter may sometimes still be necessary to prevent environmental harm during materials handling and storage but can also unnecessarily obstruct the reuse of materials that pose no threat to the environment. Such collection schemes should be supported by a value-based conception of waste which indicates the resource value of materials, along with their potential environmental impact (e.g. hazardous waste) or preferred treatment methods (e.g. recyclables).

Already, the ordinary disposal of certain wastes, such as batteries and paper, is strongly discouraged because of their potential hazard or recyclability and a similar approach could be taken to address the disposal of reusable or repairable rather than hazardous products. A step in the right direction are separate collection schemes aimed at, for instance, electronics, with the clear objective of recycling and reusing such products appropriately, as required by for instance the WEEE Directive (EC, 2012). Consumer commitment to the separate collection of valuable wastes of any kind could also speed up the throughput of certain products, like electronics, which would otherwise end up unused and forgotten, lost for timely reuse and delayed for recycling.

Regarding the leniency of the hierarchy towards lower options and the lack of incentives to aim at the highest priorities, relatively strict regulation or taxation already exists in some countries to reduce landfill, and could be further implemented to fully phase it out. In addition, waste policy is often complemented by recycling rate targets, which unfortunately are only relative performance criteria, but which could be related to dematerialization goals through comprehensive economy-wide analysis of material flows, as total material throughput is a function of among others waste outputs and recycling loops. Also, a clear distinction in the hierarchy between open-loop and closed-loop recycling could greatly contribute to dematerialization.

The lack of guidance for implementing the waste hierarchy could be partly resolved by distinguishing between materials; a publication by the US Congress Office of Technology Assessment, (1989) argues that a hierarchy may only have utility when it is applied on a material by material basis instead of for MSW in general. For instance, Papargyropoulou et al. (2014) specify a hierarchy for food waste only. The Scottish Government defines a separate hierarchy for materials such as food waste, wood and plastic films by suggesting some of the lower options are “acceptable” or to “avoid” depending on the material (Scottish Government, 2013). The guidance essentially shows for which materials a movement up the hierarchy is more urgent (a priority order within a priority order) although it still does not specify under what conditions the lower options actually should be considered.

Trade-offs between different waste management options, and between investments in waste management and other sectors, could be facilitated by an overarching framework on waste and resource management. Such an overarching framework can be resource productivity – the ratio of economic output and material inputs – which was presented to the Club of Rome as a path to sustainability (Von Weizsäcker et al., 1997) and has been prominently promoted by the European Union with the Road Map to a Resource Efficient Europe (EC, 2011). Alternatively, based on an understanding of natural systems, many conceptions of sustainable resource management emphasize circular flows above all else. In the so-called circular economy, landfill and waste incineration are both undesirable while reuse and recycling form the backbone of the economy. The circular economy is an “emerging policy paradigm” in China and was formalized in the 2008 Law on the Circular Economy (Park et al., 2010). Similar to the resource productivity approach in Europe, it is not purely an environmental but also an economic strategy (Yuan et al., 2006).

The resource productivity approach seems most appealing for integrating dematerialization ambitions with the use of the hierarchy, as it imposes a quantifiable criterion for prioritization on the waste hierarchy, namely the resource productivity of material journeys. Though resource productivity is arguably hard to calculate, it may pose fewer challenges than LCA, while providing more guidance than the hierarchy alone can. At the same time, it relates strongly to absolute material reductions through the concept of absolute decoupling. However, according to Jevon's paradox (e.g. Alcott, 2005), increased resource productivity could still increase material consumption, thwarting the desired outcome of dematerialization. Similarly, circularity only implies dematerialization for primary materials but sets no limits on secondary flows, ultimately allowing uncontrolled total material throughput. Absolute target setting thus remains essential, also when adhering to the hierarchy under the umbrella of resource productivity or circularity.

Finally, it has been pointed out that the waste hierarchy does not always indicate the environmentally best option. However, it should be acknowledged that dematerialization in itself is also a limited concept, since reducing material throughput does not always entail lower environmental impacts. Especially when using the waste hierarchy within a larger resource productivity approach, the emphasis on economic outputs may neglect or sometimes even exacerbate environmental effects. The heterogeneity of the waste flow, as a consequence of the enormous variety of products for consumption, leads to a very large variety of environmental impacts; improved policy frameworks, both on an economy-wide level and for waste management only, cannot take away the necessity of sometimes having to solve problems on case-by-case basis, for instance through the use of LCA.

6. Conclusions

The article shows that the waste hierarchy as a philosophy underlying waste and resource policy is not sufficient for achieving absolute reductions in material throughput in the economy. Although the aims of the waste hierarchy largely coincide with a dematerialization agenda, the potential for fulfillment of these aims is uncertain. The hierarchy is a solid strategy for avoiding landfill, but there is doubt about the merits of the hierarchy with regard to minimizing environmental impacts and natural resource use. Moreover, the policy implementation of the waste hierarchy has been limited mostly to the lower options. The limitations of the hierarchy are suggested to stem from several issues including the limited powers of waste managers with regard to prevention, the leniency towards the lowest options and the lack of attention for the highest ones, and a lack of guidance for implementation of the hierarchy and its use for decision-making across different sectors.

Several solutions are suggested to improve the use of the hierarchy with regard to achieving dematerialization. A value-based conception of waste along with appropriate collection infrastructure could prevent the loss of valuable waste and increase the timely reuse and recycling of used products that would otherwise be stored and neglected by their owners. The hierarchy can be more strictly specified regarding open-loop and closed-loop recycling, as well as for different combinations of materials and treatments, including bans on landfill of particular materials and products. To ensure total material throughput stays within acceptable limits, waste management targets can be directly related to higher level dematerialization goals with the help of material flow analysis.

It is found that dematerialization is not a guaranteed consequence of following the waste hierarchy, nor of following resource-oriented approaches like resource productivity or circularity. Resource-oriented approaches can however deal more effectively with problems that transcend the waste sector, and an approach which emphasizes resource productivity may marry dematerialization with the waste hierarchy by providing both a criterion for limiting total material throughput (decoupling) as well as for prioritization of waste treatments (resource productivity). Further research should focus on the merits of resource productivity with regard to waste management, improving collection practices for reuse, value-based conceptions of waste, and target setting for waste management and material throughput.

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