WASTE TO RESOURCES: MOVING TOWARD THE 2030 SUSTAINABLE DEVELOPMENT GOALS

Graham Aid
Ragn-Sells AB, Sweden & Linköping University, Sweden
David Lazarevic
Finnish Environment Institute, Finland & KTH Royal Institute of Technology, Sweden
Anders Kihl
Ragn-Sells AB, Sweden

ABSTRACT

The United Nation’s Sustainable Development Goals (SDGs) set an ambitious umbrella framework for regional and national governments around the world; addressing a breadth of areas such as providing for economic growth, reducing harmful pollution, improving resource efficiency and waste management, eradicating poverty, and enabling access to necessary infrastructure, housing and services. In working toward these goals, nations need to reconcile the potential of inter-goal conflicts arising from policy and steering mechanisms that only work toward specific goals. In reviewing the development of European waste policy, action has concentrated on achieving the broad societal goals of improving sanitation and reducing negative environmental and health consequences. Moving forward, many regions and nations have also begun to address waste considering multiple goals that strive for triple bottom line improvements via promotion of, for example, the circular economy. This raises the question, are the tools and political objects of past waste management regimes fit for the new functions and goals that are expected of future systems?

This paper investigates the policies and calculative tools that are a product of historic developments and assesses whether they are still relevant in light of our collective SDGs. Waste management principles and regulatory instruments (e.g. the waste hierarchy, and landfill taxes) are evaluated in the context of the SDGs. Similarly, key calculative tools, such as resource efficiency indicators (e.g. GDP/domestic material consumption) are evaluated in the context of the multiple SDGs. We argue that many of these principles and tools need to be reconsidered to support action toward the SDGs and to prevent inter-goal conflicts. Suggestions for adaptations of principles and tools are outlined and discussed. Such evaluation can benefit both European countries and emerging countries looking to “leapfrog” toward modern and balanced sustainable development and waste management.

KEYWORDS

Circular Economy; Resource Efficiency; Waste Hierarchy; Resource Transition

1 INTRODUCTION

Mankind benefits from resource use in the form of, for example, food, housing, clothing, transportation, sanitation and energy. Indeed, ever growing quantities of these goods and services will be required in the coming decades if a significant proportion of the global population is to achieve a 'decent' standard of life. However, the linear take-make-waste use of our material resources, in combination with continued economic growth, has led to increasing amounts of post-consumer waste, increasing need for resource extraction, and growing greenhouse gas emissions. The effects of these trends can cause great detriment to the environment and its inhabitants [1–5]. Additionally, we live on a finite planet; only approximately 27% of the 84 billion tons of resources entering the global economy today can be considered renewable [6]. This leads toward a situation of increasing scarcity of many of the materials society uses [5,7]. Continued mismanagement of these resources will further drive environmental and scarcity problems which threaten current and future generations' prosperity, health, and even political stability [7–9].

In September of 2015, on the 70th anniversary of the United Nations, more than 150 world leaders adopted the 2030 agenda for sustainable development [10]. This agenda includes 17 sustainable development goals (SDGs) and 169 targets meant to guide nations and stakeholders around the world in taking the transformative steps critically needed for flourishing people, planet and prosperity. While the agenda focuses on 17 goal areas, these goals are not independent between themselves; as one area can have tightly interwoven aspects and interactions with other goal areas. For example, progress toward Goal 11 "sustainable cities and communities", will depend much on work with areas such as education, sanitation, climate, employment, equality, etc. As put by David Nabarro, special adviser on the 2030 Agenda for Sustainable Development [11],

"The 17 goals represent an indivisible tapestry of thinking and action that applies in every community everywhere in the world. They are universal, but they are also indivisible… they represent a total, a completely intertwined lattice of action that is relevant for every human being everywhere."

Figure 1 summarizes the 17 SDGs. While tightly interconnected throughout, one can see some general themes to each row. The first row can be perceived as addressing basic human needs. The middle row focuses more on our economies; our production and consumption (socio-technical) systems. Finally, the last row looks mostly toward sustaining the environment and our common international prosperity.

In addition to having the broad support of the majority of governments around the world, the SDGs set themselves apart from previous global goals (such as the Millennium Development Goals) by explicitly noting the tight interdependence of the goals through cross-connecting targets and indicators [12]. As such, the agenda actively promotes institutions to step out of the predominant singular 'silo' focus when forming measures and activities for transitioning toward the SDGs. For example, when formulating policy for waste management, links and tradeoffs with other goal areas such as good health, zero hunger, and life below water should be considered.

Figure 1- The seventeen Sustainable Development Goals (SDGs) of the United Nations' Sustainable Development Agenda [10]

Waste management is an evolving socio-technical system, of which the goals and functions have changed over time. In the pre-industrial era, what we today call 'waste management' was primarily a resources issue; where dust-yards acted as material recovery facilities producing secondary raw materials [13]. Industrialisation changed waste management practices and from the end of the 19th century to late 60's/early 70's the key public value of waste management shifted one of hygiene and public health [14,15]. The next waste management transition started in the beginning of the 1970's, which saw environmental protection added to public health as the primary goal of waste management, due to the environmental impacts of landfilling and incineration which made their way into the public domain [15]. More recently, we have seen the sustainable use of natural resources added to these existing goals [16] as a result of increasing concerns over resource scarcity. Hence, the applicability of current waste management principles, objectives, policy instruments and tools need to be reexamined when considering waste management in the context of any new objectives and waste management functions.

Aim and Research Question

This paper aims to investigate the policies and calculative tools that are a product of historic developments and assesses whether they are still relevant in their current state in light of the global SDGs. In particular this article pursues the question:

Where historic approaches are seen as lacking, what are some potential adjustments or substitutes for policy and calculative tools to better support the collective work toward the SDGs?

In addressing this question, a literature review was performed to describe the historic development of policy tools for waste management and sustainable development. This review was followed by a comparative assessment of key principles and measures for waste management via the lens of the United Nation's SDGs.

2 THE EVOLVING NATURE OF WASTE MANAGEMENT

Waste management can be approached from a variety of perspectives. The appropriate selection of treatment technologies is essentially a downstream problem [17]. To understand waste management in terms of technical, economic, institutional and social forms of organisation a socio-technical approach is required.

The evolution of waste management described, very briefly, above can be understood an outcome of the transition [18] from one socio-technical system to another. The concept of regimes is a useful device in which to understand how socio-technical systems evolve. Socio-technical regimes can be understood in a narrow sense as “semi-coherent sets of rules, which are linked together …. The alignment between rules gives a regime stability, and ‘strength’ to coordinate activities” [18]. Waste management regimes are typically constituted of a number of principles that provide dynamic stability by guiding perceptions and actions. Whilst these principles can be understood as cognitive institutions [18], common across EU countries, whose articulation into regulatory institutions (e.g., Directives, laws and regulations), economic instruments (e.g., taxes) and political objectives (e.g., targets and definitions) leads to the variation of technological trajectories of national waste management regimes [16].

Several studies have been undertaken on waste management transitions, albeit from different perspectives, which point several major shifts in the socio-technical constellations of European waste management systems. From the perspective of conventional regimes, Buclet [17] suggests that the evolution of European waste management regimes (Germany, the Netherlands, France, Italy and Greece) can be characterised the two distinct periods. The ‘old’ waste management regimes which had stabilised in Western Europe by the 1970s and the ‘new’ Western European waste management regimes which emerged during the late 1960s/early 1970s and stabilised toward the end of the 1990s. The principles of the ‘old’ waste management included: responsibility of the local authority to collect waste; with appropriate frequency and means; to dispose of this waste without risk to public health; with as little nuisance as possible; the costs are borne by households and businesses (user pays); households and businesses were obliged to participate in the collective scheme; and the local authority was obliged to accept all waste supplied for disposal [17]. The rationale for a regime change was the recognition of a disequilibrium between the physical metabolisms of economies and the physical environment in which these economies are embedded. During the 1970s, new conventional principles for Western European waste management regimes emerged as a response to landscape changes primarily articulated by actors in the environment and energy movement. Buclet [17] highlights these ‘new’ principles as: the free trade principle, the subsidiarity principle, the precautionary principle, the proximity principle, the prevention principle, and the polluter pays principle (often referred to as extended producer responsibility). Table 1 synthesises the landscape factors, principles, policies and legislation, institutional articulation and dominant technologies of this ‘new’ regime. Although the waste hierarchy is not specifically mentioned in Table 1, we can see the presence of the waste hierarchy in terms of policies and legislation. For instance, target setting (for re-use, recycling, incineration and landfilling), bans and taxes all contribute to the aim of moving up the waste hierarchy.

Table 1. Development of national regimes for municipal solid waste 1970-2000

	1st Phase: 1970-1980	2nd Phase: 1980-1990	3rd Phase: 1990-2000
Events, trends, affecting regime	Increasing consumption and waste Increasing environmental awareness	Continued Continued Incidents on soil and ground water pollution caused by landfilling Incidents on toxicological effects of incineration NIMBY for waste disposal Incidents on waste exports Privatisation and deregulation	Continued Continued Less/none Less/none Continued Continued Continued Friction on standards, definitions, capacity, use, implementation and enforcement
Conventional principles of the MSW regime	From public health to environmental hygiene Municipalities collect and dispose	From environmental hygiene to managing resources and material cycles (NL D) Proximity principle and self-sufficiency principle Emerging conflicts with free trade	Extended producer responsibility Precautionary principle Valorisation principle (F)
Policies and legislation	Waste management plans introduced, with little impact Environmental licensing of disposal facilities	Development of national/regional waste plans (NL, D) With target setting for specific waste flows in terms of prevention, re-use, recycling, incineration and landfill Strict standards for landfilling and incineration (NL, D)	Continued (F, I, GR) Similar for valorisation and landfilling Packaging policies Landfill taxes (F, I, NL) Landfilling ban on combustible waste (NL, F) “Upstream” fees on packaging materials (D, F, I)
Institutional articulation	Waste management plans introduced, with little impact Environmental licensing of disposal facilities	Waste regions created to deal with NIMBY and scale increase Systems developed for notification and approval of waste exports Large operators enter waste management, multi-utilities and other	New instructions for collection of waste (only D) and processing (not NL) packaging waste
Dominant technologies	Landfilling Incineration (occ.) Compositing (occ.) Recycling, glass, paper	Controlled landfilling Incineration, tight standards Compositing (of organic waste. Plus metals and slag Prevention programmes , techniques	Of homogenous waste Continued Continued Continued, plastics/RDF EMS, eco-design, chain management, reverse logistics

Reproduced from Buclet [17]
D: Germany; F: France; GR: Greece; I: Italy, NL: the Netherlands

From a transition perspective, Parto et al. [14] identify two previous waste management transitions in the Netherlands. The first—with origins in the mid-19th century and stabilising between 1920 and 1960—was characterised by the move from private sector dominated collection, recycling, re-use and unregulated disposal, to public sector administration of centralised disposal systems. A second transition commenced in the early 1970s stabilising by the mid-1990s which was characterised by the move from centralised waste disposal to integrated waste management, with the reintroduction of private sector actors as major stakeholders. Kemp [19] notes this second transition highlights the move back to the "old practice of recycling" found in the Netherlands 150 years ago.

3 WASTE MANAGEMENT IN LIGHT OF THE SUSTAINABLE DEVELOPMENT GOALS

When formulating policy to support transitions toward the SDGs, interactions and trade-offs with other goals should be explicitly taken into consideration. This can be a daunting task when addressing waste management, as societies' governance of waste materials is tightly interwoven to several of the SDGs. SDG 12 "Responsible Consumption and Production" has the most targets specifically addressing waste management. Indeed, when analyzing the inter-relation of the goal's targets, Le Blanc [12] shows that SDG 12 is explicitly[1] interrelated with fourteen of the other SDGs; the most interconnections of any SDG. Figure 2 shows the interconnections of the SDGs via explicit cross goal mentions in targets.

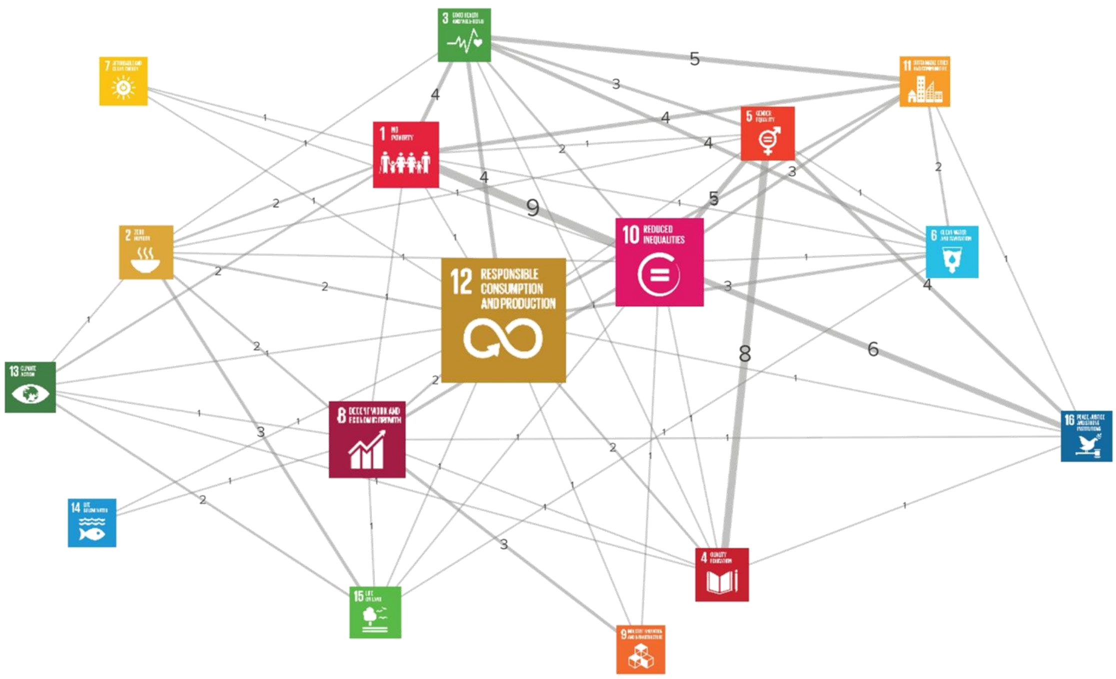

Figure 2 – The explicit interconnections of the SDGs via their targets. Data from [12]

[1]Figure 2 shows explicit links. These links are not assumed through interpretation, but clearly stated via the targets.

This tight interconnection between SDG 12 and the other goals is understandable as our management of resources (primary and waste) will have an impact, in particular, on progress related to areas such as water, economic growth, infrastructure, urban development, and land environments[2]. While the explicit and conceptual interconnections between waste management and the various SDGs are quite diverse in their detail, as shown in Supplementary Material A and Table 2, several of the inter-connections can be broadly classified as dealing with I) supporting the development of our socio-technical systems[3], and II) protecting human and environmental health and flourishing[4].

4 A COMPARATIVE ASSESSMENT OF POLICY TOOLS FOR WASTE

This section provides a comparative assessment of various policy tools for waste and resources in light of the SDGs and their targets. The analysis begins by focusing on the waste hierarchy, as it is a principle which many other policy tools, i.e. taxes, bans, goals, etc., are linked. Subsequently, our framework for assessing policy tools in relation to the SDGs is outlined. For each policy tool, a short background on the tool and its intention is given, followed by an assessment of how it fits with the SDGs and recommendations for how the tool might be adapted or otherwise treated in order to better encourage transitions toward our collective goals.

The waste hierarchy

The waste hierarchy established a priority order of waste treatment options in terms of lowest possible environmental impact and minimization of final waste [20]. It can be considered a cognitive institution in the way it categorises waste treatment options according to their perceived environmental impact [21]. See Figure 3 for an illustration of the waste hierarchy.

---

[2] Supplementary Material A (https://goo.gl/RdlvP0) highlights some of the specific targets in goals 6, 8, 9, 11, 12, 14, and 15 that are seen by the authors as particularly impacted by the way society builds policy around and directs waste management.

[3] These are dominated by Row 2 of the SDGs which in general focus on socio-technical and economic prosperity.

[4] These are dominated by Rows 1 and 3 of the SDGs in general which focus on people and planet, their health and flourishing.

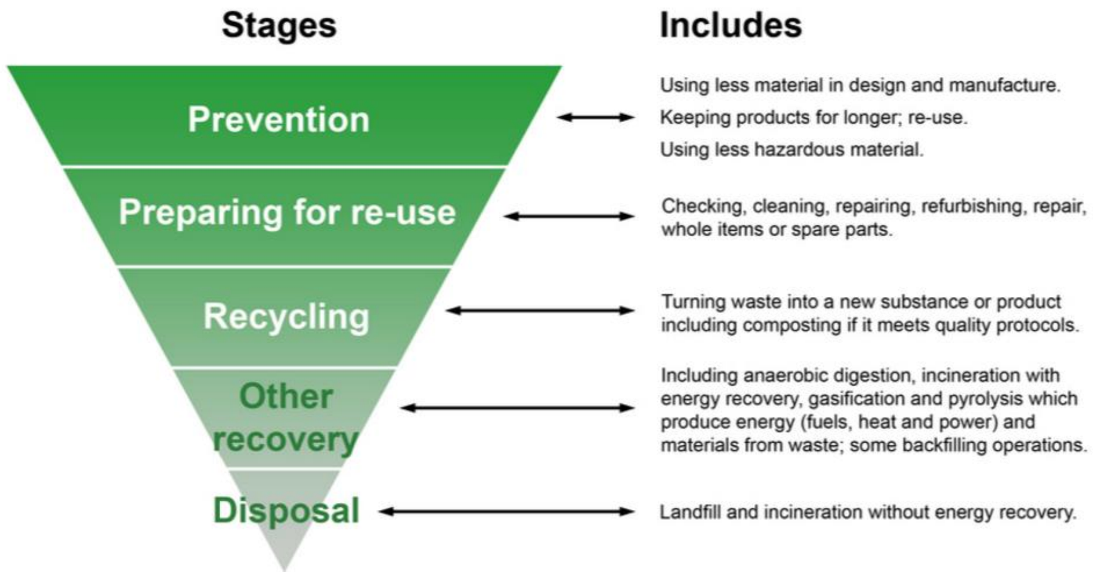

Figure 3 – The waste hierarchy as illustrated by DEFRA, UK [22]

Policy instruments

A number of policy instruments have been applied in order to achieve the broader policy objective of 'moving up the waste hierarchy'. At the European level, regulatory institutions and instruments establish the legal validity of the waste hierarchy. For instance, the waste framework directive 2008/98/EC [23] establishes the waste hierarchy as a priority order constituting the "best overall environmental option in waste legislation and policy", where "The following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy: (a) prevention; (b) preparing for re-use; (c) recycling; (d) other recovery, e.g. energy recovery; and (e) disposal." [23]. Recycling *targets* for specific materials (paper, metal, plastic and glass) of 50% by 2020, are established to drive waste up the waste hierarchy. Likewise, the landfill directive 1999/31/EC established landfill diversion targets to divert organic municipal waste away from landfill to treatment options further up the waste hierarchy (e.g., composting or anaerobic digestion).

At a national, and in some cases regional, level, regulatory instruments (e.g. landfill or incineration *bans*) and economic instruments (e.g. landfill and incineration *taxes*) have been implemented, in different constellations (i.e. target materials and level of taxation) to divert waste from lower levels of the waste hierarchy toward either material or energy recovery.

Comparison to SDGs

We begin our analysis by comparing some of the SDG targets related to resource management to the priority order of the waste hierarchy principle. This initial analysis is followed by an analysis looking at some of the policy instruments stemming in a large part from the waste hierarchy principle. We assess the priority order alternatives one-by-one via two goal groups elicited from resource management's inter-connections with other SDGs. Some of these key interrelations are highlighted in Table 2, for a more detailed analysis of interrelations see Supplementary Material A[5].

To simplify the analysis of the waste hierarchy's priority order options, we have represented the SDG relevance groups via questions.

For I) <u>supporting the development of our socio-technical systems</u>, we use a question that

[5] https://goo.gl/RdlvP0

addresses issues of resource efficiency[6], resource scarcity, and effective use of natural resources.

"*Does the activity de-facto replace/prevent virgin material extraction*?"[7]

For II) <u>protecting human and environmental health and flourishing,</u> we use questions that address pollution to water, air, and soil and assess the activity via its impact on the ability of future generations to pursue a good standard of life.

"*Does the activity remove contaminations from the eco-cycle*?" and, similarly,
"*Does the activity prevent debts for future generations*?"

Table 2 – Key SDG targets with relevance to resource management – divided into I) Socio-technical development and II) Human and environmental health and flourishing

SDG group	**SDG**	**Key Target of Relevance**
I	8	*Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programmes on sustainable consumption and production, with developed countries taking the lead*
	9	*By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities*
	11	*By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums*
	12	*By 2030, achieve the sustainable management and efficient use of natural resources*
II	3	*By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination*
	6	*By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally*
	11	*By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management*
		By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels
	13	*Integrate climate change measures into national policies, strategies and planning*
	14	*By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution*
	15	*By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements, and by 2030 ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development*

Prevention: I) Yes, given the function does not need to be replaced. II) This depends on the

[6] For example, functionally recycling copper prevents up to 500 tons of upstream waste and materials required to extract virgin copper (per functional cycle) [37].
[7] Functional recycling is classified by some as 'closed loop recycling'.

products contents.

Preparing for re-use: I) Yes, given the reuse provides a similar function. II) No.

Recycling: This depends in a large extent to what type of recycling is being performed. Is the recycling functional recycling (substituting virgin materials for the original upstream function of the waste) or is it down- or cascade-recycling (open loop recycling)? I) If functional recycling: Yes; If down-cycling, No. II) Depends on the products contents.

Other recovery, e.g. energy recovery: I) Yes. II) This depends on how the slags and ashes are handled.

Disposal: Similar to recycling this depends in large to what type of landfilling is being performed. Is the landfilling a safe EU qualified site with proper protections or is it an unsafe, uncontrolled landfill. The answer to the questions will also depend on what we are landfilling. Is the material something we need to separate from the eco-cycle? I) No. II) Yes, if this is the safe landfilling of undesired contaminants.

Recommendations for the waste hierarchy principal

As can be seen from recycling and landfilling above, the answers to our questions depend heavily on the value chain process and the specific properties of materials sent to such a process. Therefore, we have suggested an adapted version of the waste hierarchy to assist as a *rule of thumb* in guiding policy and regulatory instruments. The levels in the suggestion are not uncompromising, but are meant to help in better understanding the differentiation between e.g. safe landfilling of contaminants vs unsafe landfilling of materials, or functional recycling vs non-functional recycling. Table 3 presents the adapted decision support tool. In this adapted tool, the storage of materials is divided into three separate categories (safe stockpiling, safe landfilling of contaminants, and unsafe landfilling. Additionally, material recycling is divided into functional recycling and non-functional recycling for assessment.

Table 3- Proposed adapted waste hierarchy decision support tool comparing pathway options

Alternative	Example	De-facto replace/prevent virgin extraction?	Remove contaminations from the eco-cycle? Prevent debts for future generations?
SDGs Addressed			
Prevention	Sodastream	**Yes**	Depends on the product's contents
Repair and reuse	Shoe repair	**Yes**	**No**
Safe stockpiling - waiting for future functional recycling	Secure WEEE stockpiling / Secure tailing dams	**Yes** but time limited	Depends on how the stockpiling is done
Functional recycling	Recycling cardboard	**Yes**	Depends on emission requirements
Energy recovery	Waste incineration where fossil energy is replaced	**Yes**	Depends on how the slag and ashes are handled
Safe landfilling of contaminants	Landfilling in an EU certified landfill	**No**	**Yes**
Non-functional recycling	Construction of sound barriers that are not needed	**No**	Depends on the material's contents
Unsafe landfilling	Covering old landfills with mixed materials - refilling	**No**	**No**

Policy instruments working toward the Waste Hierarchy

National and regional governments have instituted various policy instruments in working toward the waste hierarchy principle. Policy instruments developed in the last decades include various bans, taxes, plans, goals, and standards[8]. In the rest of this section we take up three policy instruments: recycling rates as goals, the landfill tax, and resource use goals for comparative assessment alongside the SDGs.

Recycling Rates as Goals

Recycling rates have been used as policy instruments in many cities, nations, and regions in Europe [23,24]. Target recycling rates were designed to increase resource efficiency and to steer materials from processes lower on the waste hierarchy, such as landfill, which were seen

[8] See Table 1, for a detailed exploration of the development of these instruments.

as less material efficient and more environmentally hazardous. In recent decades target recycling rates have been created for a wide range of materials (C&D material, household waste, plastics, electronics, etc.) and are measured according to various methodologies (e.g. collection rates or internal recycling rates) [23,24].

When comparing various types of recycling to the SDGs, as shown in Table 3, not all recycling operations are equally beneficial in society's work toward the global goals. For recycling rates to be more in-line with the SDGs they should be structured to take into account whether 1) the recycling is functional or non-functional and 2) whether the recycling activity is returning potentially hazardous materials back into society[9]. As such recycling rates would not merely promote recycling for recycling's sake, but promote specific recycling actions that contribute to a sustainable transition.

Landfill Taxes

Similar to recycling rates, landfill taxes have been implemented in many nations as a policy instrument to steer material flows to options higher in the traditional waste hierarchy [25,26]. Throughout their use in recent decades, landfill taxes have proven effective in steering waste streams from landfill to other uses such as incineration or recycling [27]. Additionally, landfill taxes have created an added source of revenue for regional and national governments [28].

The technology and methods for safe landfilling have greatly improved in the last twenty years. However, the grouping of several technologies (e.g. unlined and poorly controlled landfills from the 1970s – and highly engineered, professionally controlled EU landfills in the 2010s) into the same 'landfill' option box and statistic column continues. As with recycling rates, landfill taxes do not differentiate between different forms of landfilling. Indeed, there are some regulations today on how a landfill should be constructed and run [23], as well as bans in some countries on what types of materials can be landfilled [26]. However, in many countries, landfilling (and in some cases storing) waste materials is still taxed with no regard to the function of the lanfilling (e.g. storage for later recycling, secure stabilization of contaminants, or least expensive disposal of materials) and with no regard to the quality of the landfilling operation above that of relevant regulation. As such, current landfill taxes can act as a market mechanism steering potentially hazardous materials away from secure deposit and instead toward circulation back into society.
One can see that the various storage alternatives are not equal when comparing the three categories of landfilling/storage listed in Table 3 to the SDGs. Safe storage of resources to achieve functional recycling in the near future can provide positive benefits to both the first and second SDG target groupings, given the storage and treatment of byproducts is performed in a benificial manner[10], while the safe landfilling of contaminants to remove them from the eco-cycle can prove benificial for human and environmental health (perhaps even more-so than non-functional recycling). Finally, unsafe landfilling provides no benefits to our resource efficiency or to our environmental health. Through comparison to the SDGs, landfill taxes should be re-evaluated, taking into consideration the development of landfilling technology and the reason for landfilling or storage.

Resource Use Metrics

While not explicitly connected to the waste hierarchy principle, material resource use is a particularly important driver of global development that has broad relevance for most of the

[9] For a review of the dynamic tendencies of what is considered hazardous in Sweden see Table 2 of [34].
[10] For a more detailed examination of the potential economic consequences of material storage (stockpiling) and waste material economies-of-scale see [34]

SDGs (especially Group I in our analysis) as well as our conception of how waste should be managed. Measuring resource use can help us understand how much material input our economies require for providing societal functions [29]. In measuring our resource efficiency over time (and looking for signals of decoupling of resource use from economic growth) it has become common to compare resource use metrics to economic metrics such as gross domestic product (GDP).

Arguably the most common resource efficiency measure in use today is that of DMC (Domestic Material Consumption) per capita / GDP per capita [29,30]. However this indicator does not include the wastes produced outside a country's borders connected to that country's consumption. In using DMC/GDP many nations have been able to show a relative decoupling of resource use and economic growth [29]. If the policy-makers for a nation take a global perspective, as outlined by the agenda [10], such 'off-shore' footprints should also be included. As shown by Wiedmann et al. [29], when these 'off-shore' footprints are included in material efficiency measures many developed nations and regions (including the EU-27) have not achieved decoupling in the last two decades. In fact, as shown in Figure 4, many of these nations are using *more* resources per dollar than 20 years ago.

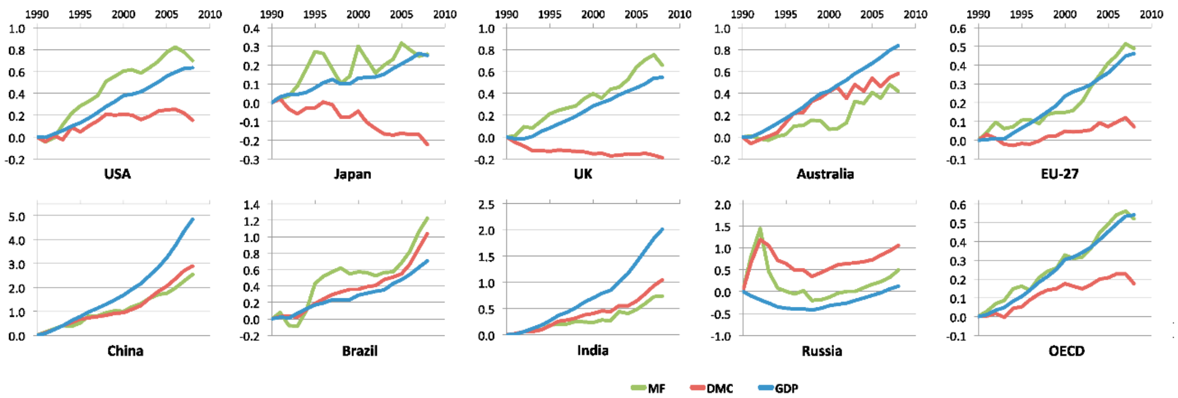

Figure 4 - Relative changes in total resource use (MF and DMC) and GDP-PPP-2005 between 1990 and 2008. Partial figure from [29]

In looking to work toward the SDGs, the Material Footprint (MF) metric[11] of Wiedmann et al. is more suited to mirroring the aims of goals working toward efficient use of material resources, however this measurement also leaves out important material fractions which impact the health of our water systems, air quality, and land ecosystems. Both the DMC and the MF metrics leave out unused extracted materials (domestic and 'offshore'). This unused fraction includes, for example, mining wastes which create immense acid mine drainage problems [31], which cost tens of billions of dollars yearly to remediate internationally [32]. The most suiting indicator to measure resource efficiency may be that of Total Material Consumption (TMC). This indicator includes all domestic and 'offshore' materials required for a nation's consumption. In applying TMC as an indicator, nations would achieve a better understanding of the entire footprint of their nations, and in turn be able to measure the full consequences of activities such as functional recycling vs down-cycling. For more details on what DMC, MF (RMC), and TMC do, and do not, include see Supplementary Material B[12].

5 DISCUSSION

[11] The Material Footprint (MF) metric is also known as the Raw Material Consumption (RMC) metric.
[12] https://goo.gl/uemtTx

Conflicts in moving toward goals

Moving forward, how we manage our waste resources will have an impact on many of our shared goals. Sometimes, as illustrated in Table 3, actions that will benefit one/several goal/s could in turn have a negative impact on our work toward other goals. Therefore it is important that policy makers and executive authorities deal with such goal conflicts in a transparent way. Rules of thumb, such as those elaborated above, can give general guidance along with other principles (such as the precautionary principle). However, at times, deeper systems studies will need to be done to support decision on how to deal with goal conflicts. Especially when new waste streams arise and as new knowledge on various wastes' impacts to the SDG targets is produced.

Potential for proactive policy tools

Many nations have implemented anti-smoking campaigns and tobacco taxes as they realize what we do today (smoking or not) can have a significant impact on our common goals; even if the major consequences will not come for several years. This may be the case for some of our critical resources as well. We can see, for example, that phosphate is predicted to be a critical material (important for the economy, hard to substitute, and increasingly more difficult to extract) in the coming decades [33–35]. Being mindful of such situations, policy tools aiming to maximize recovery, utilization, and recycling of phosphate from wastes (such as enabling safe stockpiling and extraction by signaling stable prices for new investment) could provide synergistic effects in working toward current and future environmental and resource focused targets.

Relevance to the circular economy

If we are to increasingly see wastes as a resource, as put forth by the new policy measures such as the European Circular Economy Package [36], how relevant will goals such as waste minimization be in regards to the SDGs? In a circular economy, key elements and molecules need to circulate in closed loops, and as such they should not be "done away with" or be "taxed away". Therefore the principle is that the "right" substances should be circulated. In line with the comparisons above, leadership is needed is helping to make further differentiations between wastes and between life cycle options. In working toward our multiple goals, wastes that are sent for lower value applications (non-functional recycling) and wastes that create current and future environmental and health problems should be minimized - not cycled. However, wastes that enable functional, and safe cycling should not be indifferently treated in the same manner.

Future work

There are many aspects that can be investigated regarding the interplay of waste and the SDGs. Two areas of particular importance will be that of policy tools not included in this analysis, and the relevance of policy development in Europe in relation to emerging economies.

This article took up the waste hierarchy, recycling rates as goals, landfill taxes, and resource use indicators as historically derived policy tools focused on waste and resource management. Other key policy tools not touched upon in depth in this article include the precautionary principle, the proximity principle, and the polluter pays principle, and the subsidiarity principle. Future research would benefit from the analysis of these tools (principles, regulative, prescriptive) alongside the SDGs.

European management of waste has gone through several regimes according to, among other things, the goals and trends of the time (See Table 1). This article has described some situations, where historic developments in the EU have led to sub-optimal measures in regards to the SDGs. Should emerging economies who have yet to deal with issues highlighted in earlier European regimes take the same path? Is there potential for these nations to leapfrog the EU in their steps for progress?

6 CONCLUSION

As highlighted by the SDGs, our world is facing vast and interconnected challenges; e.g. the challenges of climate change, food security, social injustice, lack of water, and material resource scarcity. Working to solve such interconnected problems will require a systems' approach and a mindful review of our historic and potential future policy tools for waste and resources. This article investigated some key European policy tools for waste and resources and assessed their effectiveness in light of the SDGs. The comparison showed that further differentiations between value chain options for waste impacted the evaluation of options which are often grouped as one. For example, the safe landfilling of undesired contaminants was not shown as equal (under the SDGs) to the unsafe landfilling of materials or to the stockpiling of critical materials for extraction. Similarly, functional recycling and non-functional recycling will give different effects in working toward the SDGs. As such 'across the board' landfill taxes and recycling rate goals should be reevaluated in working toward the sustainable development agenda. Additionally, in measuring our progress toward resource efficiency, consumption indicators which exclude unused resources and international resource use can give quite different trend signals than more complete indicators that do include broader resource use metrics. Systems focused reevaluations for waste and resource policy tools can benefit both European countries and emerging economies looking to "leapfrog" toward modern and balanced sustainable development and waste management.

REFERENCES

[1] Blanchard, O., 1992. Energy consumption and modes of industrialization. Energy Policy, 20, 1174–1185.
[2] Chertow, M., 2000. The IPAT Equation and Its Variants. J. Ind. Ecol., 4, 13–29.
[3] Wenheng, W., Shuwen, N., 2008. Impact Study on Human Activity to the Resource-environment Based on the Consumption Level Difference of China's Provinces or Autonomous Regions. China Popul. Resour. Environ., 18, 121–127.
[4] Gerbens-Leenes, P.W., Nonhebel, S., Krol, M.S., 2010. Food consumption patterns and economic growth. Increasing affluence and the use of natural resources. Appetite, 55, 597–608.
[5] Singh, J., 2016. Beyond Waste Management: Challenges to Sustainable Global Physical Resource Management. The Royal Institute of Technology, Sweden,
[6] SERI, WU, 2016. The Global Material Flow database
[7] Dobbs, R., Oppenheimer, J., Thompson, F., Mareels, S., et al., 2013. Resource Revolution : Tracking global commodity markets Trends survey 2013. McKinsey Glob. Inst., 44.
[8] Ross, M., 2002. Natural Resources and Civil War: An Overview with Some Policy Options.
[9] World Bank, Global Mining., Washington DC.
[10] UN, 2015. A/RES/70/1 - Transforming our world: the 2030 Agenda for Sustainable Development.
[11] UNIDO, 2016. Making the Goals Happen. MakingIt, 26–27.
[12] Le Blanc, D., 2015. Towards Integration at Last? The Sustainable Development Goals as a Network of Targets. Sustain. Dev.,187, 176–187.
[13] Velis, C.A., Wilson, D.C., Cheeseman, C.R., 2009. 19th century London dust-yards: A case study in closed-loop resource efficiency. Waste Manag., 29, 1282–1290.

[14] Parto, S., Loorbach, D., Lansink, A., Kemp, R., 2007. In: Parto, S, Herbert-Copley, B (Eds.), Ind. Innov. Environ. Regul. Dev. Work. Solut., United Nations University Press, pp. 233–257.
[15] Hafkamp, W., 2002. Munic. Waste Manag. Eur., Springer Netherlands, Dordrecht, pp. 7–26.
[16] Lazarevic, D., Buclet, N., Brandt, N., 2011. In: Lakkala, H, Vehmas, J (Eds.), Proc. Conf. "Trends Futur. Sustain. Dev., Futures Research Centre, University of Turku, June 9-10, 2011 Tampere, Finland, pp. 214–229.
[17] Buclet, N., 2002. Municipal waste management in Europe: European policy between harmonisation and subsidiarity., Kluwer Academic Pub, Dordecht.
[18] Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. Res. Policy, 33, 897–920.
[19] Kemp, R., 2007. In: Lehmann-Waffenschmidt, M (Ed.), Innov. Towar. Sustain. Cond. Consequences, Physica-Verlag, pp. 87–94.
[20] Lazarevic, D., Buclet, N., Brandt, N., 2010. The influence of the waste hierarchy in shaping European waste management : the case of plastic waste. Reg. Dev. Dialogue, 31, 124–148.
[21] Lazarevic, D., 2012. Life Cycle Thinking and Waste Policy: Between Science and Society.
[22] DEFRA, 2011. Guidance on applying the Waste Hierarchy. Dep. Environ. Food Rrual Aff., 1–14.
[23] European Commission, 2008. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives Text with EEA relevance.
[24] Haupt, M., Vadenbo, C., Hellweg, S., 2016. Do We Have the Right Performance Indicators for the Circular Economy?: Insight into the Swiss Waste Management System. J. Ind. Ecol.,.
[25] Nicolli, F., Mazzanti, M., 2013. Landfill diversion in a decentralized setting: A dynamic assessment of landfill taxes. Resour. Conserv. Recycl., 2013, 81, 17–23.
[26] CEWEP, 2016. Landfill taxes & bans, 1–3.
[27] Bartelings, H., Beukering, P.J.H. van, Kuik, O.J., Linderhof, V.G.M., et al., 2014. Effectiveness of landfill taxation., Dept. of Economics and Technology.
[28] Waste Sweden, 2014. Klusterinitiativ. En förstudie om kommunal avfallsverksamhet som motor i regional utveckling.
[29] Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., et al., 2015. The material footprint of nations. Pnas, 112, 6271–6276.
[30] Schaffartzik, A., Wiedenhofer, D., Eisenmenger, N., 2015. Raw Material Equivalents: The Challenges of Accounting for Sustainability in a Globalized World. Sustainability, 7, 5345–5370.
[31] Blowes, D.W., Ptacek, C.J., Jambor, J.L., Weisener, C.G., 2003. Treatise on Geochemistry, vol. 9, Elsevier, pp. 149–204.
[32] Feasby, D.G., Blanchette, M., Trembly, G., 1991. In: MEND Secretariat (Ed.), 2nd Int. Conf. Abatment Acid Drain., Tome, pp. 1–26.
[33] McKinsey Global Institute, 2011. Resource revolution: Meeting the world's energy, materials, food, and water needs., London.
[34] Kihl, A., Aid, G., 2016. Driving Forces and Inhibitors of Secondary Stock Extraction. Open Waste Manag. J., 9, 11–18.
[35] Van Kauwenbergh, S., 2010. World Phosphate Rock Reserves and Resources., Muscle Shoals, AL.

[36] EC, 2015. COM(2015) 614 final: Closing the loop - An EU action plan for the Circular Economy. Brussels.
[37] Schmidt-Bleek, F., 1999. The factor 10/MIPS-concept: bridging ecological, economic, and social dimensions with sustainability indicators.