

International comparative study of 3R and waste management policy developments

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Abstract Reduce, reuse, and recycle (3R) policies form the basis of waste management and global warming countermeasures globally, so we conducted a comparative study of 3R and waste management policies in the European Union (EU), USA, Korea, Japan, China, and Vietnam.

An international workshop for 3R and waste management policymakers was held in Kyoto, Japan, and a bibliographic survey was also conducted to collect data. 3R policies are clearly given priority in the hierarchy of waste management in every country studied. Thermal recovery,

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which includes power generation from waste heat and methane gas collected from organic waste, is also a priority; this is consistent with the increased use of countermeasures to reduce greenhouse gas (GHG) emissions. In the EU, waste management is characterized by practical and effective 3R policies through the development of realistic regulations and by the policymakers' desire to simplify management systems. The policy ideal in China, however, is the development of a circular economy that targets reductions in the amount and hazardousness of waste. Limits on the number of final disposal sites, strategies for procuring resources, and GHG emission countermeasures are closely linked with 3R policies, and further development of 3R policies in parallel with such issues is expected.

Keywords 3R · Recycling · Waste management · International comparison · Policy developments

Introduction

It is generally recognized that reduce, reuse, and recycle (3R) and waste management policies form the basis of developing a material cycles society. However, 3R and waste management policies differ among countries owing to each country's particular circumstances or political strategies. In this study, therefore, our aim was to compare the current situation, historical background, and effectiveness of 3R policies within one region [the European Union (EU)] and five countries (USA, Korea, Japan, China, and Vietnam). The characteristics and effectiveness of 3R policies in each country and within the EU are examined, and the future directions of developments for a material cycles society are discussed.

Methods

The Kyoto workshop on 3R and waste management was held in Kyoto, Japan, on 29–30 October 2009. The aim was to collect comparative data on institutional schemes of 3R and waste management. The participants were policymakers and researchers from the European Commission, Germany, England, Italy, Denmark, Sweden, USA, Korea, China, Vietnam, and Japan. EU Member States are generally considered to have developed integrated and advanced waste management systems, whereas Asian countries have been importing recyclable resources in recent years, essentially playing the role of global recycling facilities. Given these circumstances, the purpose of the workshop was to compare and discuss 3R and waste management policies in these different regions and to clarify their characteristics and effectiveness. As a means of collecting more

information, copies of Japan's national report on 3R and waste management were distributed to participants in advance and similar reports were obtained from participating countries. In addition, a field survey was carried out in several countries to confirm the condition of treatment facilities and waste management systems and to better understand the countries' policies and their effectiveness.

Results and discussion

Trends in 3R and waste management policies

Characteristics and constitution of waste management policies

Table 1 shows the waste management policy frameworks in the EU and the five countries. Driven by global environmental problems and the depletion of natural resources, the major focus of waste management policies changed during the late twentieth and early twenty-first centuries. Formerly, the focus was on promoting environmentally sound waste treatment to avoid local environmental pollution, whereas policies have shifted to pursue the concept of sustainability by introducing and promoting 3R policies.

USA Enactment of the Resource Conservation and Recovery Act (RCRA, significantly amended in 1984), Pollution Prevention Act (amended in 2002), and Resource Conservation Challenge (2004) has led to the development of a waste management policy centering on resource conservation and pollution prevention in the USA. The RCRA states the fundamental principles for the treatment of solid waste and for the reduction and management of hazardous wastes, but municipal solid waste (MSW) is managed under the regulations of each state.

Under the Pollution Prevention Act, the 2010–2014 Strategic Plan is currently being drawn up. According to a draft, the purposes of the plan are to (1) reduce greenhouse gas (GHG) emissions, (2) reduce the manufacture and use of hazardous substances, (3) decrease the use of water, (4) create effective business activities, and (5) develop institutions and integrate established practices for pollution protection. The draft also states that achievement of the first four goals will result in co-benefits [1].

The Resource Conservation Challenge is a program complementary to the RCRA and Pollution Prevention Act. It aims to prevent pollution and promote reuse and recycling, reduce the use of hazardous chemicals, and conserve energy and resources. Its action plan sets MSW recycling targets [2].

The US Environmental Protection Agency (EPA) is also currently working on amending the EPA Strategic Plan. According to the draft, they will shift the political priority

Table 1 Waste management frameworks

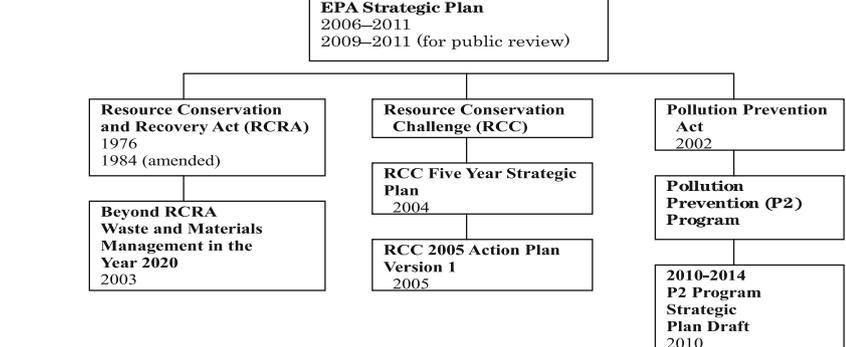
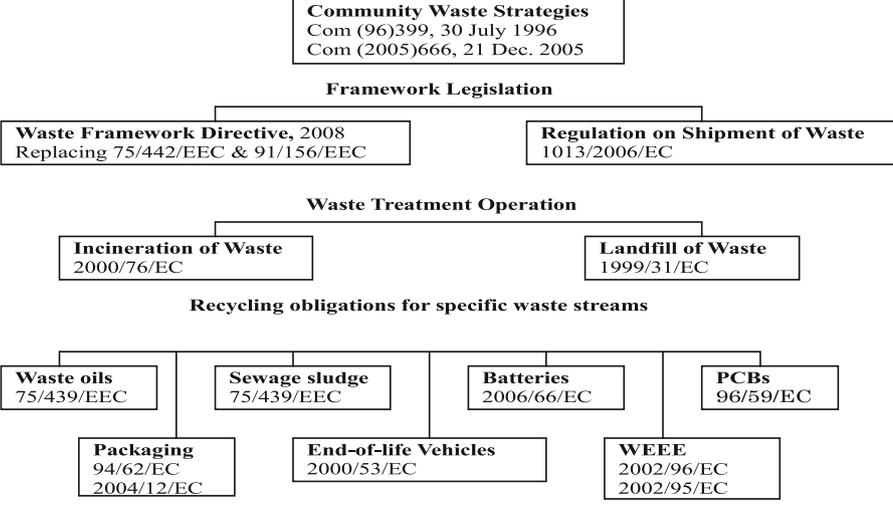
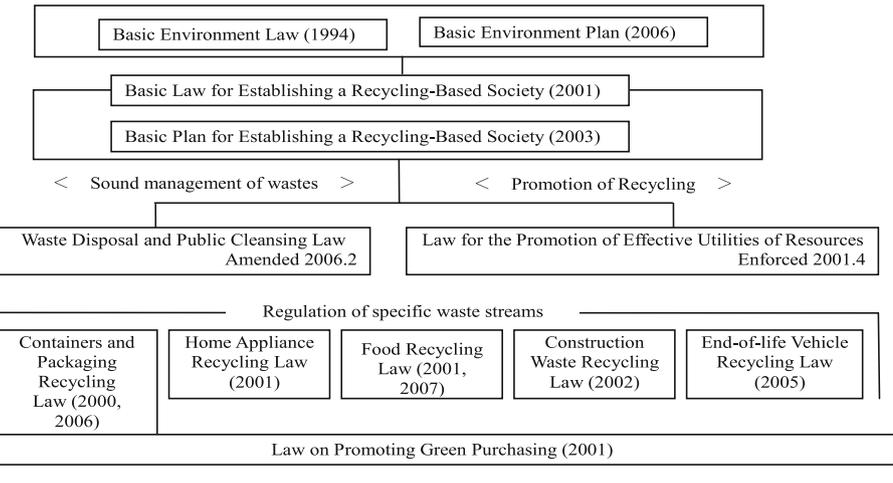
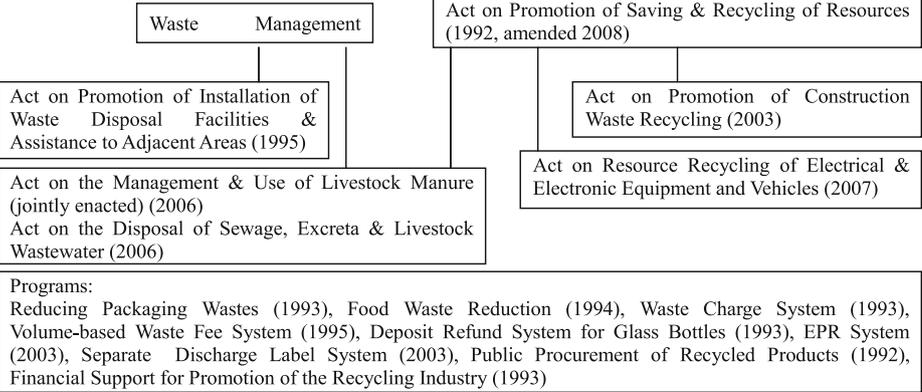
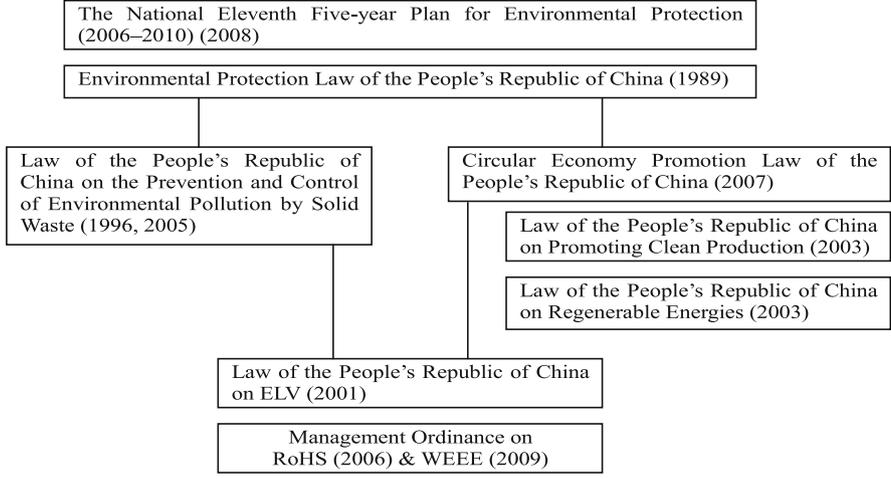
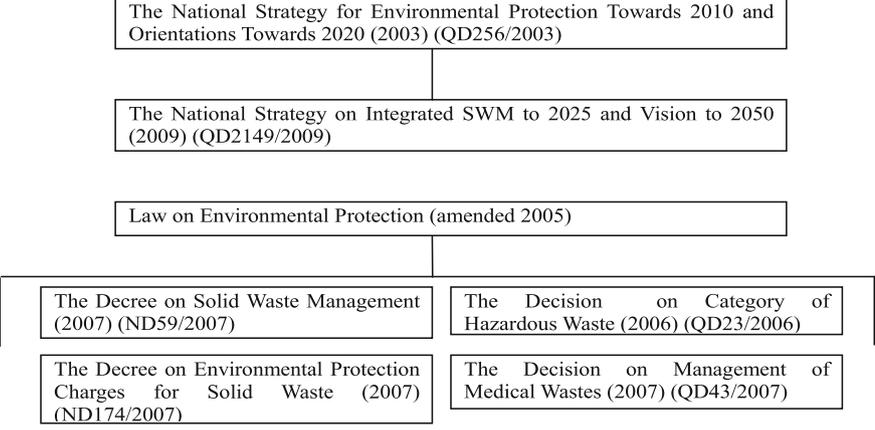
Country/ Area	Framework
US 32), 33)	
E U 5)	
Japan 34)	

Table 1 continued

Countries	Waste management system
<p>Korea 16), 31), 35)</p>	<p>Comprehensive National Waste Management Plan, Basic Plan for Resource Recycling, Basic Plan for Resource Recirculation</p>  <p>Act on Promotion of Installation of Waste Disposal Facilities & Assistance to Adjacent Areas (1995)</p> <p>Act on the Management & Use of Livestock Manure (jointly enacted) (2006)</p> <p>Act on the Disposal of Sewage, Excreta & Livestock Wastewater (2006)</p> <p>Act on Promotion of Saving & Recycling of Resources (1992, amended 2008)</p> <p>Act on Promotion of Construction Waste Recycling (2003)</p> <p>Act on Resource Recycling of Electrical & Electronic Equipment and Vehicles (2007)</p> <p>Programs: Reducing Packaging Wastes (1993), Food Waste Reduction (1994), Waste Charge System (1993), Volume-based Waste Fee System (1995), Deposit Refund System for Glass Bottles (1993), EPR System (2003), Separate Discharge Label System (2003), Public Procurement of Recycled Products (1992), Financial Support for Promotion of the Recycling Industry (1993)</p>
<p>China 19)</p>	 <p>The National Eleventh Five-year Plan for Environmental Protection (2006–2010) (2008)</p> <p>Environmental Protection Law of the People's Republic of China (1989)</p> <p>Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste (1996, 2005)</p> <p>Circular Economy Promotion Law of the People's Republic of China (2007)</p> <p>Law of the People's Republic of China on Promoting Clean Production (2003)</p> <p>Law of the People's Republic of China on Regenerable Energies (2003)</p> <p>Law of the People's Republic of China on ELV (2001)</p> <p>Management Ordinance on RoHS (2006) & WEEE (2009)</p>
<p>Vietnam 22), 27)</p>	 <p>The National Strategy for Environmental Protection Towards 2010 and Orientations Towards 2020 (2003) (QD256/2003)</p> <p>The National Strategy on Integrated SWM to 2025 and Vision to 2050 (2009) (QD2149/2009)</p> <p>Law on Environmental Protection (amended 2005)</p> <p>The Decree on Solid Waste Management (2007) (ND59/2007)</p> <p>The Decision on Category of Hazardous Waste (2006) (QD23/2006)</p> <p>The Decree on Environmental Protection Charges for Solid Waste (2007) (ND174/2007)</p> <p>The Decision on Management of Medical Wastes (2007) (QD43/2007)</p>

from waste management to resource management as a strategy to reduce GHG emissions [3].

Waste management policy in the USA is currently integrated and includes measures to reduce GHG emissions, manage hazardous chemicals, and conserve natural resources.

EU In the EU, the Waste Framework Directive (2008) [4] has been established as the basic waste management legislation, and EU Member States have implemented domestic laws on waste management under this directive. The most notable characteristic of the EU's waste management system is the promotion of 3R policies in parallel with waste management regulations. The Directive on the Incineration of Waste (2000) and the Directive on the Landfill of Waste (1999) concern waste management. The Directive on the Incineration of Waste primarily sets standards for the application of best available techniques/best environmental practice (BAT/BEP) for environmental conservation, and it has had a notable effect in reducing dioxin emissions. The Directive on the Landfill of Waste sets standards for a tiered reduction of the disposal of wastes containing organic materials at final disposal sites (i.e., landfills). To reduce the amount of wastes for final disposal, the directive has promoted the introduction of 3R policies [5, 6]. The Directive on Waste Electrical and Electronic Equipment (WEEE) and the Directive on Restriction of Hazardous Substances (RoHS) were established in 2002 for the purpose of promoting sound material recycling and preventing pollution from the hazardous chemicals contained in such wastes. WEEE recycling has been promoted through the introduction and use of WEEE collection points. The extended producer responsibility (EPR), which requires that a producer of products manages them through reuse, recycling, and disposal even after their useful life and must develop and produce products that are easy to reuse and recycle, was applied to the basic concepts for the development of 3R policies for WEEE and packaging. Germany was the first country within the EU to apply EPR to packaging waste, in 1992 [7], and that was followed by legislation on collecting and recycling of end-of-life vehicles (ELV) and waste batteries.

Although EPR is recognized as an important concept in the UK, its waste management policy is based on the principle of shared responsibility which presupposes that the responsibility for production of a product, circulation, consumption, disposal, and recycling is shared by everyone [8]. The government has signed a voluntary agreement with industry to reduce wastes and promote recycling of packaging materials, food, and paper. The UK introduced a landfill tax, which is currently 40 GBP/t and will increase by 8 GBP annually to 72 GBP/t in 2013. Italy has introduced economic measures through a unit-based fee system whereby a management fee is paid according to the

quantity of waste to discharge to encourage better waste management, and about 15% of municipalities, or 29% of Italy's population, currently are covered by this type of system [9].

Japan The basic law for establishing a Material Cycles Society (2000) defines recyclable resources and states the principles for their utilization [10]. The law has the goal of a society wherein the consumption of natural resources is restrained and the environmental load is reduced as far as possible, through promotion of the 3R as well as the environmentally sound waste management. The law set quantitative targets for three indicators: resource productivity, cyclical use rate, and final disposal amount. These goals have also been pursued on a global scale through the Group of Eight (G8) process known as the 3R initiative. The basic legislation concerning waste management in Japan consists of the Waste Disposal and Public Cleansing Law (amended in 2010), which is the basic law of waste management, and the Law for the Promotion of Effective Utilities of Resources (2001), which is the basic law for recycling of used resources. The laws for recycling specific items such as containers and packaging, WEEE, food waste, construction waste, and ELV were established in these laws. In addition, the Law on Promoting Green Purchasing was enacted in 2001, with the purpose of promoting government procurement of recycled products. Japan's waste management system is characterized by the existence of two independent basic acts on waste management as well as on material recycling, under which the laws concerning recycling of specific items are laid down. The legislative framework is similar to those of the EU and Korea.

Korea The basic legislative framework on waste management in Korea consists of the Waste Management Act (amended in 2007) and the Act on Promotion of Resources Saving and Recycling (amended in 2008) [11]. The full-text amendment of the Waste Management Act was implemented in 1991 to introduce waste recycling, a deposit system, and standards for incineration and landfill [12]. The Act on Promotion of Resources Saving and Recycling is a revision of the Act on Promotion of Resource Recycling enacted in 2002, and it lays out the basic plan for material reuse, the fee system for waste treatment, regulations on the use of one-way packaging and goods, and EPR [13]. EPR was also included in the Act on Resource Recycling of Electrical and Electronic Equipment and Vehicles, which was enacted in 2008 [14].

The initial driving force for the promotion of 3R policies in Korea was a strong campaign by neighborhoods against the construction of waste treatment facilities [14]. The Promotion of Installation of Waste Disposal Facilities and Assistance to Adjacent Areas Act [15] was enacted in 1995 to ensure that facilities were adequately established. At the

same time, a fee system for waste generation was introduced as a strict economic measure against increases in the amount of waste, in addition to other measures such as separated collection and regulations on the use of one-way packaging. From 2005, organic wastes were no longer accepted at landfills and had to be recycled [16].

China The basic environmental legislation in China is the Environmental Protection Law of the People's Republic of China (1989), under which other laws were established. The Environmental Pollution Prevention and Control Law by Solid Waste was enacted in 1996 and amended in 2005. It introduced the application of 3R policies for solid municipal, industrial, and hazardous wastes and required not only a reduction in the amount of waste but also in its hazardousness [17]. Treatment consists mainly of detoxification of wastes, but the law does not establish a priority in terms of treatment methods (e.g., incineration or landfill). The inventory on hazardous wastes was also established in this act.

The Circular Economy Promotion Law, enacted in 2008, is the basic law concerning material cycles and waste management in China [18]. Several factors are said to be behind the enactment of the Circular Economy Promotion Law, including a lack of resources, insufficient use of recycled materials, and a national strategy of tackling the problem of resource depletion, accompanied by the desire for sustainable economic growth. In other words, the substantial lack of resources in the face of a rapidly growing economy caused China to expand its use of recycled materials. At the same time, China's economic growth was accompanied by a massive increase in the amount of waste generated; this produced serious social and environmental problems and an urgent need to improve China's waste management systems. Consequently, the integrated use of recycled resources and the promotion of zero emissions at production facilities were considered to be essential, especially in the circular economic zone where many industrial facilities are located. The Circular Economy Promotion Law thus emphasizes the promotion and management of 3R activities in the industrial sector and includes economic incentives, such as a reduction in, or exemption from, the value-added tax, for the integrated and circulative use of resources [19].

In order for the Circular Economy Promotion Law to have substantive effects, WEEE and MSW management systems needed to be enhanced through improving recycling and waste treatment techniques and strengthening the financial base of companies utilizing recycled resources. Although the focus of waste management policies in China has been on the problem of resource depletion and maintaining rapid economic growth, the environmental protection system with regard to imported recycling materials also needed improvements. Furthermore, measures

also had to be taken against increased MSW caused by population expansion and economic development in urban areas. To this end, the ELV Recycling Law (2001) and Management Ordinance on WEEE (2009) were established [19]. The production of automobiles is increasing dramatically in China and is predicted to result in a massive increase in ELV in the near future. Nevertheless, rather than ensuring sound waste management of ELV, the ELV Recycling Law emphasizes the prevention of illegal remodeling, ensures car safety, and promotes the purchase of new models with environmentally friendly features. Furthermore, existing recycling facilities lack the capacity to meet the predicted demand for ELV recycling [20, 21].

Vietnam The basic legislation for environmental management in Vietnam is the Environmental Protection Law (amended in 2005), which takes precedence over other laws concerning waste management. The waste management system was established under the Decree on Solid Waste Management (2007), which establishes environmental protection measures for solid waste treatment [22]. The Decree covers the overall waste management policy and prioritizes recycling, reutilization, and treatment and recovery, to prevent land consumption by landfills [23]. The collection, transport, and treatment of waste are subject to fees of 40,000 VND/t for MSW and as much as 6,000,000 VND/t for hazardous wastes [24]. Hazardous and medical waste categories are defined under the decision [25, 26]. The former regulation on the control of hazardous wastes (decision no. 155/1999/QD) was incorporated in the Decree regulations on solid waste management as articles 70–75 at the time of its amendment.

The targets for waste management in Vietnam are determined under The National Strategy on Integrated SWM for the years of 2025 and 2050 (2009) [27]. The mid-term strategic targets for 2025 are to have separated MSW. Solid wastes from business activities in urban areas and hazardous and non-hazardous wastes from industrial sectors are to be managed completely (100%) in an environmentally sound manner, and 90% of all construction wastes in urban areas and municipal solid wastes in the suburbs are to be collected. In addition, the strategy calls for minimizing the amount of final disposal by 2050 through the collection of all solid wastes, promotion of 3R policies, and employment of advanced and environmentally sound techniques. In Vietnam's case, the incentive for the promotion of 3R activities in urban areas seems to arise from a sense of crisis about the upcoming depletion of land available for use as landfills [28].

Waste management targets

The EU and other countries employ a common hierarchical approach in their 3R and waste management

Table 2 Recycling targets in the USA [2, 32]

2001 MSW	Generation (Mt)	Generation rate ^a (%)	Recovery (Mt)	Recovery rate (%)	%	Proposed 2008 recovery goals		
						Mt	Increase (%)	Increase (Mt)
Organic waste								
Food, other	26.2	11.4	0.7	2.8	5	1.28	2.2	0.58
Yard waste	28.0	12.2	15.8	56.5	60	16.8	3.5	1.0
Paper								
Paper and paperboard products	81.85	37.2	36.7	44.9	53.8	44.1	8.9	7.32
Packaging and containers								
Wood packaging	8.17	3.6	1.25	15	24	2	9.2	0.75
Plastic wrap	2.58	1.1	0.17	6.6	19	0.5	12.8	0.33
Beverage containers	11.3	5.0	2.93	26	39	4.36	12.7	1.43
Total	158.1	68.9	57.55	36.4	43.7	69.04	7.3	11.5

Other targets were to maintain the national average MSW generation rate at not more than 4.5 lb (about 2 kg) per person per day each year through 2008; and to increase recycling rate of the total annual MSW produced to 35% in 2008 from 31% in 2002

Mt million ton

^a Generation rate; Generation (Mt)/the total 2001 MSW generation (229.2 Mt) × 100

Table 3 Waste management targets in the EU [30]

Targeted products	Targeted period	Min. recovery	Min. recycling	Collection rate
Packaging	2008	60%	55%	
Cars	2015	95%	85%	100%
Electronics	2006	70%	50%	Min, 4 kg per inhabitant per year
Batteries	2011		50–75%	
	2012			25%
	2016			45%
Tires	2006	Zero landfill of tires		
Biowaste diverted from landfills	2006	Reduction to 75% of the 1995 level		
	2009	Reduction to 50% of the 1995 level		
	2016	Reduction to 35% of the 1995 level		
New targets	2015	Separate collection of paper, metal, plastic, and glass		
Waste framework directive	2020	50% of household waste		
	2020	70% of construction and demolition waste		

Table 4 Waste management targets in Japan [10, 37]

	Fiscal year 2000 (base year)	Fiscal year 2006 (performance)	Fiscal year 2015 (target)
Resource productivity	260,000 yen/t	350,000 yen/t	420,000 yen/t
Circulation use ratio	10%	12.5%	14–15%
MSW, per person per day (decrease)	1,185 g	1,116 g (–5.8%)	1,070 g (–10%)
Household waste, per person per day (decrease)	654 g	601 g (–8.1%)	520 g (–20%)
MSW from business sectors	17.99 Mt	15.82 Mt (–8.1%)	14.40 Mt (–20%)
Recycling amount (increase)	5.9 Mt (~11%)	10 Mt (~20%)	12 Mt (~24%)
Final disposal	56 Mt	29 Mt	23 Mt

Table 5 Recycling targets for individual items in Japan [10]

Classification	Item	Target rate (%)	Definition of target	Target fiscal year
Containers and packaging	Glass bottles	91	Percentage of cullet use relative to the amount of glass bottles manufactured in Japan	2010
	PET bottles	–	–	–
	Plastics containers and packaging	–	–	–
	Paper containers and packaging	–	–	–
	Steel cans	–	–	–
	Aluminum cans	–	–	–
	Paper cartons	–	–	–
	Cardboard	–	–	–
Paper		62	Percentage of recycled paper use relative to the amount of paper manufactured in Japan	2010
Home appliances	Air conditioners	70	Recycling/disposal	–
	Cathode-ray tube TVs	55	Same as above	–
	Refrigerators and freezers	60	Same as above	–
	Washing machines	65	Same as above	–
	Liquid-crystal TVs, plasma TVs	50	Same as above	–
Construction waste	Asphalt and concrete lumps	98	Percentage of recycled material weight relative to the weight of specific construction waste	2012
	Concrete lumps	98	Same as above	2012
	Construction waste timber	95	Same as above	2012
Food waste	Food manufacturers	85	$\frac{[(\text{Generating prevention amount}) + (\text{recycling amount}) + (\text{heat recovery amount}) \times 0.95 + (\text{treatment amount})]}{[(\text{generating prevention amount}) + (\text{generating amount})]}$	–
	Food retailers	45	Same as above	–
	Food wholesale business	70	Same as above	–
	Food service industry	40	Same as above	–
Personal computers and peripherals devices	Desktop computers	50	Resource recycling/recovered	–
	Notebook personal computers	20	Same as above	–
	Cathode-ray tube displays	55	Same as above	–
Small, secondary batteries	Liquid crystal displays	55	Same as above	–
	Nickel-cadmium batteries	60	Recycling/disposal	–
	Nickel-hydride batteries	55	Same as above	–
	Lithium batteries	30	Same as above	–
	Sealed lead acid batteries	50	Same as above	–

PET poly(ethylene terephthalate)

policies. However, there are also unique approaches within the various countries. For example, in China, where the concept of the circular economy is promoted as a policy ideal, Article 3 of the Solid Waste Pollution Prevention and Control Law clearly states that reduction (the first priority in the 3R management hierarchy) should be achieved not only in the amount of wastes but also in

the waste’s level of hazardousness [29]. The EU’s waste management system is characterized by concerns about the practicality and effectiveness of its 3R policies, the development of a realistic legal framework, and the underlying attitude of policymakers toward simplifying the bewildering expansion of waste management systems [30].

Table 6 3R policy targets in Korea [16, 31]

Municipal waste management goals				
Category	2005	2008	2010	2012
Expected generation (t/day)		48,003	47,989	47,975
Reduction rate relative to 2005		2.5%	4.2%	5.8%
Waste generation (t/day)	48,398	46,083	45,990	45,177
Recycling amount (t/day)	27,243	26,678	27,134	27,558
Recycling rate (wt%)	56.3	57.0	59.0	61.0
Regulations on packaging methods				
Category	Ratio of total packing size (%)		Number of packing layers	
Food stuffs	10–20		≤2	
Cosmetics	< 10		≤2	
Detergents	< 10		≤2	
Sundries	30–35		≤2	
Quasi-drugs	< 10		≤2	
Miscellaneous products	< 20		≤2	
Annual reduction targets for synthetic resin packaging materials				
Item	Ratio of synthetic resin packages (%)			
Egg holders	< 40			
Apple and pear holders	< 65			
Instant noodle containers	< 85			
Agricultural, livestock, and fishery products	< 90			
Electrical appliances	ESP packaging for items under 20,000 cm ³ in volume is prohibited			
Target recycling rates				
Item	Target rate (%)			
Used paper	72			
Used glass	71			
Used glass bottles	50			
Used steel cans	65			

Most of the countries are also setting concrete quantitative targets. The waste management targets are summarized in Table 2 (for the USA), Table 3 (the EU), Tables 4 and 5 (Japan), and Table 6 (Korea). A new waste management strategy is currently being drawn up in the USA, so the targets in Table 2 may soon be subject to revision.

Waste management targets serve as the progress benchmarks of 3R policies, and the targets are determined at the same time as the waste management hierarchy. The targets for reduction of overall wastes have the highest priority, followed by the targets for specific recycled items and targets for specific waste management measures.

The USA, Japan, and Korea all set targets for waste generation. In the USA, the maximum target for waste generation, which was to be achieved by 2008, is

4.5 lb person⁻¹ day⁻¹ or approximately 2 kg person⁻¹ day⁻¹ [2]. The target is under revision and discussion. In Japan, the target for non-industrial waste generation in 2015 is 1,070, or 520 g person⁻¹ day⁻¹ for household solid waste [10]. If achieved, these targets would bring about a 10% (total MSW) and 20% (household waste) reduction relative to the base year of 2000 for the USA and Japan, respectively. In Korea, however, the reduction rate relative to the estimated MSW amount in the target year is applied as a target index. The MSW amount of waste for 2012 is estimated to be 47,975 t/day, and the reduction target is 45,177 t/day or 5.8% [31].

Targets for waste management measures are also used in the USA, EU, Japan, and Korea. In the USA, the target recycling rate in 2008 was 35 wt%, relative to 31 wt% in 2002 [2]. In terms of the amount of material recovery, this

Table 7 Breakdown of MSW management methods in each country

Countries	Recycling	Incineration	Landfill	Total
USA ^a	268 (33.2)	102 (12.7)	438 (54.1)	808 (100.0)
EU ^b	215 (41.0)	102 (19.5)	207 (39.5)	524 (100.0)
Japan ^c	100 (25.1)	290 (72.6)	9 (2.3)	399 (100.0)
Korea ^d	221 (57.8)	71 (18.6)	90 (23.6)	382 (100.0)

Data are presented as in kg person⁻¹ year⁻¹ (%)

^a 2008 data; incineration, only with energy recovery [36, 40]

^b 2008 data [41]

^c 2007 data; landfill, not including residue [42]

^d 2007 data [43]

represents an increase from 57.55 million ton (Mt) in 2001 to 69.04 Mt in 2008. In the 2010–2014 Strategic Plan, which is currently being revised, the target amount of 3R materials increases by approximately 58 Mt by 2014 [1]. The EU determined that separation and collection should be deployed by 2015 for paper, metals, plastics, and glass, and it set the long-term recycling target at 50 wt% of household waste to be recycled by 2020. The EU also aims to gradually reduce the amount of total household-generated waste containing organic material in landfills (75% in 2006, 50% in 2009, and 35% in 2016) [30]. In Japan, the recycling target is 12 Mt (24 wt% of waste generation), and the target for final disposal is 23 Mt (41% relative to the base year of 2000) [10]. In Korea, the recycling target for 2012 is 27,558 t/day (10 Mt/year), or 61.0 wt% of total waste generated [31].

The USA, EU, and Korea also set recycling targets for packaging materials. In the USA, the target recovery amount for each material is defined, and the rate of recovery is calculated relative to the amount of each material as waste in the base year 2001 [2]. The target rates of recovery are 24.2% (+9.2%) for wooden packaging, 19.4% (+12.8%) for plastics, and 38.7% (+12.7%) for drinks packaging. It is likely that thermal methods are not regarded during the calculation of recovery rates in the USA. In the EU, the targets for material recycling and the targets for recovery, including heat utilization, are defined relative to the waste amount generated in the base year [30]. The material recycling target is 55 wt%, whereas the target rate of recovery is 60%. In Korea, the recycling target for each material is set yearly; in 2008 it was 50 wt% for glass and 65 wt% for steel cans [16]. The Korean performance report shows that the recycling rates for glass bottles, aluminum cans, and steel cans exceed 75 wt% [31]; thus, the target recycling rates may be subject to amendment. In addition, quantitative targets have also been set for reducing the use of packaging materials, and the selection of materials is also regulated [16].

Comparison of the effectiveness of 3R and waste management policies

Waste generation and treatment measures

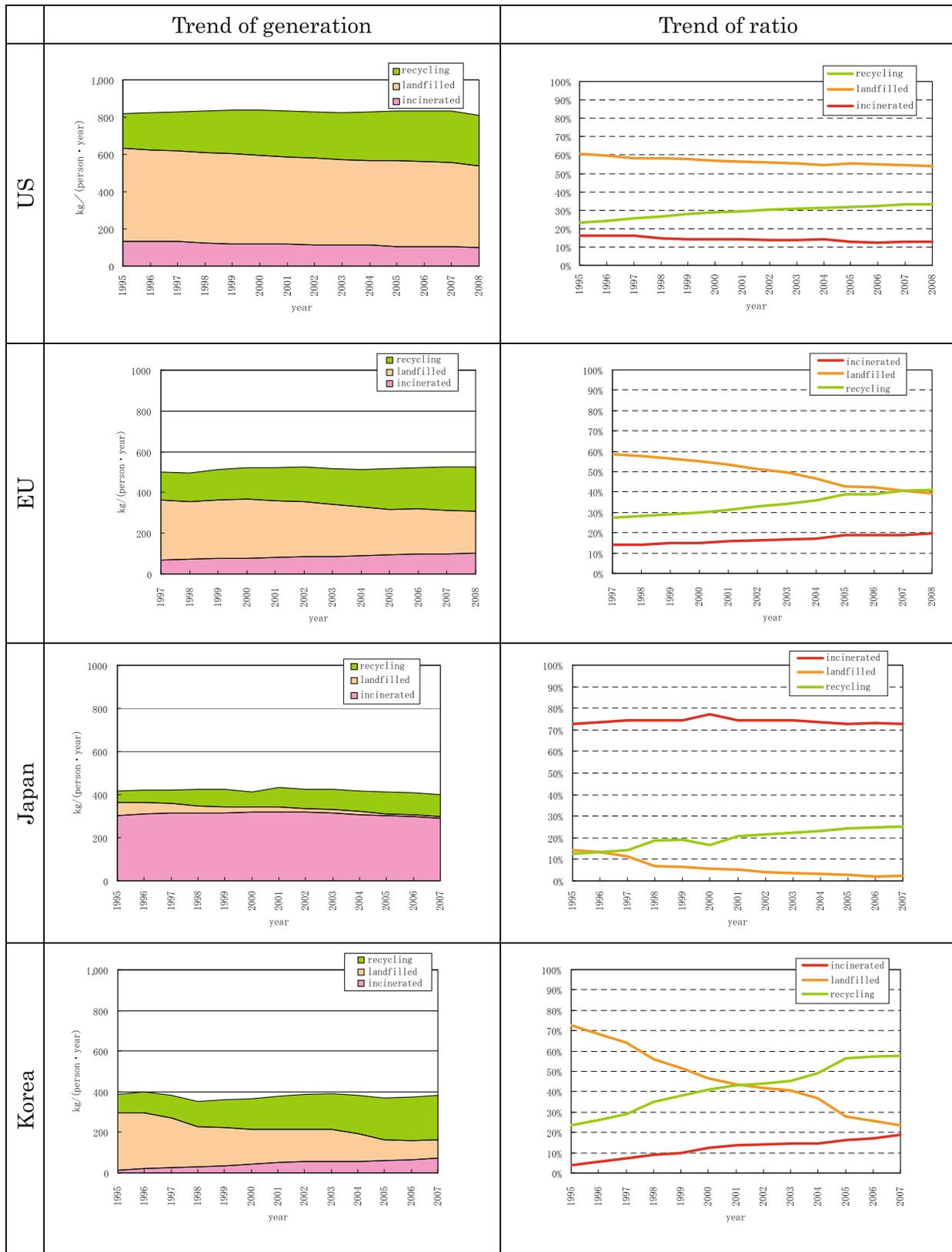
Tables 7 and 8 show the amounts of waste generated and the methods (recycling, incineration, and landfill) used to treat MSW in the EU, USA, Japan, and Korea. Figure 1 shows the distribution of the management methods. In Japan, the total amount of landfilled materials includes incinerated materials that have gone through shredding and sorting processes at treatment facilities, recycled materials, and final disposal materials, including incinerated residues. Thus, for comparison, the amount recycled in Japan was calculated as (amount of waste generated) – (directly incinerated amount + direct landfilled amount); this was also done for data from the EU, although the calculated quantities are greater than the amounts in published data. Furthermore, although thermal recovery is not included in recycling in the USA, EU, and Korea, it is included in recycling in Japan.

The USA has the highest rate of waste generation (800 kg person⁻¹ year⁻¹), followed by Japan and Korea (both around 400 kg person⁻¹ year⁻¹). In terms of MSW composition in the USA, the most dominant component is packaging, which accounts for 30%, followed by waste containing organic materials (27%), paper (24%), and steel and plastics (18%; percentage by weight in 2008) [38].

Waste management methods are quite different in Japan from in the EU and the other countries. Waste incineration predominates in Japan and the rate of final disposal in landfills is extremely low, whereas the rate of incineration is usually low elsewhere (Table 7; Fig. 1). There are also differences among the EU, USA, and Korea. The landfill rate in the USA and the EU reaches about 40–50% of the total amount of waste generated, but it is only about 20% in Korea. Korea also has a much higher recycling rate (almost 60 wt%) than the EU and USA (about 30–40 wt%). The yearly changes in management methods shown in Table 8 indicate that changes have been relatively gradual in the USA, whereas the landfill rates have drastically decreased as the recycling rates have increased in the EU, Japan, and especially in Korea.

Recycling rates in 2007 were highest in Korea (58 wt%), followed by the EU (41 wt%), USA (33 wt%), and Japan (25 wt%) (Fig. 2). The rate of recycling in Korea increased rapidly since restrictions were imposed on disposing of organic waste in 2005. In Korean statistics, separated and collected organic waste is counted as recycled waste [39]. The ratio of organic waste to total recycled waste was 45 wt% in 2008, indicating that almost half of recycling material is organic waste. However, although the organic waste is currently subject to composting and utilization as

Table 8 Amount and ratio of MSW generated (per person per year) by waste treatment method in the USA [36, 40], EU [41], Japan [42], and Korea [43]



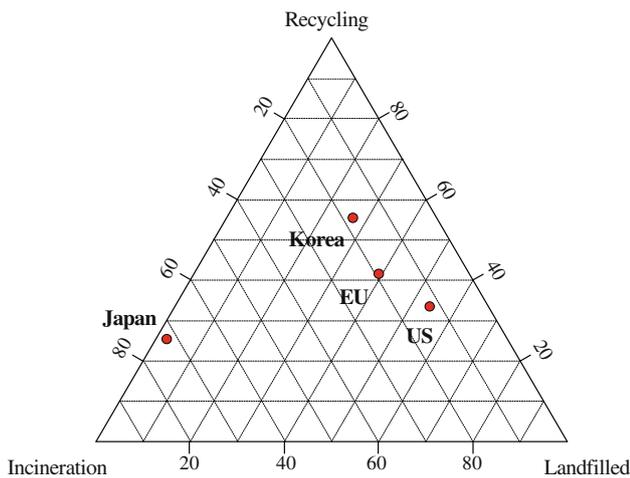


Fig. 1 Distribution of the rates of incineration, recycling, and landfilling in the USA [36, 40], EU [41], Japan [42], and Korea [43]

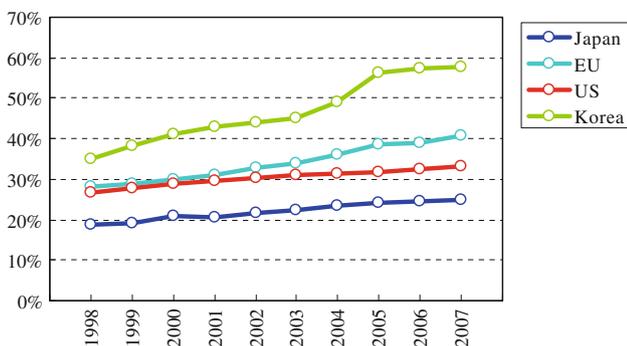


Fig. 2 Recycling rates in the USA [36, 40], EU [41], Japan [42], and Korea [43]

feed, there are still technical and economic problems with the use of organic waste [31]. Similarly, disposing of organic waste in landfills is prevented by law in the EU; this may have resulted in a higher recycling rate. In the USA, the rate of recycling refers mainly to paper and garden organic waste. In Japan, the rate of recycling refers mainly to paper and packaging waste. One reason for a low recycling rate is that the recycling of organic waste is not quite advanced enough.

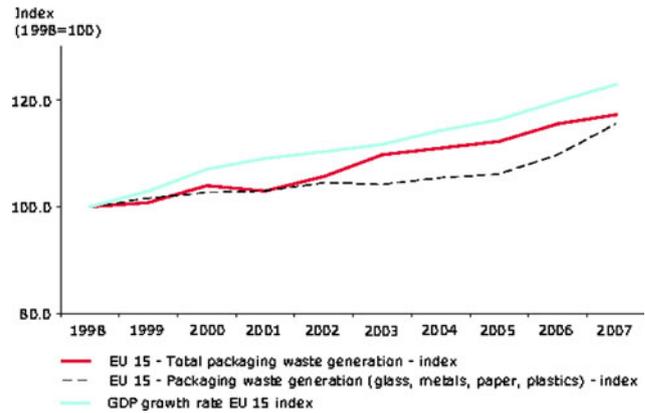


Fig. 3 Generation ratios of containers and of total packaging in the EU (15 member states) (1998 = 100) [47]

Policies on recycling packaging materials

Data on the recycling of packaging materials in the USA, EU, and Japan are shown in Table 9. There are differences among the scope of packaging materials collected in these countries. In the USA, the categories are glass, paper (corrugated cardboard boxes, milk containers, collapsible boxes, other bags, and packaging), metals (steel and aluminum cans), plastics [poly(ethylene terephthalate) (PET) bottles, high-density polyethylene, low-density polyethylene, and others], and wooden packaging [36, 40]. In the EU, the categories are glass, plastic packaging, paper packaging, and wooden packaging [44]. In Japan, the categories are glass, steel cans, aluminum cans, food trays, PET bottles, drinks boxes, corrugated cardboard, and other paper and plastic packaging [10]. In Japan and the EU, the categories are clarified in detail because the burden of the expense for collection and recycling falls on industry, whereas in the USA, the targets for recycling rate of packaging and containers are set by federal government, but collection systems are developed by each state or local government rather than at the federal level [45].

The recycling rate of packaging materials (the amount of recycled packaging as a proportion of total packaging waste generated, or C/B in Table 9) is highest in the EU at 58.8 wt%. The EU also has mandatory regulations and clear recycling targets. The rate is lowest in Japan

Table 9 Current generation and recycling of waste containers and packaging and basic recycling policy in the USA, EU, and Japan

Categories	USA [36, 40]	EU [44]	Japan [42, 46]
A: Total MSW generation (kg person ⁻¹ year ⁻¹)	808	524	399
B: Packaging waste generation (kg person ⁻¹ year ⁻¹)	249	165	93
C: Recycled packaging production (kg person ⁻¹ year ⁻¹)	109	97	22
Recycling rate (C/A) (wt%)	13.5	18.5	5.5
Recycling rate (C/B) (wt%)	43.8	58.8	23.7

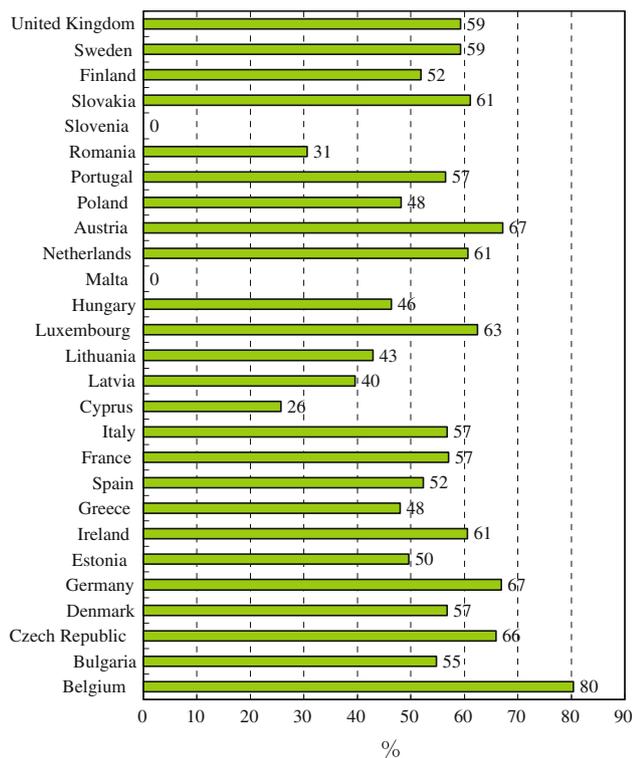


Fig. 4 Recycling rates for containers and packaging in the EU (in $\text{kg person}^{-1} \text{ year}^{-1}$) [44]

(23.7 wt%), which has a legal recycling system but no clear targets for recycling. The US rate (43.8 wt%) is closer to that of the EU.

The USA generates the greatest amount of packaging waste per person ($249 \text{ kg person}^{-1} \text{ year}^{-1}$), 1.5–2 times the amounts in the EU ($165 \text{ kg person}^{-1} \text{ year}^{-1}$) and Japan ($93 \text{ kg person}^{-1} \text{ year}^{-1}$). In the EU, despite the early development of recycling specifically aimed at reducing packaging waste, the generation of packaging waste has increased (Fig. 3). There are also great differences among the rates of packaging recycling in these countries (Fig. 4). The existing recycling systems may have targets that are clearly enough defined for the reduction of waste packaging materials [5].

Promotion of packaging waste reduction and a mandatory recycling system have been implemented at several stages in Korea, including product design, sale, and collection and recycling. Under the EPR, introduction of mandatory recycling (including of tires and WEEE) by businesses is under way. In addition, reduction in the use of packaging is currently promoted by restrictions on the size of product packaging and by the use of a deposit system. Although public data on the rate of packaging recycling in Korea are not available, we estimated the amount of packaging recycling to be $41.7 \text{ kg person}^{-1} \text{ year}^{-1}$,

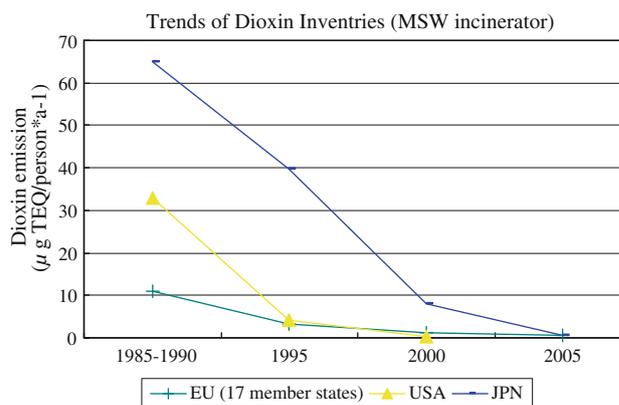


Fig. 5 Dioxin emissions from MSW incinerators in selected countries [49–55]

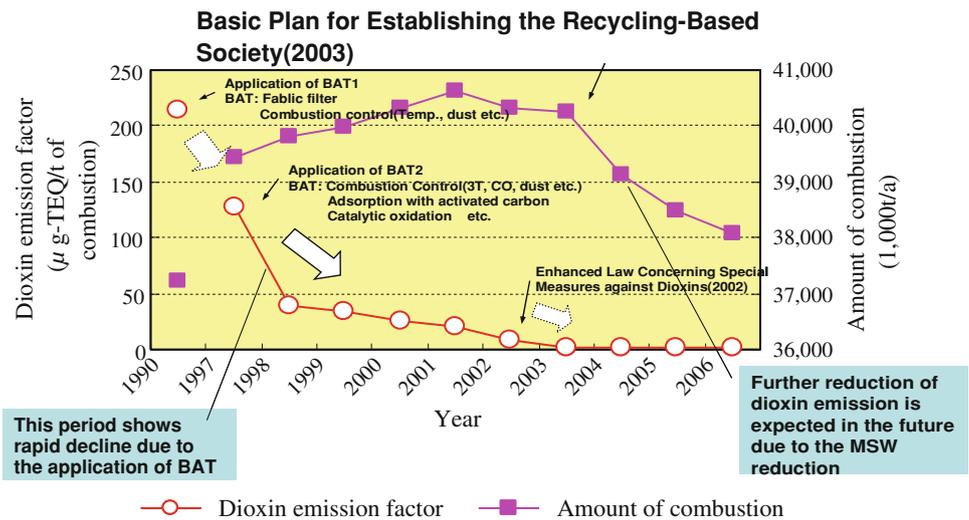
assuming that the amounts of glass, cans, plastic, and resins shown in the Korean waste statistics [39] are packaging wastes. The dominant components were glass and plastics (PET bottles). Glass, in particular, accounted for almost half of the total amount. This estimation places Korea between Japan ($22 \text{ kg person}^{-1} \text{ year}^{-1}$) and the EU ($97 \text{ kg person}^{-1} \text{ year}^{-1}$).

Dioxin emissions from waste incineration

Waste incineration is a source of dioxin emissions, and the trends in dioxin emissions per capita from waste incineration for several countries are shown in Fig. 5. In Japan, dioxin emissions exceeded $60 \mu\text{g-TEQ person}^{-1} \text{ year}^{-1}$ (TEQ, toxic equivalent) until strict political measures to control dioxins emissions, in the form of guidelines for the reduction of dioxins emission, were taken in 1997, at which point a large decrease in emissions occurred. In the USA, the rate of incineration had also been relatively high, (over $30 \mu\text{g-TEQ person}^{-1} \text{ year}^{-1}$) until 1995, when countermeasures were taken and emissions rapidly decreased. In the EU, the unit dioxin emission rate had also been relatively low, $11 \mu\text{g-TEQ person}^{-1} \text{ year}^{-1}$, until 1995 because the incineration rate had been relatively low and the early abatement of dioxin emission (Fig. 5).

Figure 6 shows the relationship between dioxin emissions and waste incineration in Japan from 1990 to 2006 [48]. Most combustible waste was incinerated during this period, but after the Special Law on Countermeasures against Dioxins was implemented in 1999, incineration facilities were updated and a rapid decrease in emissions occurred. The rate of decrease leveled out for a few years, but dioxin emissions eventually decreased by more than 99% of the original level, driven by improved technology and the later promotion of 3R policies, which brought about a reduction in the amount of waste incinerated.

Fig. 6 Dioxin emissions from waste incinerators and total amount of waste incinerated in Japan [48]



Management of chemical substances and household hazardous waste

As a basic principle, policies on managing chemical substances should be promoted in an integrated manner with 3R and waste management policies. The management principles of hazardous wastes and persistent chemical substances are as follows: (1) avoid the use of hazardous chemicals (clean), (2) use the substances cyclically if no adequate alternatives are available to meet the utility expected (cycle), and (3) prevent their emission into the environment and stabilize current and previously generated stocks or waste (control) [56]. In the USA, following similar principles, the Pollution Prevention Act lays down chemical management in a manner consistent with the Toxic Substances Control Act. The Pollution Prevention Act sets management policy for chemical substances and prioritizes source prevention over other measures. These include environmentally sound recycling, which is permitted only when source prevention is not possible, and waste treatment, which is permitted only when source prevention and recycling are not possible. Disposal and emission are defined as the last measures. Peeler [57] gave an example from Washington State, where a Chemical Action Plan is being undertaken concerning the management of mercury, polybrominated diphenyl ether (PBDE), and lead. Hylander [58] warned that, especially in the case of mercury, a better treatment exists than recycling, that hazardous substances are used in some cases despite existing alternatives, and that recycling becomes much easier when basic materials are not contaminated with hazardous substances.

An important issue that still remains to be solved in some countries such as Japan and the EU is the management of household hazardous waste (HHW). The European Commission Directorate of the General Environment

conducted a study on HHW and published its final report in 2002 as a part of a strategy to enhance sound life-cycle management of products [59]. In the report, HHW was defined as “waste that may increase hazardousness of municipal solid waste when being landfilled, incinerated or composted,” and a focus was put on the hazardous household chemical substances. Fourteen chemicals were classified as high priority for solid waste management: As, Pb, Cd, Cr, Cu, Ni, Hg, Zn, PCBs, benzene, tetrachloroethylene, trichloroethylene, tetrachloromethane, sodium cyanide. They were identified from an emissions inventory from treatment facilities, such as landfills and incinerators. Asari et al. [60] conducted a survey of HHW possession and of the participants’ experiences concerning involvement in HHW collection and recycling systems. The results indicated that providing information about the hazardousness of a product significantly increased the rate of participation in HHW collection and recycling systems. In Japan, there is a warning system for marking the presence of specific chemical substances in electrical and electronic equipment (JIS C 0950, J-MOSS) to control heavy metals such as mercury and cadmium, which are constituents of products such as personal computers, televisions, and refrigerators [61].

Policy trends for waste management and prevention of GHG emissions

The US EPA [62] reported that waste management and GHG emissions are strongly correlated. The report concluded that waste reduction and recycling promotion are considered highly important in reducing GHG emissions for the following reasons: (1) promotion of recycling will reduce energy utilization, (2) reduction of waste incineration will also reduce emissions, (3) prevention of methane gas generation by reducing the amount of landfill waste

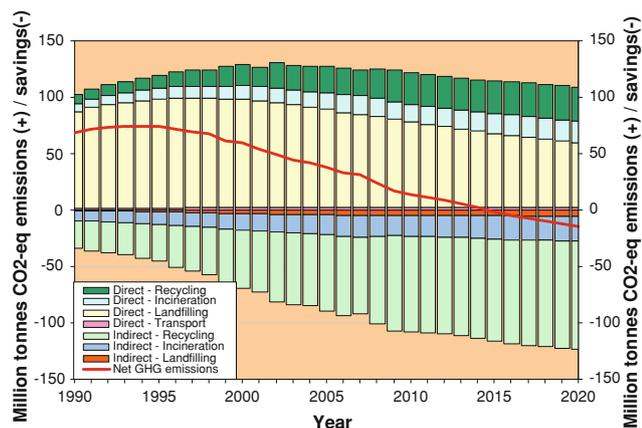


Fig. 7 GHG emissions from MSW management measures in the EU [5]

will also contribute to emissions reduction, and (4) protection of forests through paper recycling will help to maintain their carbon dioxide absorption function.

In the EU, under the Directive on Landfill of Waste (council directive 1999/31/EC), the amount of biodegradable municipal waste being landfilled is targeted to be reduced to 75% of the 1995 level in 2006, 50% in 2009, and 35% in 2016. According to GHG emissions estimates derived from MSW management in the EU [5], waste prevention measures and recycling of biodegradable municipal waste could result in a reduction in GHG emissions of approximately 75 Mt-CO₂ in 2010 and 60 Mt-CO₂ in 2020 (Fig. 7). The following assumptions were made in these estimates: the amount of MSW generated would increase from 520 kg person⁻¹ year⁻¹ in 2004 to 680 kg person⁻¹ year⁻¹ in 2020, and the ratios of management methods in 2020 would be 34% for landfill, 42% for recycling, and 23% for incineration with power generation. The emissions associated with the transport, treatment, and disposal of waste were counted as direct GHG emissions. Indirect reductions in GHG emissions were also calculated, including the use of recycled materials in place of natural resources and the substitution of power generated from fossil fuels. Better MSW management was shown to be effective in reducing GHG emissions, and the report concluded that introduction of more effective recycling as well as power generation from waste would accelerate the reduction of GHG emissions [5].

Conclusion

The international comparative research on 3R policies showed that the directions of 3R policies are developed not only as simple waste management strategies but also as an

approach to obtain synergistic effects with national strategies which aim at landfill prevention, procurement of resources, and reduction of GHG emissions. In addition, for circulation use of resources, it was identified that hazardous waste management is recognized as an important issue for consideration.

The first direction is the promotion of 3R policies to prevent final disposal in landfills, as has been done in the EU, Japan, and Korea. In these countries, the difficulty in obtaining final disposal sites has been the driving force for 3R development. In terms of organic waste, however, these countries have taken different approaches. In Japan, advanced incineration facilities have been provided at the national level, and prevention of dioxins emission has been a strong social issue as well. As a result, dioxin emissions have been greatly reduced through the use of technology and the reduction of the amount of organic waste incinerated. In the EU and Korea, however, prevention of final disposal of organic waste in landfills has been largely implemented on an administrative level, without sufficient introduction of appropriate incineration facilities. Composting of organic waste has therefore been a more important component of their 3R measures. The rate of incineration is less than 20% in the EU and Korea, even though thermal recovery has clearly been defined as a global warming countermeasure in these countries.

In the second direction, the aim of 3R policies is to secure resources in countries experiencing rapid economic growth, such as China and Vietnam. In these countries, hazardous waste management is also an important policy concern. The utilization of recycled resources has been effective in these countries because the procurement of resources has been slow relative to their economic growth. Because they need resources, these countries have been active in importing recycled resources, but that has resulted in the necessity of taking measures to prevent the import of hazardous materials that are often included in the recycled resources. Therefore, in these countries, management of hazardous wastes has been prioritized over other 3R measures, or even ranked as a higher policy objective. This is particularly true in China. Although legislation in China has been developed soundly so far, China may need to develop greater abilities to manage and implement the legislation to achieve better outcomes on 3R and hazardous waste management. Although there is also a legal system for hazardous waste management in Vietnam, the risk management of secondary materials carried from abroad has not been fixed. The development of 3R policies is inextricably associated with hazardous waste management.

In the third direction, the aim is to develop an integrated policy centered on 3R to obtain synergetic effects on waste management, protection of natural resources, and reduction of GHG emissions. In the USA, landfill issues have been

relatively less urgent as compared to other countries. Even so, the USA have developed pollution restrictions for land and groundwater, as seen in the Comprehensive Environmental Response Compensation and Liability Act. The US policy currently under discussion is intended to bring about a shift in focus from waste management to an integrated and synergetic approach. This challenge is revolutionary in the sense that 3R as a code of conduct on waste management is given a higher policy position as part of total environmental management, although how such a paradigm shift will be accomplished is still uncertain.

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